Handbook of Fruits and Fruit Processing

Second Edition

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Edited by
Nirmal K. Sinha
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Preface

Fruits are botanically diverse, perishable, seasonal, and regional commodities. They come in many forms, shapes and sizes, colors, flavors, and textures; and are an important part of a healthy diet. Some fruits have been billed as "superfruits" because of their unique nutritional properties and phytochemical composition. Low intake of fruits and vegetables has been suggested by the World Health Organization (WHO) as one of the risk factors for noncommunicable diseases such as various forms of cancers, cardiovascular diseases, diabetes, etc.

Besides vitamins, minerals, fibers, and other nutrients, fruits contain phenolic compounds having pharmacological potentials. Consumed as part of a regular diet these naturally occurring plant constituents are believed to provide a wide range of physiological benefits as antioxidants, antiallergic, anticarcinogenic, anti-inflammatory, etc. This new edition of handbook of fruits and fruit processing discusses these and other functional properties of fruits and fruit products.

According to the Food and Agriculture Organization's (FAO) 2010 yearbook, the total production of fruits in the world increased from 470.4 million tons during 1999–2000 to 587.6 million tons in 2009. Fruits are important in global commerce. The total value of world's fruit export and import increased from about $45 billion during 1999–2000 to about $105 billion in 2008. In the United States, approximately 60% fruits are consumed as processed products. The utilized production value of fruits in the United States according to USDA has increased from approximately $10.5 billion in 2000 to $15.02 billion in 2010. This shows the importance of fruits in agricultural productivity and growth. In most countries, there is an increasing emphasis on value-added agriculture and realization about the nutritional importance of fruits in the diet. The chapters on major fruits in this text highlight the leading fruit producing countries, production and consumption trends, and preservation and processing of fruits into various products.

Innovation, research, and development efforts in this field are aimed at improvements in production, postharvest storage and processing, safety and quality, development of new processes and products to increase demand and consumption of fruits, and expansion of this sector. We believe a contemporary reference and source book such as this handbook, which can describe, distil, and disseminate important and relevant scientific information and advances in this field is valuable for the flow of such information. Our efforts in the second edition are to expand and improve the coverage of the original book published in 2006. Some of the major highlights of this new edition with 35 chapters include chapters on physiology and classification of fruits, horticultural biochemistry, microbiology and food safety (including HACCP, safety and regulation of fruits entering world trade), sensory and flavor characteristics, nutrition, and naturally present bioactive phenolics, postharvest physiology, storage, transportation and packaging, processing and preservation technologies (freezing, canning, aseptic processing, non-thermal technology, drying, etc.), and details on major fruits including tropical and superfruits, frozen fruits, canned fruit, jelly, jam and preserves, fruit juices, dried fruits and wines. This text is organized into five parts:

Part I: Fruit physiology, biochemistry, microbiology, nutrition, and health (five chapters)
Part II: Postharvest handling and preservation of fruits (seven chapters)
Part III: Product manufacturing and packaging (five chapters)
Part IV: Processing plant, waste management, safety, and regulations (four chapters)
Part V: Production, quality, and processing aspects of major fruits and fruit products (fourteen chapters)

This text is a joint effort of many individuals and signifies a remarkable cooperation and teamwork. The editorial team consists of five members from Asia, Europe, Middle East, and USA with expertise and experiences in this field. Four of these editors were part of the first edition. Dr. Wu with extensive teaching and industry experience specially in aseptic processing is a new editor. Each chapter has been contributed by dedicated professionals from across the globe

representing academia, government institutions, and industry. We hope this new edition with additional features would be a valuable source and reference book for students, professionals, product developers, scientists, and other professionals interested in this field. We sincerely hope this handbook addresses the needs of its readers and advances their understanding and knowledge of fruit science and technology.

We express our gratitude to all the authors and reviewers and thank them for their time and efforts. We acknowledge and thank the editorial and publishing group at Wiley-Blackwell Inc. and Aptara corporation, especially, David McDade, Samantha Thompson and Shikha Sharma for their guidance and supports to this project. We are grateful to our families and the institutions we work, for their encouragement.

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James Wu, M. Pilar Cano

Part 1
Biology, Biochemistry, Nutrition, and Microbiology

1
Physiology and Classification of Fruits

Kuo-Tan Li

Abstract: Fruits are an essential part of human diet and culture. Various classification systems have been applied to fruits to meet various objectives. Physiological and morphological characteristics of a given fruit species or even a given cultivar affect its postharvest life and processing quality. This chapter provides a fundamental background on how a fruit develops in the field and how fruits are categorized in modern society.

INTRODUCTION

Fruits are indispensable in human diet to supply essential vitamins, for example, vitamin A, B_6, C, E, thiamine, niacin, minerals, and dietary fiber (Fourie 2001). Fruits are also savories that provide a pleasing taste. The majority of species of fruits that are grown and consumed in the modern world have been domesticated by the late Neolithic and Bronze Ages between 6000 and 3000 BC. In addition, a number of fruits that have been extensively collected from the wild by the native people were not domesticated until the early twentieth century (Janick 2005). Some other fruits, although commonly

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utilized by the local people, remain exotic to the rest of the world. Nowadays, fruit production and processing are among the major industries in many countries, and the trading and distribution of fruits have become an important international economic activity. Although world production and consumption of fruits have increased significantly, most people's diets still fall short of the mark set by United Nation's Food and Agriculture Organization (FAO 2003).

Botanically, a fruit is the reproductive structure of a flowering plant in which seeds form and develop. In culinary arts, fruit normally refers to an edible, juicy, and sweet entity derived from a flower on any flowering plant. Among so many species of flowering plants with so much anatomical diversity, only a relatively small group of species and fruit types are common in human diet. Nevertheless, the physiological and morphological characteristics of a given fruit species or even a given cultivar affect its postharvest life and processing quality. Therefore, it is advisable to obtain a fundamental understanding on how a fruit develops in the field and how fruits are categorized in modern society.

DEVELOPMENT OF A FRUIT

A fruit is developed from a flower and its associate tissues. The onset of fruit development begins as early as the differentiation of flower by which the apical meristem on a shoot forms a flower or inflorescence instead of a leaf or a shoot. Anatomical changes begin at the edge of the meristem, first generating the calyx and the corolla, and later the androecium (male) and the gynoecium (female) tissues. The process of flower differentiation can be completed within a few days in annual plants to nearly a year in some perennial plants. The differentiation of gynoecium continues to form the carpel or pistil in which the ovule is hosted. A gynoecium may consist of a single carpel, multiple distinct (unfused) carpels, or multiple connate (fused) carpels. Inside gynoecia ovules, within one or more ovaries develop and later become seeds upon fertilization. When mature, gynoecia may function to attract pollinators through aroma or nectar. At bloom or in some instances prior to bloom, gynoecia receive pollen grains on their specialized surface structure called a stigma and in some cases actively select genetically different pollen grains so as to avoid inbreeding. Gynoecia may facilitate the growth of pollen tube to the ovule and the delivery of sperm to the egg. The gynoecium forms the pericarp. The pericarp in most fruits differentiates into three distinct layers. The outer layer is called exocarp and normally becomes the peel of the fruit. The middle layer is the mesocarp, the major edible part of most fleshy fruits. The inner layer is the endocarp, which directly surrounds the ovary and the seed.

Pollination and Fertilization

Most flowering plants will not set fruit without pollination or fertilization. Pollination is the process of transferring pollen grains from anthers to stigmas. Pollination in some species occurs spontaneously at bloom due to their special structure of the flower or the specialized arrangement of their stigmas and stamens, for example, grapes and tomatoes. Pollination in most other species usually will not be completed without natural vectors, i.e., wind or insects (Stebbins 1970). The majority of common fruit crops require insect for pollination, and the pollination efficiency is usually improved by introducing bee (*Apis*) hives to the orchard during blooming season (Morse and Calderone 2000). Flowers of some tropical fruit crops, for example, mangos, are not attractive to bees. Instead, their major pollinators are native flies (Sung et al. 2006). In commercial production, their pollination can be benefited by introducing the oriental latrine fly (*Chrysomya megacephala*) to the orchard during bloom (Hu et al. 1995). Some fruits are dioecious, and pollen grains must be transferred from a male flower in a male plant to a female flower in a female plant to complete the pollination process. Examples of dioecious fruits include the wind-pollinated mulberries and the insect-pollinated kiwifruit (Hopping 1990). In monoecious fruit crops such as wind-pollinated chestnuts, walnuts, and pecans; and insect-pollinated lychee (Stern 2003), watermelons, and cucumbers, pollen grains must be transferred from a male flower to a female flower either on the same plant or on separate plants to continue the fertilization process.

Fertilization takes place after the germination of pollen grains on the stigma. A pollen grain after successful germination contains two sperm cells. Upon entering the ovule, one sperm cell fertilizes the egg cell and the other unites with the two polar nuclei of the embryo sac. The sperm and haploid egg combine to form a diploid zygote and later the embryo of the seed. The other sperm and the two haploid polar nuclei form a triploid nucleus and later the endosperm, a nutrient-rich tissue nourishing the developing embryo (Raghavan 2006). The ovary, which encompasses the ovule, develops into the pericarp of the fruit and helps to protect and disperse the seeds.

In self-fertilized fruit crops, for example, in most peach and nectarine cultivars, successful fertilization can occur within one flower, and pollen grains from other flowers or from other cultivars are not necessary (Weinbaum et al. 1986). On the other hand, fertilization in cross-pollinated fruit crops, for example, in most apple, pear, almond, and rabbiteye blueberry (*Vaccinium ashei*) cultivars, will not succeed with pollen grains from flowers of same cultivars or other cultivars with incompatible genetic background. Therefore, it requires the mixed planting of two genetically compatible cultivars in an orchard block to achieve a satisfactory yield (Visser and Marcucci 1984, Dedej and Delaplane 2003). In some fruit crops, for example, northern highbush blueberries (*Vaccinium corymbosum*), although self-pollination is possible to set fruit, cross-pollination by mixed planting two cultivars will increase the fruit size and quality (Huang et al. 1997, Ehlenfeldt 2001, Bieniasz 2007).

The embryo of the developing seed produces plant hormone gibberellins at early development stages to trigger the production of auxins and stimulates fruit growth (Ozga et al. 2002). In conclusion, pollination and fertilization are normally required to initiate fruit growth.

Fruit Set

Fruit set refers to the retention of fruit on the plant after bloom. Most fruit crops produce numerous functional flowers but only a small percentage of the flowers continue to develop into mature fruits. Normally, less than 5% of apple flowers and less than 3% of orange flowers would continuously grow and mature by harvest.

In stone fruits, such as peaches, cherries, and plums, flowers will drop and fruits will not develop without a fertilized embryo. In some fruits, such as apples and pears, the fruit may set with few or no seeds, but the growth of the cortex exterior to a seedless carpel will be affected (Drazeta et al. 2004).

Flower or fruit drop may occur in various periods before full maturation of the fruit (Racskó et al. 2007). *Early flower drop* occurs before anthesis or petal fall, most likely when the flowers have not yet fully developed. Flower dropping shortly after anthesis, known as *late flower drop*, is a result of poor pollination or failure in fertilization. In most fruit crops, the fruit normally drops soon after bloom if fertilization has failed. In sour cherries, fertilization occurs in about 40% of flowers only (Lech and Tylus 1983). *Mid-season fruit drop*, often called *June drop* in the northern hemisphere, *December drop* in the southern hemisphere, or physiological fruit drop by plant physiologists, is a common phenomenon in which a significant portion of young fruits drop within several weeks after bloom. Mid-season fruit drop can be a delayed response to inadequate fertilization, involving the competition among fruits or between fruit growth and vegetative growth for resources (Agustí et al. 2002), environmental stress, or hormone imbalance (Racskó et al. 2006). Upon the completion of mid-season fruit drop, final fruit set is determined, and the remaining fruits usually continue to grow toward full maturity. In some instances, for example, "McIntosh" apples, a significant preharvest fruit drop may occur. The mechanism of this problem has yet to be fully explained (Ward 2004), but can be likely due to internal ethylene production (Blanpied 1972).

The growth and development of the fruits remaining on a tree is still influenced by many internal and environmental factors (Ho 1992). The presence of seeds is the major factor in the early fruit development stages. The growth and development of fruits in late stages are independent of seed development.

Parthenocarpy and Stenospermocarpy

Seedless fruits are often preferred by consumers. Some fruits can continue to grow without developing normal seeds in the carpel. Seedless fruits can be a result of parthenocarpy or stenospermocarpy.

In parthenocarpic fruit set, a flower continues to develop into a fruit without pollination or fertilization. Parthenocarpy can be a natural event or induced by cultural practices (Gustafson 1942). Commercial banana and pineapple cultivars are naturally parthenocarpy, requiring no pollination (Simmonds 1953). Many citrus fruits will also set parthenocarpic fruits but require pollination to stimulate fruit growth. Seedless watermelons are commercially produced by cross-pollination between diploid and tetraploid parents (Terada and Masuda 1943). Parthenocarpy in watermelon can also be induced by the application of plant growth regulators (Terada and Masuda 1941) or by using soft X-ray irradiated pollen (Sugiyama and Morishita 2000).

In stenospermocarpic fruit set, both pollination and fertilization are required to initiate the growth of fruit, but the embryo aborts soon after fertilization, while the fruit continues its normal growth. Seedless grapes can be a result of natural stenospermocarpy as in the case of "Thompson Seedless" and "Flame Seedless" cultivars (Bharathy et al. 2005, Hanania et al. 2007) or artificially induced stenospermocarpy by plant growth regulators as in the production of seedless grapes in Japan (Shiozaki et al. 1998). Many lychee cultivars are liked for their shrivel seeds, a result of natural stenospermocarpy (Xiang et al. 2001).

Fruit Growth

The growth of a fruit to reach its final size and weight involves an increase in cell numbers in the early stage and an increase in cell size and intercellular space in the late stage.

Cell Division

Fruit growth begins with a slow phase that is corresponding to cell division. During this stage, cell numbers are increasing, while the changes in fruit size and weight are not significant. The number of cells in a fruit is set upon the completion of cell division. The period of cell division and its contribution to the growth of entire fruit are not consistent among different fruit species (Carini et al. 2001). In *Ribes* (currants and gooseberries) and *Rubus* (raspberries and blackberries), cell division is completed by anthesis, and cell number of a berry will not change after bloom. Cell division in apple completes in about 4–5 weeks after bloom and accounts for about 20% of the total fruit growth period. Cell division in pears normally continues for 7–9 weeks after bloom and accounts up to 45% of the total growth period (Toumadje and Richardson 1998). In strawberries, cell division continues and the cell number increases up to harvest.

Cell Enlargement

A fruit enters the fast-growth phase upon the completion of cell division, and the sizes of individual cells and

intercellular air spaces start to increase. At bloom, intercellular air spaces are absent or very small. Concurrent with cell enlargement, air spaces increase to a maximum. When a cell enlarges, its vacuole increases in size and finally occupies most of the volume inside. The vacuolar, i.e., the cell sap inside a vacuole, contains mostly water and sugars with normally a small amount of organic acids and other compounds. During the cell enlargement stage, pigments may also form and accumulate in vacuoles in epidermis cells (Schwab and Raab 2004).

Seasonal Growth Curve

The durations of cell division and cell enlargement stages determine the seasonal growth rate and the final size of a fruit. Fruit size can be plotted against time. The resulted plot typically expresses a sigmoid or S-shape curve with various degrees of curvature depending on fruit species and environmental conditions in which the fruit develops. Fruits are generally categorized into two groups according to their seasonal growth patterns: that expressing a single sigmoid curve and that expressing a double sigmoid curve (Westwood 1995).

Single Sigmoid Growth Pattern A single sigmoid seasonal growth pattern begins with a slow initial growth rate followed by a phase of rapid linear increase in fruit size and then a declined growth rate when approaching full maturity. Examples of fruits expressing a single sigmoid growth pattern are apple, pear, strawberry, walnut, pecan, etc. Such fruits in the slow initial growth stage show few physiological changes but rapid morphological changes corresponding to the cell division phase. The mid-season fast growth stage corresponds to cell enlargement and rapid physiological changes. The declined final growth rate signals the maturation of the fruit.

Double Sigmoid Growth Pattern Some fruits express a double sigmoid seasonal growth pattern with two separate rapid size increasing phases linked by a slow-growth phase. Examples include stone fruits (peach, plum, cherry, etc.), and other fruits (grape, fig, etc.). Changes in fruit size are not significant during the slow mid-season growth phase while internal physiological and morphological growth proceeds. In stone fruits, the slow-growth phase is corresponding to the hardening of the endocarp and the formation of the pit (Dardick et al. 2010). In grape, development of the embryo inside the seed is almost completed by the end of the slow growth phase (Dokoozlian 2000).

Maturation, Ripening, and Senescence

Maturation, ripening, and senescence of a fruit are in a continuous process before and after harvest. This process involves numerous morphological, physiological, and metabolic changes as a result of gene transcription and enzyme generation (Giovannoni 2001).

Maturation of a Fruit

As a fruit continues to grow toward harvest, its palatability is improved by the morphological and physiological changes. Maturity and ripeness have different meanings. When a fruit reaches its full maturity, its size and weight reach a maximum and its growth rate decreases. A fully matured fruit is capable of continuing normal development to "ripen," or to improve its palatability, after harvest. However, the development of maturity can only happen while the fruit is still attached to the plant.

Ripening of a Fruit

Ripening refers to the physiological and biochemical changes of a fruit to attain desirable color, flavor, aroma, sweetness, texture, and thus eating quality. The process of ripening usually does not occur until a fruit reaches its full maturity. Ripening of a fruit may occur on the plant or after harvest, depending on the species. A fully matured apple or mango fruit on the tree will continue to ripen (Bender et al. 2000), while European pears and bananas will not palatably ripen on the tree and are commercially harvested at full maturity and then forced to ripen for acceptable quality.

Senescence of a Fruit

When a fruit passes it maximum ripeness, it begins to breakdown and decay. Rather than a simple breakdown process, senescence is the final phase in ontogeny of a fruit, in which a series of normally irreversible physiological and biochemical events is initiated, which leads to cell breakdown and death of the fruit (Sacher 1973).

Physiological Changes of a Fruit toward Maturity

Color When a fruit grows toward its full maturity, many physiological changes in addition to its size and shape are happening simultaneously. Typically, the first noticeable change is the decline of chlorophyll in the chromoplast of the skin cells so the ground color of the fruit fades. Concurrently, attractive color of the skin and flesh develops due to the accumulation of anthocyanins, carotenoids, or flavones in vacuoles of epidermal cells (Fernández-López et al. 1992, Ikoma et al. 2001).

Seed Maturity Seeds in the fruit usually reach full maturity prior to the entire fruit does. The maturation of seeds is indicated by the darkened color of the seed coat.

Carbohydrate Profile For many fruits that accumulate starch during the cell enlargement stage, for example, apple, European pear, and mango, part of the stored starch is hydrolyzed to sugars during maturation. Major sugars in fruit are sucrose, glucose, and fructose (Brookfield et al. 1997).

For fruits that do not accumulate starch, for example, grapes, citrus, and peaches, a significant amount of sucrose is transported into the fruit during maturation and later partially transformed to glucose and fructose (Holland et al. 1999).

Acids The acid content in the fruit decreases accompanying the increase in sweetness during maturation. Major acids in the fruit are malic, citric, and tartaric. Most fully matured fruits contain less than 1% acid. Among the exceptions, lemon and lime fruits accumulate citric acid and increase acidity to more than 3% toward full maturity (Ramadan and Domah 1986).

Aroma and Flavor Compounds Aroma and flavor development occur when a fruit is reaching its full maturity. Aromatic compounds are generally volatile esters and alcohols (Gunata et al. 1985). Both aroma and flavor components accumulate up to full ripeness and then begin to decline as the fruits enter senescence phase. The desirable aroma and flavor may then be mingled with off-flavor materials. The accumulation of aromatic compounds during ripening and senescence is determined in large part by the genetics of the individual cultivar. However, environment, cultural practices, agrichemicals, and nutrition also have impact on flavor through effects on fruit development (Mattheis and Fellman 1999).

Firmness As a fruit is reaching its full maturity, cell walls become less interconnected due to pectin degradation and intercellular space expansion, resulting in reduced fruit firmness. Fruit softening and other textural changes in peach appear to have a number of stages, each involving a different set of cell wall modifications (Brummell et al. 2004). During maturation of grape, the cell walls in the skin lose structural polysaccharides and calcium continuously. Meanwhile, the incorporation of structural proteins and the cross-linking among phenolic compounds become active especially in the walls of epidermal and subepidermal cells (Huang et al. 2004).

Tannins In sweet persimmons (nonastringency persimmons), coagulation of tannins occurs when fruits are fully matured (Yonemori and Matsushima 1987). However, coagulation of tannins do not occur at full maturity in astringent cultivars, thus postharvest care is required to remove their astringency (Taira et al. 1992, Ben-Arie and Sonego 1993).

Respiration The rate of respiration normally increases when fruits are maturing. The degree of increment is dependent on the type of fruit (climacteric or non-climacteric) and differs among cultivars. Generally, early cultivars that mature in the early summer have a high respiration rate, short postharvest life, and early senescence. On the other hand, late cultivars that are harvested in the cool season have a low respiration rate and long storage life. Many berries, for example, strawberry, mulberry, raspberry, and blackberry have very high respiration rate. On the other hand, nuts and dry fruits have very low respiration rate at harvest (Kader and Barrett 2005).

FRUIT CLASSIFICATION

Various classification systems have been applied to fruits to meet the objectives of classification. Fruits can be classified based on their origins (Kader and Barrett 2005), growth patterns (Westwood 1995), postharvest respiration rates and ethylene responses (Lelièvre et al. 1997), anatomical features (Spjut 1994), or the consumer's preference.

Fruits Classified by Their Origin

According to their origins and major production areas, fruits are commonly grouped into three types: temperate fruits, subtropical fruits, and tropical fruits. Most temperate fruit crops are deciduous and cultivated in regions with a period of chilling temperature in the winter for successful growth and yield (Westwood 1995). Temperate fruits include most common fruits from *Rosaceae* family and popular small fruit crops. Tropical and subtropical fruit crops differ from each other on the degree of tolerance to low temperature. Subtropical fruits include most citrus crops and some other evergreen species (Jackson et al. 2010). Tropical fruits mostly originated in tropical rain forests; they do not tolerate a temperature below 10°C. In addition to the well-known tropical fruits, for example, banana, mango, papaya, and pineapple, many other tropical fruits, fairly common and favored in specific regions, are rarely seen outside the tropics and therefore considered exotic for people living in the temperate and subtropical regions (Morton 1987). Examples of each fruit type are listed in Table 1.1.

Fruits Classified by Respiration Rates and Ethylene Responses

Many fruits at full maturity maintain a consistent, low respiration rate and are called *nonclimacteric* fruits. The respiration rate of such fruits responds primarily to temperature. On the other hand, fruits showing a remarkable increment in respiration rate in maturation are called *climacteric* fruits (Biale 1960). Examples of climacteric and nonclimacteric fruits are listed in Table 1.2. In addition to their distinctive respiration patterns, climacteric and nonclimacteric fruits also differ from each other in their response to ethylene (Lelièvre et al. 1997). When the climacteric fruit matures, a traceable amount of ethylene is produced, which triggers more ethylene production and a series of ethylene-related ripening and senescence processes. These responses can also be triggered by external application of ethylene to a mature climacteric fruit.

Ethylene production and reaction can be downregulated by the reduction in temperature (Cheng and Shewfelt 1998),

Table 1.1. Classification of Common Fruits by Their Origins and Main Production Regions

Temperate Fruits	Subtropical Fruits	Tropical Fruits
Apple, pear, peach, nectarine, plum, cherry, apricot, grape, strawberry, brambles (raspberry and blackberry), currants, gooseberry, blueberry, cranberry, kiwifruit, pomegranate, fig.	Citrus fruit (sweet orange, mandarin, tangerine, pummelo, grapefruit, lime, lemon, kumquat), avocado, cherimoya, lychee, loquat.	Banana, pineapple, mango, papaya, carambola (star fruit), guava, passion fruit, mangosteen, longan, jackfruit, durian, rambutan, sapota.

the increase in CO_2 content in the environment, the decrease in O_2 content (Kerbel et al. 1988, Gorny and Kader 1997), or the application of ethylene synthesis or reaction inhibitors such as aminoethoxyvinylglycine (Bregoli et al. 2002) and 1-methylcyclopropene (Blankenship and Dole 2003). These techniques have been commercially adopted to extend the postharvest life of climacteric fruits (DeEll et al. 2003).

Botanical Classification of Fruits

Fruits can also be categorized into different types based on their anatomical origins. A fruit can be a simple fruit, derived from a flower, or a compound fruit, formed by many flowers. Either type of fruits can be further classified into subtypes.

Simple Fruits

A simple fruit is developed from a simple or compound ovary in a flower with only one carpel. Simple fruits can be dry or fleshy.

Simple Dry Fruits

A simple dry fruit is a fruit with dried pericarp. Simple dry fruits may be either dehiscent, i.e., opening to discharge seeds, or indehiscent, i.e., not opening to discharge seeds.

Table 1.2. Examples of Climacteric and Nonclimacteric Fruits

Climacteric Fruit	Nonclimacteric Fruit
Apple, banana, European pear, mango, papaya, persimmon, kiwifruit, cherimoya, avocado, guava, plantain, plum, peach, passion fruit, apricot, bread fruit, jackfruit, pawpaw, durian, feijoa, tomato, Indian jujube.	Grape, Asian pear,[a] orange, grapefruit, lemon, lime, pineapple, cherry, strawberry, lychee, blackberry,[a] blueberry, cranberry, raspberry,[a] pineapple, pomegranate, loquat, pitaya (dragon fruit), carambola (star fruit), rumbutan, Chinese jujube.

[a] Although these fruits are generally considered nonclimacteric, cultivars in the climacteric category have been reported.

Achene An achene is a dry single fruit formed from a single carpel (monocarpellate) and is not opening at maturity (indehiscent). Achenes contain a single seed that fills the pericarp, but the seed coat does not adhere to the pericarp. Achenes are most commonly seen in aggregate fruits. In strawberries, what we think of as the "seeds" on the fruit surface are actually achenes. A rosehip (or rose-hep), the fruit of rose, is in fact an aggregate fruit composed of many achenes (Genders 1966).

Capsule A capsule is a dry single fruit made of two or more carpels. Most capsules are dehiscent at maturity and the seeds within are exposed. A few exceptions are indehiscent, for example, the African baobab (*Adnsonia digitata*). Capsules of some species split between carpels, of others each carpel splits independently. Seeds are released through openings or pores that form in the capsule. In Brazil nut (*Bertholletia excelsa*), the upper part of the capsule dehisces like a lid and the seeds ("nuts" in commercial terms) are exposed (Rosengarten 1984). This type of capsules is called a pyxis.

Capsules may frequently be confused with the true nuts. The difference between a capsule and a nut is that a capsule splits when matures and the seeds inside are released or at least exposed, whereas a nut does not split or release seeds.

Caryopsis A caryopsis is a dry simple fruit resembling an achene. It is also monocarpelate and indehiscent. The only difference between a caryopsis and an achene is that in a caryopsis the pericarp is fused with the seed coat into a single unit. The caryopsis is commonly known as the grain and is especially referred to the fruit of *Gramineae* (or *Poaceae*), for example, corn, rice, barley, and wheat (Arber 2010).

Cypsela A cypsela is an achene-like simple dry fruit formed from the floret in a capitulum, the inflorescence or flower head of *Asteraceae*, for example, sunflowers. What we normally call a sunflower "seed" is a cypsela fruit. The husks of the seed are in fact the hardened pericarp of the fruit.

Fibrous Drupe A fibrous drupe differs from a typical drupe by its hardened, fibrous exocarp and mesocarp. Examples of fruit crops that bear fibrous drupes are coconut, walnut, and pecan. The shell of the coconut is derived from the exocarp

and mesocarp, while the meat is the edible inner layer of the hardened endocarp. The husks of walnut and pecan are produced from the exocarp and mesocarp tissues of the pericarp while the part known as the nut is developed from the endocarp (Rosengarten 1984).

Legume A legume fruit, or commonly called a pod, is a fruit in the family *Fabaceae* (or *Leguminosae*) in botany. It is a simple dry fruit that is developed from a simple carpel and usually dehisces on two sides (Tucker 1987). Peas, beans, and peanuts are examples of well-known legume fruits.

Nut A nut is a simple, indehiscent dry fruit containing one single seed protected by hardened ovary wall. The seed of a nut is usually intimately attached with the ovary wall at full maturity. In botany, nut refers to the fruit of *Fagaceae*, such as chestnut; or *Betulaceae*, such as hazelnut or filbert.

Simple Fleshy Fruit

Simple fruits in which the pericarp, whole or part of it, is fleshy at maturity are called simple fleshy fruits. In most simple fleshy fruits, the pericarp and the carpel are fused together.

Berry A berry is a simple fleshy fruit having seeds and pulp produced from a single ovary. The entire ovary wall of the berry ripens into an edible pericarp. Depending on species, a berry may usually have one or many seeds embedded in the flesh of the ovary. Similar to nuts, berries are ambiguously referred to many edible small fruits that are not true berries in botanical sense. Examples of true berries are grape, kiwifruit, banana, currant, gooseberry, tomato, etc. On the other hand, strawberries, raspberries, blackberries, and mulberries are not true berries because they are developed from multiple ovaries. A serviceberry or juneberry (*Amelanchier*) resembles a true berry but anatomically it is a pome.

Drupe A drupe is a fruit in which the exocarp and mesocarp, the outer and middle layers of the pericarp, are soft and fleshy but the endocarp, the inner layer of the pericarp, is lignified to form a hardened shell in which a seed is enclosed. A drupe is developed from a single carpel. Stone fruits, for example, peach, plum, cherry, apricot, etc., bear typical drupe fruits. Other common fruit crops bearing drupes include jujube, mango, coffee, olive, palm date, etc.

Some fleshy fruits contain a pit but the hardened shell of the pit is derived from the seed coat rather than the endocarp. Examples are lychee, longan, etc. By definition, these are not drupes.

Pome A pome is an accessory fruit developed from one or more carpels of a single flower and its accessory tissues. Pomes are exclusively referred to the fruit produced by *Maloideae* subfamily under Rosaceae (Aldasoro et al. 1998). Examples of pome fruits are apple, pear, quince, loquat, etc. The cortex of a pome fruit is the main edible part and is derived from the receptacle (the enlarged section of a stem from which the flower develops) or the fused hypanthium (the fused bases of the sepals, petals, and stamens), the exsocarp, and the mesocarp. The core of a pome is the fused leathery endocarp and carpels containing seeds.

Most pome fruits have a distinctive cortex and core. Some, for example, serviceberry or juneberry (*Amelanchier*), bear berry-like pome fruits with juicy flesh and indistinguishable core.

Hesperidium A hesperidium is a modified berry specifically referred to the fruit of the *Citrus* family (Ladaniya 2008). The exocarp forms the outmost layer of the tough, leathery rind of the fruit and is known as the flavedo. The flavedo contains pigments and essential oils. Underneath the flavedo is the albedo or pith that is derived from the mesocarp. The endocarp forms the fleshy part with separate sections (segments). The juicy sacs inside the segment are called juice vesicles and are actually specialized hair cells.

The rind of most hesperidia is usually not being consumed with the flesh. In some cooking styles, the flavedo of lemons or oranges is used as a flavor ingredient called zest. The rind of some hesperidia, for example, kumquat (*Fortunella margarita*), is tender and sweet and usually consumed together with the juicy sacs.

Pepo The term "pepo" is referred to a fruit from the melon (*Cucubitaceae*) family. A pepo is botanically a modified berry with hard, thick rinds derived from the exocarp. The fleshy inside is composed of mesocarp, endocarp, and ovary (Whitaker and Davis 1962). Most common pepo fruits, for example, cucumber (*Cucumis melo*), water melon (*Citrullus lanatus*), and pumpkin (*Cucurbita maxima*), contain many seeds. The chayote (*Sechium edule*) also belongs to the melon family but bears pepo fruit with only one large seed. The bitter gourd (*Momordica charantia*) bears dehiscent pepo fruits that, when fully ripened, split into segments, which curl back dramatically to expose seeds covered in bright red pulp.

Compound Fruits

A compound fruit is a fruit derived from multiple ovaries within a single flower or from multiple flowers, each bearing a single ovary. The former is designated as an aggregate fruit and the latter a multiple fruit (Spjut and Thieret 1989).

Aggregate Fruit An aggregate fruit is developed from a single flower that has multiple pistils, each containing one carpel. Each pistil forms a fruitlet. Together, the fruitlets are called an aggregate or an etaerio (from French etairion, and from Greek hetaireia, association). Aggregate fruits can be etaerios of achenes, drupes, or berries. Strawberry bears aggregate fruits of achenes. Botanically, the "seeds" on a

strawberry are the true fruits and the fleshy part of the fruit is derived from the enlarged receptacle of the flower. A raspberry or blackberry is an aggregate of drupes each containing one pit. Annona fruits, for example, custard apple, cherimoya, and Atemoya, bear aggregates of berries.

Multiple Fruit A multiple fruit is derived from an inflorescence composed of multiple flowers. The ovaries of each individual flower are fused together to form a single fruit at maturity. There are different types of multiple fruits corresponding to different origins in the development. A sorosis, for example, mulberry, is a multiple fruit derived from the incorporated ovaries of the flowers. A coenocarpium, for example, pineapple and jackfruit (*Maclura pomifera*), is composed of the ovaries, floral parts, and receptacles of many flowers and the fleshy axis of the inflorescence. A fig fruit is also a multiple fruit developed from a syconium, a specialized inflorescence on *Ficus* plants.

Accessory Fruit

An accessory fruit is a fruit in which the fleshy part is mainly derived from the accessory tissues of the flower. Accessory fruits are also called false fruits or pseudocarps. For example, strawberries are aggregate fruits of achenes while are also accessory fruits because the fleshy part is the enlarged receptacle. Pome fruits with an enlarged fleshy receptacle fall in the same category. A fig fruit is another type of accessory fruit of which the enlarged hollow flesh part is the receptacle bearing multiple ovaries on the inside surface.

Culinary Classification of Fruits

Botanically, a fruit means the structure on a plant developed from a flower and the accessories of this flower. In culinary practice and food processing point of view, edible fruits are grouped into four categories: fruits, fruits used as vegetables, nuts, and cereals.

Fruits

In culinary practice and food processing, fruits commonly refer to any edible part of a plant with a sweet taste and pleasant flavor, corresponding to most edible fleshy fruits in the botanical sense. However, some botanical fruits may not be palatable or sweet, for example, lemon, avocado, and cranberry, but are still considered as fruits in cooking or processing.

In some unusual cases, a plant part other than the botanical fruit may be accepted as a fruit in cooking or processing. For example, the fleshy and sweet petiole of the rhubarb (*Rheum rhabarbarum*) is considered a fruit in the United States.

Fruits used as Vegetables

Many fruits that are not palatable or sweet when consumed raw offer savory taste when cooked or processed and are recognized as vegetables in culinary sense. Crops that are used as vegetables are mainly from the tomato family (*Solanaceae*), the gourd family (*Cucurbitaceae*), and the pea family (*Fabaceae*).

Some crops, for example, tomato, are mainly consumed as a vegetable in one region while commonly consumed as a fruit in another region.

Table 1.3. Common Culinary Nuts and Their Botanical Definitions

Culinary Nuts	Botanical Definition
Chestnut, hazelnut	True nuts
Almond, walnut, pecan, pistachio, macadamia nut	The kernel of a drupe
Brazil nut	The seed in a capsule
Peanut	The seed in a legume fruit
Cashew nut	The seed in a drupe
Lychee nut	A dried lychee fruit, the edible meat is the aril

Nuts

Although botanically only a few plant species in *Fagaceae* and *Betulaceae* produce true nuts, culinary nuts are a big group of dried seeds and fruits with diverse varieties. Many seeds and dry fruits producing oil-rich kernels within hardened pericarps or seed coats are all called nuts in food and processing industries (Rosengarten 1984). Examples of common culinary nuts and their botanical definitions are listed in Table 1.3.

Cereals

The dry fruit produced by *Poaceae* or *Gramineae* is botanically called a caryopsis, a type of dry fruit, but in culinary definition, those fruits cultivated for their edible parts are referred to as cereals or grains. Important cereal crops include wheat, rice, maize, etc. They are the major daily sustenance and unarguably the most important staple food in the world.

In addition to the caryopsis fruits from *Gramineae* family, a few species from other families bearing starch-rich seeds are also included in cereals, for example, buckwheat (*Fagopyrum esculentum*). Some oilseeds and oil-bearing materials are also considered cereals (Lusas 2000). Some cereal crops, for example, sweet corns, are used as vegetables when their fruits are young and tender.

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Biochemistry of Fruits and Fruit Products

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Abstract: Fruit ripening is a complex developmental process accompanying the last phase of fruit development and senescence. Ripening is a highly specialized and regulated process in which many of the physiological and biochemical changes occurring determine the nutritional and organoleptic quality of the fruit. Due to the tremendous commercial impact of fruit ripening on the consumers and society, considerabe efforts have been made to understand the biochemical and molecular basis controlling the process. For many years, ethylene has been considered as the ripening hormone, but current evidences indicate that the classical classification between climacteric and nonclimacteric fruit is probably an oversimplification, and the hormone plays an essential role in the processes accompanying ripening in both types of fruit. In the present chapter, we summarize most recent findings of relevant changes taking place during ripening, as ethylene biosynthesis and regulation, changes in pigment composition, aroma formation, carbohydrate, organic acids, and lipid composition. The main metabolic pathways of components of fruit quality are revised and critical assessments of molecular approaches influencing ripening are presented and discussed.

INTRODUCTION

Fruits and fruit products are good sources of vitamins, minerals, and many other components essential for human nutrition and health. Fruits of different plant species vary in size, shape, texture, color, flavor, organoleptic, and nutritional characteristics. The biological function of the fruit is to attract animals for seed dispersal, and throughout evolution, plants have adopted a diversity of features to make fruits attractive to natural predators. Fresh fruits are botanically diverse since the ontogeny and structure of both the capsule containing the seeds and the edible portion are highly different from fruit to fruit. Pome fruits such as apples and pears develop from the thalamus, while stone fruits develop from the ovary wall. Berry fruits such as tomato or grape are derived from the ovary, and strawberry or pineapple come from receptacle tissue. Citrus fruits are a modified hesperidium, in which the ovary walls develop a structure containing the locules of juice sacs. Despite the high diversity, many physiological aspects of fruit growth and development, and regulatory aspects of the biochemical and molecular changes during fruit ripening are somewhat similar. Changes in color, sugars, acidity, softening and loss of texture, synthesis of aroma and flavor components, and increased susceptibility to physiological disorders are prominent during fruit ripening. The fact that many of these processes are common in fruits of different plant species suggest that the regulatory mechanisms governing these transformations have been

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at least partially conserved during evolution and the agronomical domestication of the species. The biochemistry of fruit ripening has been the subject of comprehensive reviews (Paliyath and Murr 2006, Giovannoni 2004), and books (Seymour et al. 1993, Knee 2002). In this chapter, we summarize relevant biochemical changes during fruit ripening with emphasis on metabolic pathways of major components of fruit quality and molecular approaches influencing ripening.

REGULATION OF FRUIT RIPENING: THE ROLE OF ETHYLENE

The role of ethylene as the "ripening hormone" in regulation of fruit ripening has been recognized for many years. There are many ancestral practices for fruit manipulation and storage, which complement advance ripening, that are now known to be mediated by ethylene. The degreening of citrus fruits and bananas are two examples of ethylene-based postharvest technologies used worldwide. The notion of climacteric ripening was initially defined by Kidd and West as early as 1925 and is fundamental to understanding the physiology of the fruits and postharvest handling and storage. Fruits have been classically categorized as climacteric and nonclimacteric based on their ability to increase ethylene production and respiration rate at the onset of ripening. This climacteric behavior is invariably associated with an autocatalytic control of ethylene production. By contrast, fruits that do not produce elevated levels of both ethylene and respiration are referred to as nonclimacteric (Biale and Young 1981).

The increase in respiration and ethylene production accompanying the onset of ripening in climacteric fruit is not always coordinated. There are examples in which the rise in respiration rate precedes, or is concurrent or follow climacteric rise in ethylene production (Biale and Young 1981). Although the metabolic basis for the relationship between these two processes are still uncertain, evidences from transgenic fruits in which ethylene production has been genetically reduced indicate that ethylene is the trigger factor for the increase in respiration rate (Oeller et al. 1991).

However, this categorization is controversial and may depend on the experimental conditions. There are examples of different cultivars of plums with climacteric and nonclimacteric ripening features (Abdi et al. 1997). The duration and intensity of the climacteric responses, either ethylene production or respiration rate, may also differ substantially among species and cultivars of the same species. Moreover, in nonclimacteric fruits, ethylene treatment enhances the ripening process. Therefore, categorization of fruit ripening in these two classical groups may be an oversimplification of the natural phenomena. However, in general, ethylene production appears to be a more reliable criterion for the distinction between climacteric and non-climacteric fruits (Watkins 2002).

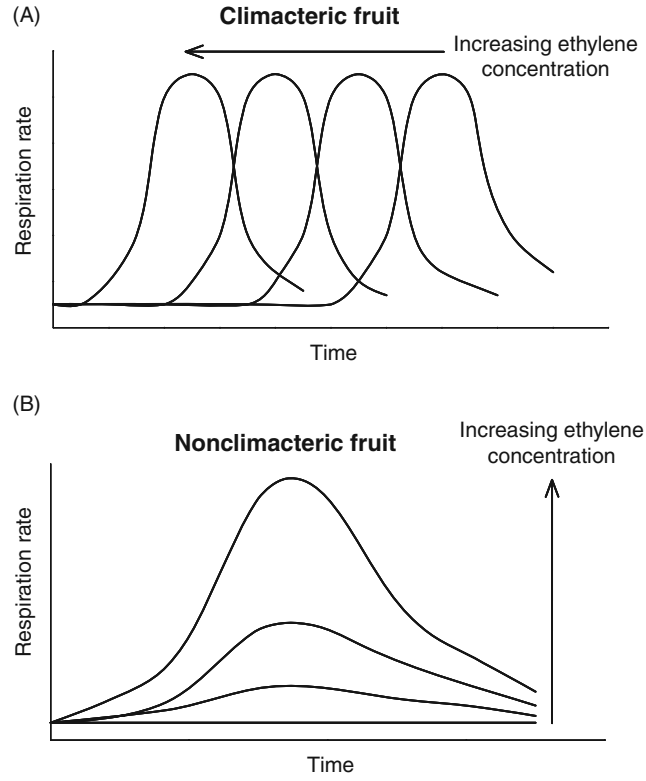

Figure 2.1. Effect of increasing ethylene concentrations on respiration of climacteric and nonclimacteric fruits.

Other important difference between climacteric and nonclimacteric fruits is the response to exogenous ethylene. In climacteric fruit, ethylene deficiency affects the time to reach the maximum climacteric respiration but not its magnitude. This response is independent on the concentration of ethylene and is irreversible (Fig. 2.1A). Once a threshold of ethylene is achieved, it initiates autocatalytic ethylene production that irreversibly hastens the ripening process even if ethylene is removed. In nonclimacteric fruit, by contrast, ethylene increases the respiratory rate in a concentration-dependent manner (Fig. 2.1B). Since autocatalytic ethylene production is not operative, once ethylene is removed, respiration declines to basal levels, and the maturation rate is consequently delayed (Biale and Young 1981). These effects of exogenous ethylene are likely to mimic the endogenously produced and are of particular importance in the postharvest performance of the fruit. Ethylene may accumulate from nonbiological contaminants and also from ripening fruits, and the responses of stored fruit may be differentially affected and the storage-life reduced.

On the basis of the differences in the responses to ethylene and in the control of ethylene production, McMurchie et al. (1972) postulated the presence of two systems of ethylene production in plants. System 1 functions during

normal growth and development and in responses to stress conditions. This system is common to climacteric and nonclimacteric fruits and to other tissues, and is regulated in a negative manner. System 2 is only present in climacteric fruits and is characterized by being stimulated by ethylene (autocatalytic). It was thought that ethylene production during the life span of the plants is produced by system 1, but only climacteric fruit would have the ability to stimulate system 2 once ethylene has reached a threshold and ripening would be initiated (Yang 1987).

Ethylene biosynthetic pathway in higher plants is now well defined, and regulation of ethylene biosynthesis during fruit maturation, especially in climacteric fruit, has been extensively studied. Excellent and comprehensive literature revisions have been compiled with recent findings and major breakthroughs (Giovannoni 2004, Barry and Giovannoni 2007, Cara and Giovannoni 2008, Bapat et al. 2010). Briefly, synthesis of *S*-adenosyl-L-methionine (SAM) from the amino acid methionine catalyzed by SAM synthase is the first step of the pathway. SAM is then converted to 1-aminocyclopropane-1-carboxylic acid (ACC) by the enzyme ACC synthase (ACS). Finally, ACC is oxidized to ethylene by an ascorbate-dependent ACC oxidase (ACO), which also generates carbon dioxide and hydrogen cyanide (NCH). Ethylene is produced in plants by many developmental and stress stimuli, and a large body of evidences indicate that ACS is the rate-limiting step in the pathway; even ACO is, to a minor extent, other regulatory factor. ACS and ACO are encoded by multigene families, which in the case of tomato are composed by eight *ACS* and five *ACO* genes (Cara and Giovannoni 2008). Differential expression of each member of these gene families in a tissue- and stimuli-dependent manner determines the timing and intensity of ethylene biosynthesis in different developmental processes. During tomato fruit ripening, it has been shown that *ACS1* and *ACS3* are expressed in green fruit, maintaining low levels of ethylene in the preclimacteric stage (system 1). *ACS2* and *ACS4* were expressed at the onset of ripening and are stimulated by ethylene, thus being responsible for autocatalytic ethylene production (system 2). Other members, such as *ACS6*, were expressed in green fruit but repressed by ethylene. Two *ACO* genes (*ACO1* and *ACO4*) were also induced during ripening and stimulated by ethylene (Nakatsuma et al. 1989, Barry et al. 2000, Yokotani et al. 2009). These results indicate that coordinated expression of specific *ACS* and *ACO* gene members in a specific and temporal manner regulate the transition from low (system 1) to high and autocatalytic (system 2) ethylene production during fruit ripening. Other factors such as ACS phosphorylation, ubiquitination, and ACO activity may also play a crucial role in modulating ethylene synthesis (Barry et al. 2007).

The role of ethylene in regulating fruit ripening has been clearly demonstrated in tomato and other plants by genetic manipulation of ethylene biosynthetic genes. Genetic engineering of *ACS* and *ACO* genes has been accomplished in several horticultural crops, such as tomato, apple, banana, or melon (Barry and Giovannoni 2007, Matas et al. 2009, Bapat et al. 2010). In tomato plants transformed with an antisense *ACS* gene, fruit ripening was severely delayed and climacteric respiration failed to increase. Exogenous ethylene restored these phenotypes, indicating that ethylene is required to induce fruit maturation, including enhancement of respiration (Oeller et al. 1991). Other results with antisense *ACO* genes showed inconsistent results because delayed some ripening-associated processes (lycopene accumulation, loss of acidity), but other physiological processes were unaltered (Murray et al. 1993, Picton et al. 1993). Similarly, transgenic melon with reduced ethylene production displayed alteration in only some of the ripening-associated events (flesh firmness, rind coloration, aroma emission, among others) but not in others such as flesh coloration, sugar content, loss of acidity, or ACS induction (Guis et al. 1997, Pech et al. 2008). ACO-antisense transgenic apples also displayed a reduced aroma volatile emission, were firmer, and were with an extended shelf life (Dandekar et al. 2004). Together, these observations indicate that fruits from different species may have different requirements of ethylene production during natural ripening, which explain the variation of phenotypes observed in the low ethylene-producing transgenic plants. This further reinforces the notion that ethylene has only a limited role in regulating physiological and biochemical characteristics of fruit ripening (Barry and Giovannoni 2007).

Ethylene perception and signal transduction are also determinants in the ripening process of fruits. Major advances have been made in understanding how ethylene binds to plant receptors and how the signal is transduced to the nucleus, activating specific programs of gene expression. There is a high degree of divergence in plants, but in general, there are two families of ethylene receptors: subfamily I of receptors most homologous to histidine kinases and members of subfamily II lacking of this kinase domain (Kendrick and Chang 2008). In tomato, at least three members of each subfamily have been identified (Klee 2004). Expression of ethylene receptors during ripening has been also studied in climacteric (Takahashi et al. 2001, Rasori et al. 2002, El-Sharkawy et al. 2003, El-Sharkawy et al. 2007, Yin et al. 2008, Tatsuki et al. 2009) and nonclimacteric fruits (Katz et al. 2004, Trainotti et al. 2005, Wang et al. 2010). Tomato ethylene receptors have distinct patterns of expression during fruit ripening and in response to stress. *ETR1* and *ETR2* are constitutively expressed, but *NR*, *ETR4*, and *ETR6* are induced during ripening. Interestingly, loss of function in most of these genes did not produce altered ripening, but reduced expression of *LeETR4*-enhanced ethylene sensitivity and accelerated ripening. Reduced expression of *NR* was not associated with an altered ripening since *LeETR4* was overexpressed (Kevany et al. 2008). These results indicate a functional compensation between some of the ethylene receptors, and some of them function as negative regulators of ethylene response. Moreover, it has been shown that LeETR4 and LeETR6 proteins are degraded in response to ethylene during accelerated fruit ripening.

Current evidences are compatible with a model in which ethylene receptor is a major determinant of ripening initiation. As the receptors are negatively regulated by ethylene, their depletion would result in a progressive increase in hormone sensitivity and a consequent accelerated ripening (Kevany et al. 2007).

The classic concept of nonclimacteric ripening implies that the process proceeds with no changes in ethylene production. In strawberry, the use of the highly sensitive laser photoacoustic gas chromatography has revealed an increase in ethylene production that appeared to be autocatalytic and in respiration rate once the red color was developed (Iannetta et al. 2006). Interestingly, it has been also shown an expression of the ethylene receptors (*ERT2* and *ERT4*) in a ripening-dependent manner (Trainotti et al. 2005). This notion is also consistent with the effect of ethylene and of the ethylene action inhibitor, 1-MCP, in the evolution of different events during strawberry ripening (Villarreal et al. 2010).

The use of the 1-MCP has been important to understand the role of ethylene in grape ripening. In a series of experiments during ripening, it has been demonstrated that ethylene is required at the onset of ripening for anthocyanin accumulation and acid decline (Chervin et al. 2004). Several anthocyanin biosynthetic genes, including alcohol dehydrogenase (ADH), were also regulated by ethylene and repressed by 1-MCP (El-Kereamy et al. 2003, Tesniere et al. 2004). These results indicate that ethylene is involved in multiple aspects of grape development. Other classical nonclimacteric fruit like citrus, display several features suggesting that at least some ripening events may be controlled by ethylene. Inhibitors of ethylene action have been demonstrated to inhibit development of peel coloration (Goldschmidt et al. 1993). Ethylene by contrast, stimulated the expression of carotenoid biosynthetic genes, reproducing the naturally induced pattern of expression (Rodrigo and Zacarias 2007). It is interesting to mention that 1-MCP suppressed the expression of carotenoid biosynthetic genes of fruit on the tree (Carmona et al., in press), indicating that this hormone is involved, at least in the induction of peel coloration, during natural fruit ripening. Analysis of ethylene biosynthesis during the reproductive development of orange fruit has shown that ethylene production in immature fruits is autocatalytic, whereas mature fruits evolve a negative feedback regulation of ethylene production (Katz et al. 2004). Collectively, ethylene also appears to be involved in the ripening process of non-climacteric fruits, although the mechanisms may be different from the climacteric fruits. It is conceivable that other unknown biochemical and molecular systems may have developed in nonclimacteric fruit to sense and coordinate the ethylene signals in spite of the reduced levels of ethylene production during ripening, suggesting the possibility of new pseudo-climacteric mechanisms.

Early studies in tomato fruit stored under controlled atmosphere pointed out to the occurrence of ethylene-dependent and -independent processes during fruit ripening (Watkins 2002). Transgenic fruits, especially melon, tomato, and apple, with reduced ethylene production, and the use of 1-MCP have proved to be valuable to examine ripening events under ethylene control. In *ACO*-antisense melon fruit, it was observed that the initiation of climacteric ethylene (ACS activity and ACC content) was under developmental or environmental control, but the rate of the process may be ethylene-dependent. Those fruits displayed altered rind yellowing, softening of the flesh, development of the peduncle abscission zone, aroma formation, and climacteric respiration, indicating that they are totally or partially ethylene-dependent. Other processes such as pulp coloration, accumulation of sugars, and loss of acidity were ethylene-independent processes (Ayub et al. 1996, Guis et al. 1997). Fruit softening was substantially affected in the ACO-antisense melon, but the activation of a subset of cell wall hydrolytic enzymes demonstrated the presence of components dependent and independent of ethylene (Hadfield et al. 2000). Other studies have demonstrated that fruit softening still occurred in fruit with a small residual ethylene production (antisense-ACO tomato and apple fruit) or in 1-MCP-treated kiwifruit (Koukounaras and Sfakiotakis 2007), suggesting the implication of ethylene-independent components.

Emission of volatile compounds and aroma formation is one of the effects more severely affected in fruits with reduced ethylene production or sensitivity. A genomic analysis in ACO-antisense apple fruit demonstrated that ethylene only regulates a reduced number of genes in the different ripening-associated processes. Ethylene-dependent genes are essential in the case of aroma production and predominantly in the final steps of the biosynthetic pathways (Schaffer et al. 2007).

CARBOHYDRATE METABOLISM

Biochemical changes during fruit development and maturation are the key determinants of fruit quality. In plants, photosynthesis produces organic compounds from inorganic carbon by using energy from the sunlight. In fruits, however, the contribution of photosynthesis to total carbon requirements declines during growth and maturation. Photosynthetically active tissues in fruit lose this capability during development as chlorophyll (Chl) is progressively lost. Contribution of photosynthesis to reproductive development varies across species. However, in many fruit trees, it ranges from 5% to 15% (Fleancu 2007).

In general, sugar accumulation in fruit is due to translocation of sucrose from leaf and bark and is stored as starch. Sucrose, the major form of transport sugar, is synthesized from glucose-1-phosphate. In some cases, sucrose is not the main transporting sugar in fruits, since it can be converted into glucose and fructose in a reaction catalyzed by the enzyme invertase. Sugar alcohols, mannitol and sorbitol, may be

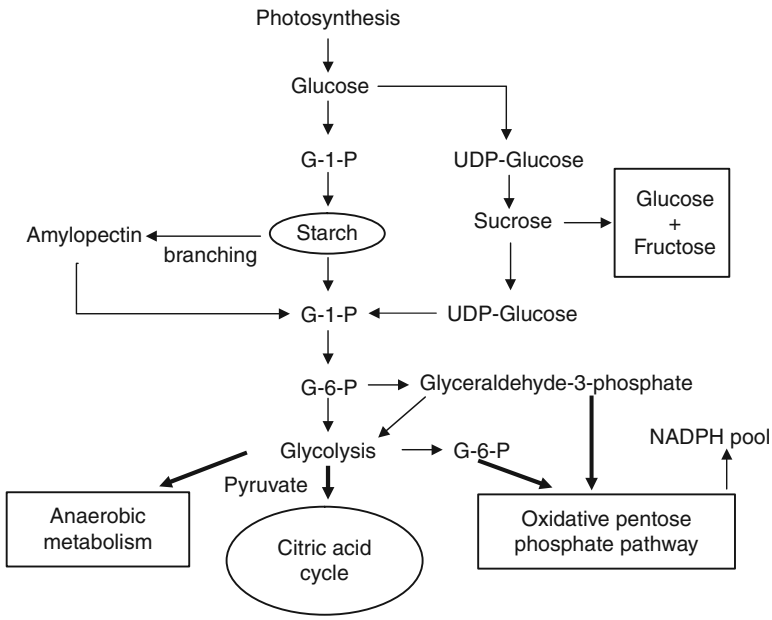

Figure 2.2. Overview of carbohydrate metabolism in fruits.

the main transport and storage carbohydrates in some fruits such as apple and olive.

Figure 2.2 summarizes the main reactions and carbon flux occurring in fruit cells. Starch is the main storage polysaccharide in most unripe fruits and is converted during maturation to reducing and nonreducing sugars. Starch is allocated in plastids and is composed of amylose and amylopectin molecules. During ripening, starch degradation occurs through a sequence of catabolic reactions in the plastid to generate glucose-1-phosphate, which is mobilized into the cytoplasm, resulting in an increase of glucose and fructose in the flesh. Sugars enter in the metabolic pool to be used as respiratory substrates during glycolysis, providing reducing power or carbon precursors for amino acid, nucleic acids, and secondary metabolites, among others, through the pentose phosphate pathway, or they can be converted to other metabolites through turnover reactions to maintain homeostasis in cells (Fig. 2.2).

During fruit development, glucose generated through photosynthesis may be used for respiration and biosynthesis of starch. However, in this phase of fruit life, carbohydrate metabolism is oriented to biosynthesis. In contrast, during maturation, there is a high requirement of energy and the pattern of sugar metabolism shifts to catabolism through respiration. This is due to the fact that the ripening is a highly demanding process in terms of energy requirements. At this stage, climacteric fruits exhibit a burst in respiratory rate. Fruits such as avocado, with high oil content in flesh, and others such as mango and banana require an elevated input of energy. Climacteric fruits are, in general, highly perishable during postharvest due to this respiratory demand. For this reason, strategies based on storage under controlled atmospheres with low oxygen, high carbon dioxide levels, and low temperatures to reduce metabolic rates have been adopted to extend shelf life of these fruits.

It is worth mentioning that in plant tissues and in fruits, glycolysis, pentoses phosphate pathway, and starch and sucrose degradation share pools of metabolic intermediates, and the direction of metabolite flow is determined by the requirements of the cells during the different stages of development and maturation.

In citrus fruits, changes in sucrose, glucose, and fructose have been described during maturation. For example, during maturation of Clementine mandarin, sucrose accumulates in juice vesicles, whereas glucose and fructose accumulate in flavedo and albedo tissues (Tadeo et al. 1987).

The enzymes invertase, sucrose synthase, and sucrose phosphatase synthase are the key enzymes in sucrose metabolism. Sucrose accumulation is determined by the balance between sucrose synthesis (due to sucrose phosphatase synthase) and degradation (due to invertase and sucrose synthase). Sucrose synthase is involved in the production of respiratory substrates and UDPG for synthesis of complex carbohydrates (Sung et al. 1988).

Sucrose phosphatase synthase activity increases during maturation of different fruits. Although this enzymatic activity remains steady during tomato fruit ripening, it increases with the synthesis of sucrose in other fruits such as muskmelon (Lingle and Dunlap 1987). In banana (Cordenunsi and Lajolo 1995) and cucurbitaceae (Irving et al.

1997), sucrose phosphatase synthase increases with starch degradation and sucrose accumulation. In citrus, it has been shown at transcriptional level that sucrose phosphatase and synthase increase in mature fruit (Komatsu et al. 1996), even though activity may be lower (Lowell et al. 1989). In contrast, sucrose synthase activity is maximum in cells from fruit at stage I, when energy requirements are maximum due to cell division and fruit enlargement. It should be indicated that sucrose synthase functions primarily in a sucrose-degrading direction (Cano-Medrano and Darnell 1997).

During glycolysis, breakdown of sugars occurs to generate the energy required for ripening. During respiration, pyruvate generated in glycolysis is converted to acetyl coenzyme A, which enters the citric acid cycle to be completely oxidized to carbon dioxide. During citric acid cycle, several organic acids are synthesized and are converted again to sugars during fruit maturation. This process is called gluconeogenesis. During gluconeogenesis, several irreversible steps in glycolysis and citric acid cycle are bypassed.

Sugars and sugar phosphates generated during starch degradation are metabolized through glycolysis and citric acid cycle. However, sugar phosphates may alternatively be used by the pentose phosphate pathway, which through a series of irreversible reactions provides NADPH that can be used as reducing power; the pool of the pentose phosphate/triose phosphate is equilibrated through reversible reactions. Elements from the glycolysis and the pentose phosphate pathway may interact and share common sugar phosphate intermediates. In the pentose phosphate pathway, interconversion of sugar phosphates occurs with 3, 5, 6, and 7 carbons. These recycling reactions allow the formation of a NAPDH pool. NADPH is key for the maintenance of the antioxidant enzyme system and fruit quality through preservation of cellular structure and function.

Exposure to low temperatures during postharvest handling may cause anaerobic respiration in mature fruit. Under these conditions, the mitochondrial electron transport is inhibited, and ATP cannot be produced through the citric acid cycle. Anaerobic respiration is the alternative pathway that mature fruits use to produce ATP through the conversion of pyruvate into lactate, in a reaction catalyzed by lactate dehydrogenase. This reaction generates NAD. During the first, the elongating phase of fruit growth in citrus, respiration occurs in the peel, whereas during maturation, there is an increase in anaerobic respiration during maturation, and the content of ethanol and acetaldehyde increases in parallel. In fruits such as apple, a decrease in pyruvate is concomitant with an increase of pyruvate decarboxylase activity, ADH, and malic enzyme. The malic acid is converted to pyruvate in a reaction catalyzed by the malic enzyme and to ethanol by pyruvate decarboxylase and ADH, which can use NADP generated through ethanol production by using the malate.

Some postharvest disorders such as watercore in apples and pears have been related to carbohydrate metabolism during fruit maturation. For example, sucrose accumulates in watercored Fuji apples. Accumulation of sorbitol and sucrose, and decrease in glucose and fructose as a consequence of alteration in carbohydrate metabolism are suggested to cause watercore development (Bowen and Watkins 1997).

In avocado, during fruit expansion, soluble sugars account for most of the increase in tissue biomass, the main carbohydrate is D-mannoheptulose, a C7 carbohydrate. Sugar content declines as oil accumulation commences. During postharvest, D-mannoheptulose decline, indicating a pivotal role in respiratory processes in this fruit (Liu et al. 1999).

The regulation of ATP-dependent phosphofructokinase is responsible for channeling carbon through glycolysis during respiratory climacteric in banana (Ball et al. 1991), although it seems this is initiated by carbon release from starch and later by activation of glycolysis (Beaudry et al. 1989).

Ethylene may induce sugar accumulation by triggering starch breakdown during postharvest ripening of some fruit such as banana, mango, and kiwi. In other fruits such as loquat, sugar accumulation is the result of transport from other organs rather than starch breakdown. Because ethylene treatment has an effect on inducing sugar accumulation in these fruits, it is postulated that the gas induces an increase in sink activity of loquat fruit (Hirai 1982).

ORGANIC ACIDS

Organic acids are among the principal compounds in the fruits producing a sour sensation or acidity. Fruit acidity is also one of the essential factors to decide the harvest time in crops where acidity is important for consumers' acceptance (Baldwin 2002).

The major organic acids in most fruits are malic and citric acids; however, the organic acid composition varies and would depend on fruit type, ripening, environmental conditions, and cultural practices. Some organic acids are characteristic of a family or genus; for example, citric acid in citrus fruits (Kefford and Chandler 1970), malic acid in apples (Tucker 1993), and tartaric acid in grapes (Sweetman et al. 2009). The proportion of individual acids is also an important factor as it has been described that citric acid can cover perception of sucrose while malic acid seems to have the contrary effect (Bonnan and Noble 1993). Some organic acids can inhibit the growth of microorganisms.

Organic acids take part in several biochemical pathways, Krebs cycle being the most important. In addition, their metabolic pathways are highly interconnected with sugars, both being the main respiratory substrates during fruit ripening (Tucker 1993). Organic acids also accumulate to elevated concentrations in the vacuole during fruit development, which may serve to maintain the high turgor pressure required for cell expansion and fruit growth (Guillet et al. 2002). Other important functions are the capacity of citric acid for sequestering oxidant metals and malic acid controlling stomatal aperture, improving plant nutrition and also used as a

parameter of fruit freshness (Hernandez Suarez et al. 2008, Fernie and Martinoa 2009, Sweetman et al. 2009). In tomatoes, a biotechnology approach showed a crucial role of malic acid on starch metabolism, ripening and sugar changes, postharvest softening, and susceptibility to bacterial infections (Centeno et al. 2011). Oxalic acid can be considered as an anti-nutrient compound as it reduces the bioavailability of calcium (Hernandez Suarez et al. 2008).

In general, young developing fruits are extremely acidic and accumulate high percentage of organic acids. As a result, pH of immature fruits is often below 3, but generally increases during fruit ripening due to the conversion to sugars. The use of malic acid as a respiratory substrate is dependent on the malic enzyme localized in several cell compartments; and in fruits, a cytosolic NADP-dependent enzyme and a mitochondria NAD-dependent enzyme have been identified (Goodenough et al. 1985). These enzymes metabolize malic acid to pyruvate, allowing the entrance of carbon into the Krebs cycle without production of pyruvate by glycolysis. The regulation of malic acid metabolism has been extensively investigated as it is one of the most prevalent organic acids in fruits (Sweetman et al. 2009). The use of natural variability of malic aid content has helped to discover different mechanisms regulating the content of organic acids in fruits, and the connection with other important metabolites like sugars. Investigations with two apple genotypes with low and high malic acid content showed that the respiration rates were similar in both genotypes, and activities of enzymes involved in the synthesis of malic acid or catabolism were not significantly different. However, the low malate content in low-acid genotype was due to a restricted ability to store malic acid in the vacuole (Berüter 2004). Alteration in malic acid accumulation also affects partitioning of incoming assimilates into other cell components such as sugars. In fruits with high accumulation of malic acid, there is an imbalance in several pathways of carbon metabolism, increasing the glycolytic flux and decreasing ATP level. Similar studies in low- and normal/high-acid peaches and citrus fruits also suggest that other mechanisms rather than organic acid synthesis may account for the differences in citric acid content among cultivars (Canel et al. 1996, Moing et al. 2000). Recent metabolomic and genetic analysis of tomato introgression lines containing altered level of malic and other organic acids have shown a low level or no correlation with organic acid metabolic enzymes, suggesting that other regulatory mechanisms such as specific organic acid transporters are important factors controlling the levels of these components in fruits (Schauer et al. 2006).

The profile and evolution of organic acids during fruit ripening is very much dependent on the species. Therefore, the following is a summarized description of main changes in organic acids during development and ripening of major fruit crops, such as tomato, apple, grapes, and citrus. In young developing tomato fruits, the concentration of malic and citric acids is similar and increases during fruit development until fruit reaches the end of the cell division phase and decreases thereafter. During the ripening phase, there is an increase in malic acid catabolism, which is decarboxylated to pyruvate, and in combination with malate dehydrogenase and citrate synthase, the content of malic acid decreases and citric acid accumulates preferentially (Davies and Hobson 1981, Goodenough et al. 1985). However, important differences in the accumulation of citric acid during the postharvest period have also been reported (Davies and Hobson 1981, Gomez et al. 2009). The storage of tomatoes at low temperatures decreased main citric and malic acids at slow rate than fruits stored at optimal temperature (Goodenough et al. 1985, Thorne and Efiuvwevwere 1988, Gomez et al. 2009).

In apples, malic acid is the most abundant organic acid, and its levels can be reduced by 50% during fruit ripening mainly due to increase in the respiration rate (Berüter 2004). Malic acid is synthesized mainly in fruits from carbohydrates via glycolysis and the pentose phosphate pathway (Blanke and Lenz 1989), and the enzymes involved in the synthesis of apple fruits are phosphoenolpyruvate carboxylase (PEPC) and NAD-dependent malate dehydrogenase (Blanke et al. 1987). The degradation of malic acid was significantly reduced by the use of inhibitors of ethylene biosynthesis or action, and in transgenic apples with reduced ethylene production (Fan et al. 1999, Defilippi et al. 2004). Exogenous ethylene application to transgenic fruits resulted in an increase in respiration and consequently in acid degradation (Defilippi et al. 2004), suggesting that malic acid metabolism is an ethylene-dependent process.

In the nonclimacteric grape berries (*Vitis vinifera*), malic acid metabolism has been extensively studied since the acid content in the grape juice is crucial for wine fermentation. Although concentrations of tartaric acid in grapes are superior to malic, the former is not used in primary metabolic reactions and therefore malic acid is the only major organic acid that is metabolized during ripening. During grape fruit development, malic acid accumulates due to metabolism of carbohydrates. At this stage, there is a high level of PEPC activity concomitant with the malic acid accumulation and just before ripening, the enzymatic activity declines (Ruffner et al. 1976, Diakou et al. 2000). In véraison fruit, malic acid is released from vacuole and is available for metabolic utilization, including Krebs Cycle, respiration, gluconeogenesis, and biosynthesis of secondary compounds (Ruffner and Hwaker 1977, Sweetman et al. 2009).

A novel mechanism for citric acid utilization in the flesh of citrus fruit during ripening has been proposed by Cercos et al. (2006). This mechanism explains the reduction of citric acid and the cytoplasmic acidity during citrus ripening. During maturation of mandarin fruits, the organic acid pool shows a dramatic decrease in the levels of citric acid (55%), while malic acid remains invariable. Microarray data of fruit growth and ripening showed the expression of the cytosolic aconitase, which transforms citrate into isocitrate, and the cytosolic NADP isocitrate dehydrogenase, which

converts isocitrate into 2-oxoglutarate. Gene expression analysis together with metabolite analysis suggests that during fruit ripening, citric acid is released from the vacuole to the cytosol and sequentially metabolized into isocitrate, 2-oxoglutarate, and glutamate (Sadka et al. 2000a, 2000b). Afterward, glutamate is utilized for glutamine production and is catabolyzed through the GABA (α-aminobutyrate) shunt. The expression of three genes of enzymes involved in the GABA shunt showed a maximum during the period of acidity loss. Altogether, it is proposed that in the pulp of citrus fruits during ripening, acidification of the cytoplasm after release of citric acid from the vacuola stimulates the GABA shunt pathway, decreasing the levels of acid (Cercos et al. 2006).

In summary, recent physiological models have integrated the Krebs Cycle, transport of metabolites between the cytosol and the mitochondria, and the regulatory activities of related enzymes explaining variations in the concentration of the main organic acids during fruit growth and in response to different temperatures (Lobit et al. 2006, Wu et al. 2007). However, the complexity of the regulatory mechanisms involved in the biosynthesis and catabolism of organic acids in fruits as well as the existence of other factors, such as specific intracellular transporters, indicate the requirement of integrating different experimental approaches and high-throughput technologies to have a global picture of how this complex process is regulated during fruit development and ripening.

LIPID METABOLISM

Lipids in fruit have important roles and serve as structural elements (components of biomembranes in cells) or as storage components (in fruits such as olive and avocado). The denomination of lipids comprehends a series of compounds, including fatty acids, diacyl and triacylglicerols, phospholipids, galactolipids, sterols, and waxes. Phospholipids (including phosphatidylcholine, phosphatidylethanolamine, phosphatidylglycerol, and phosphatidylinositol), diacylglicerols, and sterols are major components of biomembranes. Besides, other metabolites such as phosphatidic acid, free fatty acids, and diacylglicerol may be present in membranes in variable amounts. Phosphatidic acid and some phosphorylated derivatives of phospholipids are components of signal transduction processes in response to environmental cues.

Lipid Biosynthesis

Fatty Acid and Glycerolipids Biosynthesis

De novo fatty acid biosynthesis has been studied extensively in avocado and olives, the two main lipid-storing fruits (Salas et al. 2000). Acetyl-CoA is the main precursor for fatty acid biosynthesis. Acetyl-CoA is synthesized after degradation of 6-carbon sugars during glycolysis by the action of a pyruvate dehydrogenase in plastids or in mitochondria by a mitochondrial pyruvate dehydrogenase, then cleavaged to acetic acid and transported to plastid, where it is reactivated to acetyl-CoA (Salas et al. 2000). In general, fatty acid biosynthesis needs the activity of two enzymes: acetyl-CoA carboxylase and fatty acid synthase. Acetyl-CoA carboxylase catalyses the condensation of a molecule of bicarbonate with acetyl-CoA to produce malonyl-CoA, the key intermediate of fatty acids, that undergoes transacetylation before being used by fatty acid synthases, a system of enzymes responsible for a series of cycles of elongation and condensation that finally will determine the C_{16}/C_{18} ratio of the pool of synthesized fatty acids. After fatty acid synthesis, desaturation takes place in plastid, yielding unsaturated fatty acid species such as oleate and linoleate. Further desaturation to produce polyunsaturated fatty acids may then take place in plastids or endoplasmic reticulum.

Glycerolipids are produced by the attachment of fatty acids synthesized to the glycerol molecule through the Kennedy pathway, a series of reactions that take place in the endoplasmic reticulum (Salas et al. 2000).

Storage Lipids

As mentioned above, the two main fruit storing lipids in the edible pulp are avocados and olives. In avocado, lipids are stored as reserve components in the indioblast, a specialized cell type of the mesocarp in form of triglycerides, synthesized from glycerophosphate to phosphatidic acid and to diglycerides (Kikuta and Eriksson 1968).

Lipid metabolism is an important part of the ripening process in fruit. In general, lipids accumulate in fruit during development and ripening. In fruits such as avocado, triglycerides account for most of the neutral lipids, which are about 95% of total lipids. The main fatty acids in triglycerides are palmitic (16:0), palmitoleic (16:1), oleic (18:1), and linoleic (18:2) acids. Oil content increases during ripening, and oils are compartimentalized in oleosomes.

Molecular studies related to lipid and fatty acid metabolism in fruit other than olives and avocados are very scarce. However, in mango fruits, accumulation of transcripts encoding a thiolase, the last enzyme in the β-oxidation of fatty acids during maturation, has been reported (Bojorquez and Gomez-Lim 1995).

Membranes

Cell membranes are inherited structures that serve as barriers to diffusion of water-soluble molecules. Membranes are composed of polar lipids and proteins. Lipids are also resources for signaling molecules. There are about 17 different membrane systems in plant cells. Lipids in membranes belong to several classes, including phospholipids, galactosylglycerides, glucocerebrosides, and sterols, and the ratio of lipid classes varies among organelles and organs in a given plant or among plants.

To date, the best model to explain changes in membrane fluidity is the fluid-mosaic model (Singer and Nicholson 1972). It proposes a biphasic layer of phospholipids and embedded proteins. Fluidity is affected mostly by the composition of fatty acid chains in the phospholipids. In general, the more unsaturated acyl chains are (this means more proportion of oleic, linoleic, and linolenic acids), the more fluid is the membrane. Membrane integrity is a requirement for cell homeostasis and organelle functioning. Receptors in membranes are surrounded by phospholipids. When a receptor is activated by a stimulus, phospholipids are converted into signaling molecules due to effector enzyme activity. Phospholipid signaling is involved in processes such as response to stress (Meijer and Munnik 2003).

Wax Synthesis and Deposition

Waxes are components of plant cuticles, the main barrier for gas and water exchange. Waxes are embedded in a matrix of the polymer cutin, but also form epicuticular layers by deposition. Waxes consist of different types of long fatty acids. These chains are generated by sequential additions of two-carbon units from C_{16} and C_{18} acylCoAs by elongases located at the membrane (Mintz-Oron et al. 2008). Wax composition varies during fruit development and ripening. In general, biosynthesis and deposition increase during early fruit development. In tomato, it has been shown that transcripts and metabolites related to wax biosynthesis accumulate at the beginning of fruit ripening to decline at latter stages (Baker 1982, Mintz-Oron et al. 2008).

Lipid Metabolism in Fruit During Ripening and Senescence: Postharvest Changes

During fruit maturation and ripening, there is a progressive increase in ion leakage and permeability to calcium. Since phospholipase D (PLD) is stimulated by low pH and high calcium concentrations (above 10 μM), membranes are altered. During senescence, membrane fluidity decreases as a consequence of changes in lipid composition. Increase in the sterol/phospholipid ratio reduced fluidity, a change that has been related to senescence in citrus and apple fruit, and the effect is more pronounced in detached fruit (Fuh et al. 1988). Postharvest senescence begins at harvest, when metabolic reactions shift from anabolism to catabolism, involving a decline in photosynthesis, chloroplast disorganization, and degradation of proteins, nucleic acids, and lipids. Phospholipid composition of membranes is continuously altered during senescence by acyl chain desaturation.

Alteration of membrane integrity is associated with lipid peroxidation and high lipoxygenase (LOX) activity, resulting in water loss and quality deterioration. In watermelon, water soaking, a postharvest disorder characterized by maceration of endocarp and placental tissues, is associated with an increase in phospholipase C (PLC), PLD, and LOX activities. Water soaking after exogenous ethylene application increased PLC, PLD, and LOX activities, phosphatidic acid (PA) content increased whereas phosphatidylcholine and phosphatidilinositol content decreased. In contrast, 1-MCP did not completely arrest PLC and LOX activities in watermelon stored without exposure to ethylene (Mao et al. 2004). These results suggested an ethylene-independent pathway that involves activation of oxylipin cascade in the development of this disorder as shown also in other plant systems such as citrus (Alferez et al. 2006).

Nutrient supply during crop development is also a factor that may play a critical role and compromise membrane integrity during postharvest. Phosphorus (P) is a key component of phospholipid molecule. In seedless cucumber, concentration of P in the lipid fraction and concentrations of phosphatidyl choline (PC) and phosphatidyl ethanolamine (PE) of fruit directly depended on P fertilization level. Furthermore, total fatty acids were less abundant in fruits under low P nutrition, and electrolyte leakage was greater in these fruits (Knowles et al. 2001). In other cases, under P deprivation, phospholipids may be replaced by galactoglycerolipids in extraplastidic membranes (Andersson et al. 2003).

Postharvest storage influences phospholipid composition. There is direct evidence for the coordinated involvement of three types of phospholipase families (PLA, PLC, and PLD) in the response to both biotic and abiotic stresses during postharvest. These enzyme families are divided into subfamilies based on sequences and biochemical properties. Phospholipases act in tandem. PLD hydrolyzes phosphatidylcholine, phosphatidyl glycerol, and phosphatidylethanolamine to phosphatidic acid; PLC uses phosphoinositides as substrates to generate diacylglycerol and phosphorylated head groups such as inositol 1,4,5-triphosphate. PLA_2 cleaves phospholipids at *sn-2* position to lysophospholipids and free fatty acids. Hydrolysis of galactolipids from chloroplast membrane seems to be mediated by enzymes with phospholipase activity, such as PLA_2 (Matos et al. 2001). Majority of fatty acids at *sn-2* position in the phospholipid molecule are linolenic and linoleic acids. Linolenic acid is oxidized by LOXs, although cytochrome P450 and pathogen-induced oxygenases have lesser roles. Then, the resulting product, 9- or 13-hydroperoxylinolecic acid, may be further metabolized by one of three separate enzymatic cascades (Blée 1998) to produce a wide variety of oxylipins, one in chloroplasts leading to final jasmonate production in peroxisomes (Dhondt et al. 2000). Oxylipins perform a variety of functions in plants (Howe and Schilmiller 2002) and may also contribute to postharvest senescence of vegetables and fruit (Zhuang et al. 1994).

PIGMENTS IN FRUITS

A pigment is a compound characterized by having a chromophore capable of absorbing visible light. In nature, there are three major classes of pigments: the green Chls,

carotenoids providing yellow to red color, and anthocyanins responsible for the red, blue, and violet color. There are additional classes of pigments (e.g., betalains, quinones, phenalones, phyrones), which are generally of minor importance (Gross 1987). The combination and diversity of different pigments determine visual aspect of the fruit and their attraction to insects and other animals to ensure seed dispersal. In last decades, new important functions had been attributed to each class of pigments. They may have a direct antioxidant activity, thereby providing protection from DNA, protein, and lipid damage. From a commercial perspective, pigments are crucial, as they determine visual aspect of the fruits, and thus their acceptance by the consumer. Anthocyanins and carotenoids also have important implications for human health, as they are antioxidants and provide protection from cardiovascular disease and certain types of cancer (Duthie et al. 2000, Rao and Rao 2007).

Content and composition of the different type of pigments vary greatly within genus, species, and variety, and are affected by environmental and cultural factors (Gross 1987, Goldschmidt 1988, De Pascual-Teresa and Sanchez-Ballesta 2008). Moreover, during postharvest handling and storage, the content and composition of pigments may be altered. After many years of intensive research, most of the genes encoding enzymes for Chl, anthocyanin, and carotenoid biosynthetic pathways have been identified and their regulation during fruit development are now being elucidated.

Chlorophylls

Chls are porphyrins absorbing strongly in the blue and red regions of the spectrum, thus conferring green colors. The different steps of the pathway of Chls biosynthesis and degradation have been elucidated recently through biochemical analysis and molecular cloning. Chlorophyll biosynthesis from glutamic acid comprises the action of more than a dozen enzymes, and it has been recently revised (Eckhardt et al. 2004, Tanaka and Tanaka 2006, Masura 2008). Chlorophyll degradation is central to the degreening process occurring during ripening of most fruits. However, Chl breakdown has been largely neglected, and nowadays, the basic steps of the catabolic pathway have been elucidated and a few of the associated genes identified (Hörtensteiner 2006, Hörtensteiner and Kräutler 2011). The degradation of Chl involves four initial basic steps, which are apparently common to all plants, and subsequent specie-specific reactions for storing catabolites in the vacuole.

In most fruits, Chl content increases during green stages and diminishes through maturation, paralleling chloroplast disintegration. This loss of Chl, known as degreening, unmasks previously synthesized pigments and is usually followed by the biosynthesis of other pigments, leading to color changes of the fruits during maturation. There are some exceptions of fruits retaining Chls at the ripe stage, as certain apple, pear, fig, plum, limes, avocado, melon, kiwi, and grape cultivars. These fruits are characterized by a low accumulation of pigments other than Chls at the ripe stage. In some mutants impaired in Chl degradation, referred to by the general term of "stay-green," synthesis of other pigments is not altered, presenting at the full maturation a dirty brown color. Three classes of stay-green mutants are recognized. In classes A and B, Chl degradation is intact but is activated or proceeds abnormally slowly. Class C mutants are those in which at least one step of the pathway may be deficient (Matile et al. 1999). Stay-green mutant phenotype has been reported in some fruits such as tomato (the green flesh mutant; Cheung et al. 1993, Akhtar et al. 1999, Barry et al. 2008), pepper (*Chl retainer*; Efrati et al. 2005, Barry et al. 2008), and citrus (navel negra; Alós et al. 2008). These genetic variants showing altered patterns of Chl catabolism are powerful tools in the investigation of this process.

Anthocyanins

Anthocyanins, a class of flavonoids derived from phenylalanine, are water-soluble, synthesized in the cytosol, and localized in vacuoles, where pH may vary its structure and color. Chemically, anthocyanins are based on a C15 skeleton with a chromane ring bearing a second aromatic ring B in position 2 (C6-C3-C6) and with one or more sugar molecules bonded at different hydroxylated positions of the basic structure. The biosynthetic pathway leading to anthocyanins has been well characterized and genes encoding relevant enzymes have been isolated and their developmental and tissue-specific expression studied (Grotewold 2006, Davies 2009, Hichri et al. 2011). Two categories of genes are involved in anthocyanin biosynthesis. The first category encodes enzymes required for pigment biosynthesis (structural genes), and the second comprises of transcription factors, which generally influence expression of structural genes. It has been proposed that these enzymes form a supermolecular complex (metabolon) via protein–protein interaction and are anchored in the endoplasmic reticulum membrane. Regulation of the pathway is specie-specific and different genes of the biosynthetic pathway have been found to be responsible for color variations in different anthocyanin accumulating fruits, such as apple (Ben-Yehuda et al. 2005, Takos et al. 2010), bilberry (Jaakola et al. 2002, Jaakola et al. 2010), Chinese bayberry (Niu et al. 2010), citrus (Lo Piero et al. 2005, Cultrone et al. 2010), pears (Feng et al. 2010), and grape (Boss and Davies 2009). Genetic evidences indicate that MYB-bHLH-WD40 protein complex, which actuates in conjunction with promoters of structural genes, greatly influences expression of genes of anthocyanin biosynthesis pathway. MYB and bHLH proteins are DNA-binding transcription factors, while WD40 proteins are known to stabilize protein–protein interaction. MYB transcription factor superfamily can actuate as inductors or repressor of anthocyanin pathway and its expression is strongly associated with anthocyanin production in fruits. MYB trans-activation efficiency,

specificity for DNA binding, and interactions are determined by key residues in N-terminal position, although consensus motifs in C-terminal position are just beginning to be elucidated. Mutations in genes encoding for either biosynthetic or transcriptional regulation of the pathway have been linked to color phenotypes. Generally, mutations imply a loss of function, resulting in a reduction or a change in anthocyanin distribution (Espley et al. 2009). In grapes, transposable elements causing instability in genes coding for transcription factors can explain most of the variation in coloration.

Hundreds of anthocyanins have been reported and most of them are primarily based upon six common anthocyanidins (chromophores of anthocyanins): cyanidin and its derivate peonidin, pelargonidin, and delphinidin and its derivates petunidin and malvidin. Pelargonidins give orange, pink, and red colors; cyanidins provide magenta and crimson coloration; and delphinidins provide the purple, mauve, and blue color characteristics of several fruits. The large number of anthocyanins arises from glycosylation, methylation, coumarylation, and a variety of other additions such as modification with acyl moieties in a species-specific manner. Additionally, flavones participate as copigments by protecting anthocyanin molecules and influencing their color in a phenomenon known as copigmentation (Gross 1987).

Accumulation of these pigments is mainly limited to epidermal cell layers and a few subepidermal cells, although the presence in other tissues has been reported in some high-anthocyanin-containing cultivars. For example, pomegranate and peach anthocyanins may also accumulate in tissues surrounding seeds or pip, respectively, while in blood oranges, they are located mainly in the flesh. Most fruits contain two aglycones, with cyanidin being the most prevalent (present in 90% of 40 common fruits and 82% of 44 angiosperm species fruits; Macheix et al. 1990). The most widespread anthocyanin is cyanidin-3-glucoside, while malvidin glucosides are the most characteristic in red grape cultivars. Most fruits contain a mixture of anthocyanins from a simple pattern of only one major pigment, as in passion fruit (Kidoy et al. 1997), to a complex pattern of more than 20 different anthocyanins, as found in some grapes and orange cultivars. During maturation, anthocyanins are synthesized at an increasing rate, especially near maturity, reaching a maximum in fully ripe fruit. Concomitantly, anthocyanidins and glycosylation pattern gains complexity. On a quantitative basis, anthocyanin content varies considerably, from 0.25 mg per gram of fresh weight in pear peel to more than 4 mg per gram in the main sources of anthocyanins, mainly red berries and red grapes (Gross 1987).

Carotenoids

Carotenoids constitute a large group of over 700 structures that provide fruits with distinctive red, orange, and yellow coloring. Because of their hydrophobic nature, these pigments are found in association with lipid–protein complexes within plastids. In general, carotenoids are the condensates of eight isoprenoid units, whose order is inverted at the center of the molecule, constituting a 40-carbon polyene chain that may contain up to 15 conjugated double bonds. This double bond system constitutes the chromophore that provides the visible absorption spectrum and gives to each carotenoid its particular attractive color. Carotenoids are classified by their chemical structures as carotenes, constituted by carbon and hydrogen, and xanthophylls, which are oxygenated derivates. In general, all carotenoids can be considered as lycopene derivates by reactions involving hydrogenation, dehydrogenation, cyclization, oxygen insertion, double bond migration, methyl migration, chain elongation, and/or chain shortening. Being terpenoids, carotenoids are synthesized from the basic C5-terpenoid precursor isopentyl diphosphate synthesized through the 2-*C*-methyl-D-erythritol 4-phosphate (MEP) pathway, which occurs in the plastids. The primary carotenoid produced is the colorless phytoene, which is further modified to give the rest of carotenoids. In the past decade, nearly all the biosynthetic pathways have been elucidated and the successful isolation of genes has allowed identification of the key regulatory steps (Fraser and Bramley 2004). All carotenoid biosynthetic enzymes are nuclear encoded, translated as precursors, and imported into the plastids, where carotenoid biosynthesis takes place. In fruits such as tomato, citrus, papaya, and others, chromoplast-specific forms of some structural genes have been characterized, envisaging a chromoplast-specific carotenoid biosynthetic pathway (Galpaz et al. 2006, Alquezar et al. 2009, Devitt et al. 2010). Mechanisms that control carotenoid accumulation are largely unknown, although different ways of control have been reported. First, it depends on the ability to synthesize carotenoids, which is mainly regulated at the transcriptional level and direct correlation between key genes and carotenoid composition has been determined in different fruits. For example, in tomato (Bramley 2002), citrus (Rodrigo et al. 2004), and other fruits, it has been determined that carotenoid content correlates well with the level of *PSY* expression, which encodes phytoene synthase, the first specific enzyme of the pathway. Additionally, influence of post-transcriptional regulation and expression of genes other than structural ones, for example, those from light signaling pathway or MEP genes, are now beginning to unravel (Rodríguez-Concepcion et al. 2001, Toledo-Ortiz et al. 2010). Other mechanisms, whereby carotenoid build up is regulated, involve tissues that can synthesize these compounds but contain just trace amounts of them. Sink capacity in carotenoid accumulation was first demonstrated in the cauliflower orange (*or*) mutant (Li et al. 2001). The *or* gene triggers differentiation of uncolored plastids into chromoplasts and the color of the curd changes from white to orange due to β-carotene accumulation. Furthermore, sequestering structures capable of storing carotenoids within the plastids, biosynthesis of companion proteins and esterification of hydroxycarotenoids with fatty acids have also been reported to affect carotenoid accumulation (Egea

et al. 2010). Although some genes and proteins involved in these processes have been identified, further work in this area is required. Other mechanism influencing carotenoid content and composition may be carotenoid degradation. However, although this process has been demonstrated in flowers (Galpaz et al. 2006), to date there are no reports showing its direct implication in fruit carotenoid profiling.

Carotenoid content varies along fruit ripening, exhibiting three typical profiles. In high-accumulating carotenoid fruits, such as tomato, carotenoid content increases during maturation, with a transitory decrease during chloro- to chromoplast differentiation. In other fruits (e.g., carambolo), carotenoid concentration increases during ripening. Finally, in fruits which accumulate pigments other than carotenoids, such as berries or grapes, carotenoid content decreases along maturation (Gross 1987).

During immature stages and in green ripe fruits, chloroplastic carotenoids, mainly lutein and α-carotene and to a lesser extend neoxanthin, zeaxanthin, β-carotene, and β-cryptoxanthin, are found associated with Chl-binding proteins within chloroplast. In ripe nongreen-colored fruits, carotenoid accumulation takes place in the chromoplasts, which can accumulate extremely high levels of these compounds. The content and composition of carotenoids in mature fruits is much complex and variable. In carotenogenic fruits, pigments accumulate in most tissues, although content in outer pericarp is usually the higher. Composition may also vary between different tissues of the same fruit (Gross 1987). Good examples of unusual fruits are the red-fleshed grapefruit cultivars, which present higher carotenoid concentration in the flesh, mainly the red carotene lycopene, than in the peel where minute amounts of colorless carotenes accumulate (Alquezar et al. 2009). Typically, fruits contain a few major carotenoids along with a series of minor carotenoids at trace or very low levels. Eight major patterns can be discerned (Goodwin and Britton 1988): (a) insignificant levels of carotenoids (e.g., grape), (b) small amounts generally of chloroplastic carotenoids (e.g., olive, pear) (c) considerable amounts of lycopene (e.g., tomato, watermelon, papaya), (d) predominance of β-carotene and/or β-cryptoxanthin (e.g., apricot, peach, loquat), (e) large amounts of epoxides (e.g., mango, carambolo), (f) preponderance of unusual or species-specific carotenoids (e.g., red pepper); (g) substantial amounts of poly-*cis*-carotenoids (e.g., tangerine tomato), and (h) significant levels of apocarotenoids (carotenoids with a shortened carbon skeleton; e.g., citrus species). Some merging of these patterns is seen in some fruits.

VOLATILE AROMA COMPOUNDS

Flavor is one of the key attributes of fruit quality and an important trait for breeding selection (Klee 2010). The flavor is very subjective and complex trait involving the interaction of diverse metabolites such as sugars, organic acids, and aroma compounds (Baldwin 2002). A comprehensive review on fruit flavor and sensory parameters is given in Chapter 3; therefore, this section is mainly focused on the biochemistry of the main aroma compounds of fruits.

The characteristic aroma profile of a fruit is derived from a wide range of relatively small volatile molecules usually present at very low levels (Baldwin 2004). Although hundreds of volatiles are identified in the majority of ripened fruits, only few (10–20) are present in concentrations above the perception threshold and have a significant influence on the aroma (Schieberle and Hofmann 1997, Baldwin et al. 2000). The main volatiles in fruits in terms of concentration are terpenoids, aliphatic and branched esters, and small chain aldehydes and alcohols. However, other minor compounds such as apocarotenoids or furan-related also have a profound impact on the characteristic aroma. Because of the different nature of the volatile compounds, their biosynthetic origin is very diverse, comprising a number of specific and common pathways and involving different cellular compartments and organelles.

Terpenoids are one of the largest classes of aroma compounds in fruits and are synthesized *de novo* from acetyl-CoA and pyruvate (Schwab et al. 2008). Biosynthesis of terpenoids occurs through two parallel pathways: the cytosolic mevalonate pathway and the plastidic MEP pathway (Lichtenthaler 1999, Rodriguez-Concepción and Boronat 2002). Both pathways generate the C5 basic unit isopentenylpyrophosphate and its isomer dimethylallyl diphosphate, and by the sequential action of different prenyl transferases and terpene synthases (TPS), hemi- (C5), mono- (C10), and diterpenes (C20) are synthesized in the cytosol and sesquiterpenes (C15) in the plastids (Dudareva et al. 2004). TPS represent a broad family of enzymes and some of them are characterized by their capacity to synthesize multiple products, generating the wide diversity of terpenes found in nature (Degenhardt et al. 2009). One of the best examples of fruits where terpenoids are the most representative volatiles are citrus fruits (Weiss 1997). In citrus, terpenes are synthesized in specific cellular structures, the oil glands immersed in the fruit peel and the oil bodies in the juice vesicles. Terpenoid composition depends not only on the citrus species and variety, but also on the fruit tissue and stage of ripening (Weiss 1997, Sawamura 2000). In the essential oil of the peel, the monoterpene limonene accounts for more than 90% of the volatiles, followed by a complex mixture of other minor monoterpenes and sesquiterpenes (Weiss 1997). In the last decade, several TPS have been isolated and functionally characterized. Two different d-limonene synthases have been isolated from Satsuma mandarins and lemons, and their expression profiles correlate well with accumulation of d-limonene in the fruit peel and other reproductive tissues (Lücker et al. 2002, Shimada et al. 2005a). In addition, other citrus *TPS* genes involved in the synthesis of minor monoterpenes and sesquiterpenes have been also characterized (Lücker et al. 2002, Sharon-Asa et al. 2003,

Shimada et al. 2005b). A *in silico* analysis of ESTs databases of citrus fruits has identified at least 44 clusters of genes encoding putative TPS that may explain the vast diversity of terpenes found in these fruits (Takita et al. 2007). In contrast to the citrus peel, GC-olfatometry studies of citrus juices show that although limonene is a necessary component in the odor of citrus juices, other volatiles such as aliphatic esters (ethyl butanoate, hexanoate, and octanoate), aldehydes (citral, Z-3-hexenal, dodecanal, and nonanal), and alcohols (linalool and hexanol) have a higher impact on the orange juice aroma (Ruiz Perez-Cacho and Rouseff 2008), illustrating the tissue-specific profile.

In other fruits, like strawberry, the presence of specific terpenes like β-myrcene and β-pinene also has a profound effect on the fruit aroma (Aharoni et al. 2004). Other important crops where terpenes affect fruit aroma quality are grapevine and apple. In grape berries, two sesquiterpene and one monoterpene synthases involved in the formation of valencene, germacrene D, and α-terpineol, respectively, have been characterized (Lücker et al. 2004, Martin and Bohlmann 2009). Interestingly, transcripts of TPS were not detected in the mesocarp and exocarp during early stages of fruit development, but valencene synthase appeared during late ripening of the berries concomitantly with the stabilization of organic acid and high sugar rate accumulation (Lücker et al. 2004). In apple, one of the major constituents of ripe fruit volatiles is the linear sesquiterpene (*E*,*E*)-α-farnesene whose emission is predominant during fruit storage (Anet and Coggiola 1974). Intensive research has been carried out on the synthesis and regulation of (*E*,*E*)-α-farnesene since their oxidation products are hypothesized to be the causal agents of superficial scald, a physiological disorder that occurs in some apple and pear cultivars after a period of cold storage and shelf life (Rowan et al. 2001). In these fruits, synthesis of (*E*,*E*)-α-farnesene is tightly associated with ethylene production (Watkins et al. 1993), and treatment with 1-MCP largely prevents its accumulation and their oxidation products, which is correlated with a delay in the development of superficial scald (Tsantili et al. 2007). (*E*,*E*)-α-Farnesene synthases have been isolated from apple and pear and in both fruits are regulated during ripening, and their expression patterns are very consistent with (*E*,*E*)-α-farnesene accumulation during fruit cold storage in an ethylene-dependent manner (Pechous and Whitaker 2004, Gapper et al. 2006, Schaffer et al. 2007). Interestingly, transgenic apples suppressed for ethylene biosynthesis are less affected by superficial scald after postharvest storage (Pesis et al. 2009).

Another important group of volatiles in the characteristic flavor of fruits are the saturated and unsaturated C6 and C9 aldehydes and alcohols (Schwab et al. 2008). In their biosynthesis, at least four classes of enzymes are involved: LOX, hydroperoxide lyase (HPL), 3*Z*,2*E*-enal isomerase, and ADH. LOX enzyme catalyzes the dioxygenation of unsaturated fatty acids (linoleic and α-linolenic) to produce hydroperoxides and subsequently the HPL acts, releasing aroma compounds such as 3*Z*-hexenol, 2*E*-hexenal, and 2*E*,6Z-nonadienal (Klee 2010). In tomato fruits, five *LOX* genes have been identified and all are expressed during fruit ripening (Chen et al. 2004). However, only three of them seem to be regulated by ethylene, and from these, only one, *13-LOX* gene, has a great impact in the synthesis of C6 volatiles in the fruit (Chen et al. 2004). In apple fruits, some of the C6 volatiles are precursors of aliphatic esters, but no increase in LOX activity has been detected during ripening, suggesting that this activity is not limiting the biosynthesis of fruit esters (Defilippi et al. 2005b, Schaffer et al. 2007). The C6 and C9 aldehydes are further metabolized to the corresponding alcohol by the ADH enzymes. A number of ADH enzymes have been characterized in tomato and grape berries; the expression of specific *ADH* isoforms is regulated during fruit ripening in an ethylene-independent manner in parallel with an improved fruit flavor (Speirs et al. 1998).

It is recognized that aliphatic esters contribute to the aroma of nearly all fruits. Lipids are the precursors of aliphatic esters. Lipid β-oxidation pathway generates aliphatic acids, which are then substrates to form their corresponding acyl-CoAs. Aliphatic alcohols and aldehydes emitted by fruits are probably formed by the enzymatic reduction of the parent acyl-CoAs (Flamini et al. 2007). Alternatively, alcohols can also be formed by the action of ADH on aldehydes; however, aliphatic alcohols are considered less important flavor molecules due to their high odor threshold compared to the corresponding aldehydes (Schwab et al. 2008). One of the most studied key points in the biosynthesis of aliphatic esters is the final step catalyzed by the alcohol acyl transferases (AAT). These enzymes are capable of combining various alcohols and acyl-CoAs, resulting in a wide spectrum of aliphatic esters. Numerous AATs have been isolated and characterized in various fruits, and in most cases, the specific profile of esters is dependent on the supply of precursors (Olias et al. 2002, Beekwilder et al. 2004, El-Sharkawy et al. 2005, Defilippi et al. 2005a). The first cloned *AAT* was from strawberry, showing a fruit-specific expression pattern that correlates with enzyme activity and the emission of aliphatic esters (Aharoni et al. 2004). In apple fruits, 15 *AAT*s have been identified but only one (*AAT1*) is ethylene-induced and expressed predominantly in fruit skin during late ripening (Schaffer et al. 2007). By contrast, using an antisense *ACC* oxidase melon fruits, it was shown that fatty acids and aldehydes reduction were severely affected by ethylene while the last step, catalyzed by AATs, had ethylene-dependent and -independent components (Flores et al. 2002).

Branched-chain volatiles, including aldehydes, alcohols, and esters, constitute a highly abundant class of compounds in plants although their pathways and regulation have been mainly studied in fruits. Key components of banana, apple, tomato, and strawberry aroma are derived from the branched-chain amino acids valine, leucine, isoleucine, and methionine (Dudareva et al. 2006). These amino acids can also be the precursors of acyl-CoAs, which are used

in alcohol esterification reactions catalyzed by a specific group of AATs. In banana, isoleucine serves as precursors for 3-methylbutanol and 2-methylbutyryl-CoA to yield 3-methylbutyl 2-methylbutanoate, a key odor-impact in this fruit (Wyllie and Fellman 2000). In strawberry, it has been suggested that alanine serves as precursor for the ethyl esters catalyzed by the enzyme SAAT (Perez et al. 1992, Aharoni et al. 2000), and in apple, 2-methyl-butyl acetate, which has a strong apple scent, appears to be associated with the rich aroma varieties (Holland et al. 2005). Interestingly, in apple, an AAT and a branched-chain aminotransferases have been identified as control points in the biosynthesis of 2-methyl-butyl acetate (Schaffer et al. 2007). In melon, the combination of aliphatic and branched esters such as isoamylacetate and 2-methyl-butyl-acetate impart the unique melon aroma, and the contribution of novel branched-amino acid transaminases and specific AATs seems to be crucial for regulating the process (El-Sharkawy et al. 2005, Gonda et al. 2010).

Another group of volatiles are apocarotenoids, also called norisoprenoids, which possess interesting flavor aroma properties together with extremely low aroma thresholds (Winterhalter and Rouseff 2002). Apocarotenoids are derived from the oxidative cleavage of carotenoids and catalyzed by a large family of enzymes named carotenoid cleavage dioxygenases (CCD; Schmidt et al. 2006). One of the first evidences of the association between carotenoid composition and norisoprenoids emission was provided by a comparative analysis of tomato and watermelon mutants and varieties (Lewinsohn et al. 2005a, 2005b). Results revealed a direct relationship between carotenoid profile and some key volatile such as citral, 6-methyl-5-hepten-2-one, β-ionone, β-cyclocitral, and geranyl acetona, among others. On the basis of these results, an alternative route for the biosynthesis of geranial was proposed, where lycopene is degraded *in vivo* to geranial (Lewinsohn et al. 2005a). Besides other important functions of apocarotenoids in the plant physiology, a number of CCDs have been isolated from fruits and their role in the production of specific volatile apocarotenoids has been investigated. Interesting examples are the CCD1a and b from tomato that mediate the synthesis of β-ionone and geranyl acetone, which increase during fruit ripening, contributing significantly to fruit flavor (Simkin et al. 2004). Other CCDs have been identified in grape berries and melon and their pattern of expression increases during fruit ripening concomitantly with the production of C13 volatile β-ionone and 3-hydroxy-β-ionone resulting from the in vivo cleavage of β-carotene and zeaxanthin in melon and grapes, respectively (Mathieu et al. 2005, Ibdah et al. 2006). In peach fruit, many norisoprenoids strongly contribute to the aroma during fruit ripening (Aubert et al. 2003). Recently, the expression pattern of a novel CCD from peach has been related to the carotenoid-derived volatiles 3-hydroxy-5,6-epoxide-β-ionone, 3-hydroxy-β-damascone, and 4-hydroxy-3,5,6-trimethyl-(3-oxo-1-butenyl)-2-cyclo-hexen-1-one and to the typical flower scent of the white-fleshed peach fruits (Brandi et al. 2011).

Important efforts have been made to understand the biosynthesis of an interesting group of volatiles, furanones, and pyrones, having an outstanding low odor threshold (Klee 2010). These compounds, although are detected only in a limited number of species, impart important aroma to some fruits, including pineapple and strawberry (Rodin et al. 1965). These volatiles originate directly from carbohydrates without degradation of the carbon skeleton but the specific steps of metabolic pathways for most of them remain unknown (Bood and Zabetakis 2002). In strawberry and tomato fruits, the hexose D-fructose-1,6-diphosphate is converted to furaneol through different steps, including a enone oxidoreductase, and in strawberry, the furaneol is further metabolized by a *O*-methyltransferase to methoxyfuraneol (Wein et al. 2001).

OTHER COMPONENTS

Besides essential nutrients, fruits provide a variety of vitamins, minerals, dietary fiber, and many other classes of bioactive compounds, collectively called phytochemicalls, which also impart health benefits. Beneficial effects of most phytochemicals are derived from their antioxidant activity and the capacity to scavenge free radicals. Some of these constituents can also act as antiviral or antibacterial agents or have the ability to modify antioxidant pathways, detoxification enzymes, the immune system, cholesterol and steroid hormone concentrations, and blood pressure (Jongen 2002). Humans are not capable of synthesizing these phytochemicals and consequently are dependent on dietary supply. Additionally, experimental evidences indicate that the effects of fruit consumption on health depend not only on individual components but also on their synergistic action.

Concentration of these components in fruits is greatly influenced by many factors, such as genotype, climate (light, temperature), cultural practices (fertilizers, irrigation), maturity, harvesting methods, and postharvest handling. As a consequence, published values may vary dramatically and can be misleading.

Vitamins

Vitamins are defined as complex organic substances essential in small amounts for normal function of the body. In recent years, great interest has been focused on antioxidant vitamins (A, C, and E) particularly because of their likely role in prevention of coronary heart disease and cancers.

Vitamin A (retinol) helps to maintain normal reproduction, vision, and immune system. Preformed vitamin A is found in animal-derived foods, while provitamin A carotenoids are dietary precursors. Advantage of provitamin over preformed vitamin is the lack of toxicity of the first, avoiding risk of hypervitaminosis. Vitamin A requirement, expressed as retinol equivalents (RE), varies from 210 μg RE/day for children up

Table 2.1. Vitamin Content of Fresh Fruits (Values are Expressed as mg per 100 g of Edible Portion. Vitamin A is Expressed as Retinol Equivalents, Vitamin B9 as Dietary Folate Equivalents, Vitamin C as Total Ascorbic Acid, and Vitamin K as Phylloquinone)

	Vitamin									
	A	B1	B2	B3	B5	B6	B9	C	E	K
Apricot	96.00	0.03	0.04	0.60	0.24	0.05	8.57	10,000.00	0.89	3.43
Avocado	7.00	0.07	0.13	1.74	1.39	0.26	81.00	8818.34	1.97	21.00
Banana	3.00	0.03	0.07	0.67	0.33	0.37	20.00	8733.33	0.10	0.05
Blackberries	11.00	0.02	0.03	0.65	0.28	0.03	25.00	20,972.22	1.17	19.79
Kiwi (green)	4.00	0.03	0.03	0.34	0.18	0.06	25.00	92,763.16	1.46	40.26
Tangerines	34.00	0.06	0.04	0.38	0.22	0.08	16.00	26,700.00	0.20	0.00
Mango	54.00	0.03	0.04	0.67	0.20	0.12	43.00	36,400.00	0.90	4.20
Oranges	11.00	0.09	0.04	0.28	0.25	0.06	30.00	53,222.22	0.18	0.00
Papaya	55.00	0.02	0.03	0.36	0.19	0.04	38.16	61,809.21	0.73	2.60
Pinneaple	3.00	0.08	0.03	0.50	0.21	0.11	18.06	47,806.45	0.02	0.71
Plum	17.00	0.03	0.03	0.42	0.13	0.03	5.00	9545.45	0.26	6.36
Squash	10.00	0.05	0.14	0.49	0.16	0.22	29.20	16,991.15	0.12	3.01
Strawberry	1.00	0.02	0.02	0.39	0.13	0.05	24.10	58,795.18	0.28	2.22
Tomato (red)	42.00	0.04	0.02	0.59	0.09	0.08	15.00	13,700.00	0.54	7.90

Source: USDA National Nutrient Database, 2010.

to 3 years and up to 800 μg RE/day for lactating women. Only about 50 carotenoids have provit-A activity, β-carotene being the main precursor of this vitamin, followed by α-carotene and β-cryptoxanthin (half provitamin A activity respect to β-carotene). Fruits such as apricot are good sources of provitamin A due to high levels of β-carotene accumulation, while noncarotenogenic fruits, for example, strawberry and pineapple, are poor sources of this vitamin (Table 2.1).

Vitamin B complex is made up of a collection of vitamins, the most important being vitamins B1, B2, B3, B5, B6, B9, and B12. Vitamin B12 is the only one, which cannot be found in any fruit. Vitamins B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (panthotenic acid), and B6 are not abundant in fruits, although small amounts are present in avocado, orange, pineapple, and some other fruits (Table 2.1). Vitamin B9 (tetrahydrofolate and its derivates, collectively called folic acid or folate) is an essential cofactor in the metabolism of nucleic and amino acids. Dietary folate requirement, measured as dietary folate equivalents, varies from 65 μg/day for infants up to 6 months to 520 μg/day for pregnant women. In general, fruit provides about 8–10% of dietary requirements, although consuming folate-rich fruits, such as avocado, can improve this percentage.

Vitamin C refers to both ascorbate and dehydroascorbic acid, the latter being the first oxidation product of the former. Citrus fruits are particularly rich sources of vitamin C, but other fruits including kiwi, papaya, and strawberries also contain variable amounts of this vitamin (Table 2.1). Acerola fruit contains the highest known ascorbic acid content among all fruits (16.77 mg/g fresh weight).

Vitamin E is the name given to tocohromanols, a group of four tocopherols and four tocotrienols produced at various levels and in different combinations by all plant tissues. α-tocopherol is especially important from a nutritional perspective, as it has the highest vitamin E activity of all tocohromanols. Usually fruits contain low amounts of vitamin E (Table 2.1).

The only important form of vitamin K in plants is phylloquinone (vitamin K1). Green vegetables are the major source of vitamin K1, although some fruits like avocado, kiwi, or blackberries also contain significant amounts of this compound (Table 2.1).

Fiber

Fiber is a generic term including plant constituents nondigestible by the human body. Therefore, its composition varies with the type of food stuff. Fibers found in fruits form gels when eaten and contribute to fullness in the stomach. Soluble fibers slow down digestion and increase absorption of nutrients. Both, soluble and insoluble fibers, increase the intestinal health and lower the risk of heart disease and breast cancer by limiting the enterohepatic circulation of cholesterol, bile acids, and hormones. Since different fiber components have different physiological functions, the daily level of dietary requirement recommended to achieve a particular effect will vary with the type of fiber ingested. Fiber-rich fruits include avocado, blackberries, kiwi, and banana (Table 2.2) and also apples (with skin) and pears (with skin).

Minerals

Minerals have a wide variety of roles in the human body. For example, some of them, such as magnesium, are essential

Table 2.2. Distribution of Dietary Fiber and Mineral Content in Fresh Fruits (mg per 100 g of Edible Portion)

		Minerals								
	Dietary Fiber	Ca	Fe	Mg	P	K	Na	Zn	Cu	Mn
Apricot	2.00	13.00	0.39	10.00	23.00	259.00	1.00	0.20	0.08	0.08
Avocado	6.80	13.00	0.61	29.00	54.00	507.00	8.00	0.68	0.17	0.15
Banana	2.60	5.00	0.26	27.00	22.00	3358.00	1.00	0.15	0.08	0.27
Blackberries	5.30	29.00	0.63	20.00	22.00	162.00	1.00	0.53	0.17	0.65
Kiwi (green)	3.00	34.00	0.31	17.00	34.00	312.00	3.00	0.14	0.13	0.10
Tangerines	1.80	37.00	0.15	12.00	20.00	166.00	2.00	0.07	0.42	0.04
Mango	1.60	11.00	0.16	10.00	17.00	168.00	1.00	0.09	0.11	0.06
Oranges	2.40	40.00	0.10	10.00	14.00	181.00	0.00	0.07	0.05	0.03
Papaya	1.88	24.00	0.10	10.00	5.00	257.00	3.00	0.07	0.02	0.00
Pinneaple	1.40	13.00	0.29	12.00	8.00	109.00	1.00	0.12	0.11	0.93
Plum	1.40	6.00	0.17	7.00	16.00	157.00	0.00	0.10	0.06	0.05
Squash	1.10	15.00	0.35	17.00	38.00	262.00	2.00	0.29	0.05	0.18
Strawberry	2.00	16.00	0.41	13.00	24.00	153.00	1.00	0.14	0.05	0.39
Tomato (red)	1.20	10.00	0.27	11.00	24.00	237.00	5.00	0.17	0.06	0.11

Source: USDA National Nutrient Database, 2010.

cofactors in the formation of many enzymatic and metabolic processes, while others, like calcium, are structural elements needed to maintain bone density. Fruits, especially banana, are major dietary sources of potassium, the most abundant mineral in fruits (Table 2.2). Other abundant minerals in fruits are the base-forming elements calcium and magnesium and the acid-forming element phosphorous. Minerals often present in micro quantities are Mn, Zn, Fe, Cu, and Na. However, some of them may not be fully nutritionally available, for example, iron from fruits is available as nonheme and calcium bound to oxalate cannot be absorbed.

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3
Flavor of Fruits and Fruit Products and Their Sensory Qualities

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Abstract: It is generally recognized that the flavor of fruit varies qualitatively and quantitatively depending on the cultivar, maturity stage, climate and cultural conditions, and the production area for each cultivar. The flavor changes that occur between production and consumption are of enormous interest to the food and flavor industry. The introduction of new fruits and their products into the market will only be successful if consumers' expectations in terms of flavor and sensory quality are satisfied. Due to the importance of aroma volatiles in sensory quality, recent advances have been made in research on isolation and characterization of the genes involved and responsible in the synthesis of aroma volatiles, which are crucial for the flavor and sensory quality of many fruits. Recent developments in fruit flavors and their sensory qualities are presented in this overview chapter. Major topics include: analytical chemistry of fruit flavors, flavor biogenesis, flavor precursors and biotechnology, sensory evaluation of fruits, enhancement of sensory quality, genetic improvement and variation in flavor quality, flavor of fruit products, factors affecting development of flavors, and sensory quality of fruits.

INTRODUCTION

Flavor is a complex quality trait influenced by genetic and nongenetic factors, not all of which are well understood (Goff and Klee 2006). Formation of flavor compounds during growth, development, ripening, and/or senescence is influenced by genetic, preharvest, harvest, and postharvest factors (Mattheis and Fellman 1999). Various studies reported sensory characteristics followed by health considerations among primary factors for increase in fruit consumption (Verbeke 2006, Enneking et al. 2007, Poole et al. 2007). Deliza et al. (2003) reported that foods are unlikely to be accepted if consumers do not like the flavor. A large number of constituents such as acids, sugars, alcohols, aldehydes, ketones, esters, and other volatiles individually or synergistically elicit sensory responses recognized as flavor characteristics of a particular fruit. This chapter reviews flavor and sensory quality of fruits and fruit products.

HISTORY AND BACKGROUND OF FLAVOR

Volatiles (a complex group of chemical substances, such as aldehydes, alcohols, ketones, esters, lactones, terpenes) directly affect the sensory quality of fresh as well as processed fruit products. The concentration of these volatiles in fruits is variable as it depends upon a number of preharvest and postharvest factors. The evaluation of the volatile profiles of various fruits (i.e., flavor research) has been significantly driven by advances in instrumentation. Great strides were made when gas chromatography became generally available. Prior to gas chromatography, the isolation, separation, and identification of unknown volatile compounds was an extremely tedious task. The advent of fused silica capillary gas

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chromatography columns was particularly significant since fused silica column development did not limit high-resolution chromatography to a hand full of experts but made it possible for all. The development of low cost quadrapole mass spectrometers also has resulted in significant advances in flavor research. Low-cost instruments with excellent gas chromatography (GC) compatibility have also put this technique in the hands of many flavor researchers who otherwise could not afford the technique (Martin and Martin 1999).

Beyond instrumental developments, flavor chemistry has evolved in terms of understanding. Initially, researchers used gas chromatography/mass spectrometry (GC/MS) to identify long list of aroma chemicals in foods. This has resulted in nearly 7000 aroma compounds identified in foods today (Maarse and Visscher 1994). Many of these aroma compounds are present naturally in foods while others are the result of fermentation, thermal processing, or deteriorative reactions (e.g., lipid oxidation). Very soon, it was established that food flavors could not be regenerated from these lists, and some logical approach had to be formulated to determine which aroma compounds made a significant contribution to food aroma and which were insignificant. Those aroma compounds that smelt like the food were considered most important. Unfortunately, many foods did not contain "character impact compounds," but the aroma was the result of a combination of numerous noncharacteristic odorants. Historically, considerable effort has been devoted to identifying mechanisms of flavor formation in plants (biosynthesis), during heating (Maillard reaction), and fermentation (Reineccius 1999). The characterization of volatile compounds of fruit juices and nectars by headspace solid-phase microextraction (HS-SPME) and GC/MS (Riu-Aumatell et al. 2004), purge and trap technique in caja-umbu (*Spondias* spp.) fruits during maturation (Narain et al. 2007), headspace analysis of volatiles in orange beverage emulsion by SPME technique (Mirhosseini et al. 2007), headspace fingerprint to characterize strawberry aroma at superatmospheric oxygen conditions (Berna et al. 2007), supercritical CO_2 and N_2O pasteurization of fresh apple juice (Gasperi et al. 2009), liquid chromatographic determination of organic acids in papaya and pineapple (Hernandez et al. 2009), determination of low molecular weight volatiles in figs (*Ficus carica*) using HS-SPME and GC/flame ionization detector (FID) (Oliveira et al. 2010), and analysis of volatile compounds of pineapple wine using HS-SPME and GC/MS techniques (Pino and Queris 2010) have been reported.

ANALYTICAL METHODOLOGY OF FRUIT FLAVORS

Since fruit flavors exist as complex chemical mixtures, analysis has primarily involved separation technologies. Advances in the analysis of flavors in general can be applied to fruit flavor research. Fruit flavors involve both volatile and nonvolatile flavor components (Buttery and Ling 1996, Nijssen et al. 1996). Sweet and sour are the major nonvolatile flavors in fruit, and high-performance liquid chromatography (HPLC) has been the method of choice to determine the corresponding individual sugars and acids. Major fruit flavor impacting components are usually volatile and are typically determined using capillary gas chromatography, GC, GC-MS, or GC/Fourier transform infrared spectroscopy including multidimensional GC, where the second column is a chiral column. Yellow passion fruit belongs to the best known tropical fruits in the world. It has its origin in South America and has a floral, estery aroma with a distinct tropical, sulfury note. The flavor of yellow passion fruit is quite complex in its composition. There are no real character impact compounds, but the flavor is a delicate balance of different chemical classes, e.g., fruit esters, green compounds, monoterpenes, sulfur compounds, and lactones. The volatile composition of yellow passion fruits was reviewed by Whitfield and Last (1986) as well as by Shibamoto and Tang (1990).

Using passion fruit, Werkhoff et al. (1998) compared four different flavor isolation techniques: vacuum headspace method, dynamic headspace method, simultaneous distillation and extraction at atmospheric pressure, and simultaneous distillation and extraction under reduced pressure to obtain aroma concentrates that are truly representative of tropical passion fruit flavor. The most representative and typical extract was obtained by vacuum headspace sampling and subsequent liquid–liquid extraction of the aqueous phase. This vacuum headspace concentrate was prefractionated by medium-pressure adsorption chromatography on silica gel. For the first time, approximately 180 components were identified in the LC fractions of passion fruit flavor. Of these compounds, 14 components have not previously been reported as naturally occurring flavor ingredients (Werkhoff et al. 1998). They clearly demonstrate that the composition of the extracts is dependent on the isolation procedures employed. There are numerous variations to sample concentration but their complete discussion is beyond the scope of this article.

Combining Analytical and Sensory Measurements

Aspects of quality can be evaluated by sensory and instrumental methods. Correlations between instrumental and sensory attributes have also been studied for some quality parameters and in some fruits (Harker et al. 2002, Saftner et al. 2008). The correlation among analytical and sensory parameters suggests that ethyl 2-methylbutyrate, 1-butanol, pentyl acetate, and *tert*-butyl propionate are the aroma compounds with the highest influence in the sensorial score in Granny Smith apples (Lavilla et al. 1999). Saftner et al. (2008) compared the instrumental and sensory quality characteristics of blueberry fruit from ten highbush (*Vaccinium corymbosum* L.) and two rabbit-eye (*Vaccinium virgatum* Aiton) cultivars, which varied in sensory intensity and acceptability scores.

They reported that the total aromatic volatile concentrations, collected and concentrated from fruit extracts using a SPME technique, were not correlated with sensory scores for flavor, overall eating quality, or to any other sensory characteristic. Thus, volatile concentration, at least when analyzed using a SPME technique, is not a good indicator of blueberry taste or overall eating quality.

Bassi and Selli (1990) investigated the use of chemical (total sugars, acids, and phenolics) and sensory evaluation (taste and astringency) in the assessment of fruit quality in different peach and apricot cultivars. Classification into groups with regard to the main quality chemical factors corresponded well with the evaluation of taste in apricots and less well with the sensory evaluation in peaches. Harker et al. (2002) compared instrumental and sensory measurements of apple taste and flavor. They reported that the titratable acidity (TA) was the best predictor of acid taste and overall flavor; soluble solids content was the best predictor of sweet taste, and the ratio of soluble solids content to TA was the best predictor of apple flavor. Akhtar et al. (2009) reported that the sugar and acids are a primary taste compounds, enhance human perception of specific flavor notes in mango, including aroma, but pH, acidity, and TSS are also related well to sourness and astringency (Malundo et al. 2001).

Authentication of Natural Fruit Flavors

Authentication of fruit flavors as natural is important in assuring compliance with labeling regulations. Methods of adulteration become sophisticated in response to developing methodologies for detection. The use of enantiomeric ratios has been investigated for establishing the origin of several volatiles in fruit flavor (Full et al. 1993). The enantiomeric composition of lactones in several fruits has been established using multidimensional GC/MS. While these techniques may be useful in identifying adulteration in single fruit flavors, it must be remembered that other enantiomeric ratios may exist when these compounds are produced in other natural systems, such as via fermentation. The use of deuterium and C13/C12 isotopic ratios has allowed differentiation of natural and synthetic benzaldehyde (Hagedorn 1992) and terpenoid flavor compounds (Braunsdorf et al. 1993).

Organic acids serve as a useful index of authenticity in fruit products, since they have lower susceptibility to change during processing and storage than any other chemical component of fruits (Camara et al. 1994). Accurate knowledge of organic acid levels (and ratios) might be useful for determining the percentage juice content of juice products and also for detecting misbranding and/or adulteration in this food class (Coppola and Starr 1986), since each fruit has a unique pattern of organic acids (Wrolstad 1981). The organic acid composition of fruits is also of interest because of its important influence on the sensory properties of fruits and fruit juices. Even though they are minor components of fruits, in combination with sugars, they are important attributes of the sensory quality of raw and processed fruits (Wang et al. 1993). At the same time, some organic acids may be used as indicators of ripeness (Palmer and List 1973), bacterial activity, and adulteration (Evans et al. 1983, Blanco et al. 1996).

The sugar profile of blood orange juice is an important component of chemical composition and provides valuable information regarding the authenticity of fruit juices. It also has an effect on the sensory properties and nutritional value of fruit products (Niu et al. 2008).

Flavor and Chemical Composition of Fruits

The flavor is determined by the balance of sugar, free acids, and numerous volatile organic compounds, which are present only in trace amounts. Tieman et al. (2006) reported that the fresh tomato fruit flavor is the sum of the interaction between sugars, acids, and a set of approximately 30 volatile compounds synthesized from a diverse set of precursors, including amino acids, lipids, and carotenoids. Some of these volatiles impart desirable qualities while others are negatively perceived.

It has been reported that the citrus fruit flavor and aroma are composed of complex combinations of soluble compounds (malic acids, sugars, and flavonoids) and volatile compounds. The last consist mostly of monoterpenes and sesquiterpenes (Kafkas et al. 2009). An electronic nose (e-nose) has been evaluated as a nondestructive tool to characterize peach cultivars and to monitor their ripening stages, since the sensory and storage properties are related to the ripening stage (Benedetti et al. 2008). Replacement of sucrose with aspartame has been shown to intensify the flavor profile of orange-, cherry-, and strawberry-flavored beverages as 0.70% of aspartame was equivalent to 15% of sucrose (Baldwin and Korschgen 1979, Wiseman and McDaniel 1991).

BIOSYNTHESIS OF FRUIT FLAVORS

The ripening process of fruits involves many biochemical changes such as increased respiration, ethylene production, change in fruit texture and color, and production of a vast array of compounds, ultimately leading to an acceptable quality fruit. Evidently, the most rapidly growing area in fruit flavor research is focused on understanding the biogenesis of flavor compounds and characterization of precursors (Rouseff and Leahy 1995). Lalel et al. (2003a) have investigated the biogenesis of aroma volatiles during fruit ripening in mango. They have identified 61 aroma volatile compounds, out of which 35 compounds were reported for the first time in “Kensington Pride” mango. Subsequently, Lalel et al. (2003b) have reported that most of the glycosidically bound aroma compounds that were higher in skin of unripe mango, increased in the pulp as the mango fruit matured. According to them, all the glycosidically bound aroma terpenes

Table 3.1. Major Volatile Compounds of Avocado Fruit

Group	Type of Compound (s)
Alcohols	Ethanol, pentanol, hexanol, (*Z*)-nerolidol
Esters	3-Methyl-butanol
Aldehydes	Tetradecanal, hexanal, deca-2(*E*), 4(Z)-dienal, deca-2(*E*), 4(*E*)-enal, hept-2(*E*)-enal, octanal, dec-4-enal, dec-2(*E*)-enal, deca-2(*E*), 4(*E*)-dienal
Hydrocarbons/terpenes	α-Farnesene, myrcene, α-cubebene, α-copaene, β-caryophyllene, α-humulene, α-cadinene, oct-2(*E*)-ene, limonene, octane, δ-elemene, α-cubebene, elemene isomer, β-cubebene, bisabolene
Lactones/acids	3-Hydroxy-2-butanone, acetic acid
Others	2-Pentylfuran, 2-heptylfuran, caryophyllene oxide

Source: Sidhu and Kabir 2010 (Adapted from Lopez et al. 2004, Sinyinda and Gramshaw 1998).

may contribute to the aroma of fresh ripe "Kensington Pride" mango.

Hendrich and Winterhalter (1991) conducted significant research in the biogenesis of flavor volatile in passion fruit. Although esters are qualitatively and quantitatively among the most important class of volatile compounds in fruit aroma, there are very few reports on the biochemical aspects of ester formation in fruits. Because of their low odor threshold, lactones have a high flavor value in many fruits (Tables 3.1–3.4). Lactones, being important flavor substances, are made fairly expensively via chemical synthesis from keto-acids. On the other hand, microbiologically produced lactones have the advantage of being pure optically and natural. There are numerous microorganisms that are known to synthesize lactones. Lactones can be formed by de novo synthesis; by β-oxidation from ricinoleic acid, free fatty acids, or hydroxyl acids; and by reduction from unsaturated lactones or from cheese (Leahy and Roderick 1999). A number of microorganisms have been studied for the production of pectolytic enzymes for the subsequent production of fruit aromas in media containing agro-industrial residues (Uenojo and Pastore 2006).

GENETIC IMPROVEMENT AND VARIATION IN FLAVOR QUALITY

To identify the genes responsible for the synthesis of flavor-related chemicals, an attempt was made by Tieman et al. (2006) to identify loci that influence the chemical composition of ripe fruits. They identified a number of quantitative trait loci that reproducibly alter the composition of volatiles and chemicals that contribute to overall fruit flavor. Twenty-five loci were identified, which are significantly altered in one or more of 23 different volatiles and 4 were altered in citric acid content. It was further shown that emissions of carotenoid-derived volatiles were directly correlated with the fruit carotenoid content. Linked molecular markers should be useful for breeding programs aimed at improving fruit flavor. In the longer term, the genes responsible for controlling the levels of these chemicals will be important tools for understanding the complex interactions that ultimately integrate to provide the unique flavor of a tomato. Scientific discoveries regarding tomato fruit flavor components have encouraged efforts to improve this trait genetically (Chaib et al. 2007).

Table 3.2. Most Odor-active Volatiles from Fresh Pineapple

Group	Name of Compound (s)
Esters	Ethyl acetate, methyl 2-methylpropanoate, ethyl 2-methylpropanoate, methyl 2- and 3-methylbutanoates, ethyl butanoate, ethyl 2-methylbutanoate, ethyl hexanoate
Lactones	(*Z*)-1,5-Octadien-3-one, β-damascenone, γ-octalactone, δ-octalactone, γ-nonalactone, 4-hydroxy-2,5-dimethyl-3(2*H*)-furanone, γ-decalactone, δ-decalactone, 3-hydroxy-4,5-dimethyl-2(5*H*)-furanone, γ-dodecalactone, 4-methoxy-2,5-dimethyl-3(2*H*)-furanone
Hydrocarbons	1-(*E*,Z)-3,5-Undecatriene, 1,3,5,8-undecatetraene
Aldehydes	Octanal
Acids	Butanoic acid, phenylacetic acid
Others	Vanillin

Source: Sidhu and Kabir 2010 (Adapted from Tokitomo et al. 2005).

Table 3.3. Major Volatile Compounds Typically Present in Papaya

Group	Type of Compound (s)
Esters	Methyl butanoate, 3-methylbutanol, ethyl hexanoate, ethyl dodecanoate, ethyl acetate, ethyl butyrate, prop-2-yl butyrate, methyl hexanoate, methy octanoate, ethyl benzoate, butyl hexanoate, ethyl octanoate, butyl benzoate, 3-methylbutyl benzoate, ethyl butanoate
Alcohols	Butanol, benzyl alcohol, terpinen-4-ol, α-terpineol,
Hydrocarbons	Myrcene, α-phellandrene, α-terpinene, β-phellandrene, limonene, (*Z*)-β-ocimene, (*E*)-β-ocimene, γ-terpinene, terpinolene, caryophyllene
Aldehydes	Hexanal, heptanal, benzaldehyde, octanal, nonanal, decanal
Lactones	γ-Hexalactone, γ-octalactone
Others	(*Z*)-Linalool oxide, (*E*)-linalool oxide, linalool, benzyl isothiocyanate, dodecanoic acid, methyl salicylate, triacetin, methyl geranate, benzyl isothiocyanate, methyl thiocyanate, phenylacetonitrile, germacrene D, pentadecane, geranylacetone, pentane-2,4-dione, 6-methylhept-5-en-2-one, heptan-2-one, 4-hydroxy-4-methylpentan-2-one

Source: Sidhu and Kabir 2010 (Adapted from Flath et al. 1990, Pino et al. 2003, Almora et al. 2004).

Pech et al. (2005) listed the following pathways and targeted genes that are candidates for improving sensory quality: increasing the sucrose content of fruit through downregulating genes encoding sucrose hydrolyzing enzymes; lipoxygenase, which catalyzes the hydroperoxidation of lipid precursors of some aroma compounds; and phytoene synthase, which is involved in the carotenoid pathway, from which some volatiles are synthesized. Downregulation of ethylene synthesis or perception aimed at extending shelf life of climacteric fruits often results in lower production of aroma compounds (Defilippi et al. 2005, El-Sharkawy et al. 2005, Klee 2005, Pech et al. 2005, Giovannoni 2007).

Niu et al. (2008) reported that the sugar profile and total sugar contents of oranges are influenced by genotype, harvest time, and environment. Evidence for strong genetic control of total sugar content is encouraging in establishing blood orange breeding goals for increased sweetness or sugar production. Although sugars are not alone in accounting for variation in the sweetness of blood oranges, higher sugar levels, and increased sweetness are desirable factors for improving blood orange quality (Khan 2007).

FACTORS AFFECTING FLAVOR AND SENSORY QUALITY OF FRUITS

Sensory quality is important in assessing cultivars for fresh consumption as well as for the processing industry. Important quality attributes for fresh consumption were found to be color, taste, flavor, and texture attributes. Sensory properties of many tropical fruits with special emphasis on flavor notes and flavor compounds present therein have been described by Bauer (2000).

Flavor and odor of processed foods are among the most important quality attributes, and while instrumental methods of evaluating them exist, subjective or human evaluation techniques are often more appropriate and more sensitive. There

Table 3.4. Major Flavor Constituents of Yellow Passion Fruit

Group	Name of Compound (s)
Aldehydes	2- and 3-Methylbutanal, (*E*)-2-hexenal, benzaldehyde
Alcohols	1-Butanol, 2- and 3-methyl-1-butanol, 1-hexanol, (*E*)-3-hexen-1-ol, (*Z*)-3-hexen-1-ol, 1-octanol, 4-terpineol, nerol, 3-mercaptohexanol, geraniol, benzyl alcohol
Esters	Ethyl butanoate, ethyl acetate, ethyl hexanoate, hexyl acetate, (*E*)-3-hexenyl acetate, hexyl butanoate, ethyl octanoate, (*E*)-3-hexenyl butanoate, ethyl 3-hydroxybutanoate, hexyl hexanoate, (*Z*)-3-hexenyl hexanoate, diethyl succinate, ethyl 3-hydroxyhexanoate, α-terpineol, benzyl acetate, hexyl octanoate, benzyl butanoate, benzyl hexanoate, ethyl cinnamate
Lactones	2-Butanone, cyclopentanone, 7,8-dihydro-β-ionone, β-ionone, γ-decalactone
Hydrocarbons/terpenes	Myrcene, limonene, γ-terpinene, *trans*-β-ocimene, 3-hydroxy-2-butanone, terpinolene, (*E*)-4,8-dimethyl-1,3,7-nonatriene
Others	*trans*-Linalool oxide, linalool, hexadecanoic acid

Source: Sidhu and Kabir 2010 (Adapted from Werkhoff et al. 1998).

are basically two types of subjective evaluation that may be carried out: consumer acceptance (preference) and panel difference methods. Consumer acceptance tests are utilized to evaluate new products, changes in manufacturing procedures, reformulations or line extensions of existing products, or for routine quality checking on the manufactured product vs. those of competitors. This type of testing requires a large number of consumers representing a good cross-section of the population.

In the panel difference method, a small group of individuals is trained to act like an instrument in describing attributes of processed products. Panelists might be screened by their ability to detect the four senses of taste: sour, sweet, bitter, salty, and their individual threshold levels for specific flavor or odor compounds. The particular method of flavor or odor evaluation depends on the product and its characteristics, the target market and the flavor or odor components of interest. A number of product difference test exist, including paired comparison, triangle, dilution, ranking, numerical scoring, descriptive, and flavor or odor difference methods.

The main components of the overall sensation of flavor are taste and aroma (Salunkhe et al. 1991). Although taste and aroma are well integrated in their contribution to the overall flavor, aroma is often considered to play a dominant role in flavor (Goff and Klee 2006, Voilley and Souchon 2006, Baldwin 2008). The receptors on the tongue are responsible of perceiving flavors, while aroma generally contributes to total flavor.

Bursac et al. (2007) reported the sensory characteristics of fresh fruit and its purees in two strawberry cultivars, "Maya" and "Queen Elisa," conventionally and organically grown in Croatia. Conducted sensory evaluation indicated that there were slightly expressed some differences in sensory attributes observed by panelists between two different cultivars and two types of cultivation, but they did not show significant differences in any sensory attribute when dealing with two different strawberry cultivars or two types of cultivation (Bursac et al. 2007).

Baldwin et al. (1998) and Krumbein and Auerswald (1998) reported that the volatile compounds clearly influence odor and flavor perception in tomatoes, and although over 400 aroma substances have been identified in tomato fruit (Petro-Turza 1987), only about 30 of them are considered to be important for flavor based on their odor thresholds (Buttery and Ling 1993). Another critical component for consumer's perception of tomato fruit quality is texture (Causse et al. 2002, Serrano-Megias and Lopez-Nicolas 2006). Fruit texture is the result of many sensory attributes such as firmness, mealiness, meltiness, juiciness, and crispness (Harker et al. 1997, Redgwell and Fischer 2002, Szczesniak 2002).

The sensory quality of fruit has become a major criterion in making the purchasing decision by consumers. The sensory quality of fruit involves a range of attributes such as sweetness, acidity, aroma, firmness, and color. In the last decades, consumers have often complained about the poor eating quality of fruit put into the market and flavor has now become a major criterion in making the purchasing decision. The sensory quality of fruit depends on many factors, including variety, culture conditions, picking date, and postharvest handling and storage methods. However, among these factors, the genotype is probably the most critical.

Preharvest Conditions

The rate of maturity stage at harvest is one of the most important factors (after genotype) influencing flavor quality of fruits. Synthesis of nonvolatile and volatile compounds influencing fruit flavor increases with maturation and ripening. However, harvesting fruits before they reach optimal maturity is a common commercial practice because of the higher prices when the supply is low at the beginning of the harvest season of each kind and cultivar of fruits. Minimum maturity indices are often not enforced by the regulatory authorities. Another reason for harvesting climacteric fruits before their optimal maturity stage based on flavor is to assure sufficient firmness to withstand handling procedures and to maximize their storage potential. However, Fellman et al. (2003) showed that when apples are harvested at the early preclimacteric stage and kept in either air or controlled atmospheres (CA) for various durations before marketing, they never reach good eating quality.

The flavor of any fruit is a combination of sensory responses in the nose and mouth to odor and taste. A large number of constituents such as acids, sugars, volatiles, and many other miscellaneous compounds individually or synergistically elicit sensory responses that are recognized in total as a flavor of that particular fruit. Accumulation of these compounds during growth, development, as well as during ripening and/or senescence is largely influenced by the genetic, preharvest, harvesting, and postharvest factors (Mattheis and Fellman 1999). Apple is extensively cultivated in many areas around the world. Echeverria et al. (2004a) have studied the effect of harvest date and cold storage on the volatile compounds of "Fuji" apples. They obtained the highest amount of aroma compounds after 5-month storage and one day of ripening at 20°C for the early harvested fruit. Ethyl 2-methylbutanoate, 2-methylbutyl acetate, and hexyl acetate were the major aroma compounds responsible for the characteristic aroma of "Fuji" apples. According to them, storage conditions and season had a significant effect on the aroma volatile compounds of apples. The effect of optimum harvest time on the sweetness, sourness, and aroma compounds during CA storage of red delicious apples has been investigated by Fellman et al. (2003). With the advance of harvest maturity, the time required to regenerate aroma volatiles to an optimum level after removal from CA storage decreased significantly. Lopez et al. (2007) have reported that the soluble solids, TA, background color, and emission of hexyl 2-methylbutanoate, hexyl hexanoate, hexyl propanoate, butyl 2-methylbutanoate, 2-methylbutyl acetate,

and butyl propanoate contents positively influenced the acceptability of "Pink Lady" apples during 25 days of cold storage. In another study on the same variety of apple, Villatoro et al. (2008) had observed low production of aroma volatiles in the early harvested fruit, but the volatiles gradually increased as the ripeness approached.

Ong et al. (2006) have evaluated the chemical composition (i.e., TA, moisture content, crude fiber, color, pH, soluble solids, sugars, organic acids) and flavor changes during the 5-day ripening of jackfruit (*Artocarpus heterophyllus* L.). A high amount of malic acid was found in unripe fruit, but the ripe fruit contained a high amount of citric acid at the optimum day (5th day) of ripening. Using GC and GC-MS, they identified a total of 23 volatile compounds in the ripened jackfruit. Mango fruits at different maturities (61–115 days past flowering) have recently been studied for aroma volatile using e-nose and gas chromatography as well as for soluble solids and acids (Lebrun et al. 2008). They found, both the e-nose and GC were able to separate mango fruit from different harvest maturities. Soluble solids and acids data indicated that later-harvested maturities gave sweeter fruit with a different volatile profile than the earlier-harvested mango fruits.

Postharvest Conditions

Medicott et al. (1990) studied the changes in mango flavor with respect to the storage temperature and demonstrated that the mangoes stored at relatively low temperature exhibited higher flavor scores. Ripe fruit characteristics and flavor intensity are also reported to increase with storage (MacRae et al. 1989). Abbasi et al. (2009) attributed the change in the mango taste to storage time and reported that taste score of mango increased from 3.54 to 8.42 after four weeks of storage. Inhibition of volatile biosynthesis is caused mainly by limited precursors/substrate supply to the related enzymes rather than by enzyme degradation or inactivation during CA storage of pears and apples (Lara et al. 2003, Echeverria et al. 2004b, Lara et al. 2006). Free FA and particularly oleic and linoleic acids have demonstrated the best relationship with aroma volatiles biosynthesis in preclimacteric and climacteric apples during CA storage (Song and Bangerth 2003). They concluded that de novo biosynthesis of FA rather than their release from membranes or storage pools represents the limiting step in the volatile aroma production of apple fruits. The effect of methyl jasmonate on the production of aroma volatiles in apple fruit may be mediated by ethylene (Kondo et al. 2005). Calcium application has been shown to improve the aroma quality and other key standard quality parameters after mid-term storage of "Golden Reinders" fruit and this offers a simple but economical alternative to CA storage of this apple cultivar (Ortiz et al. 2010).

Fallico et al. (1996) have shown that storage temperature affects the sensory-influencing qualities of blood orange juice. In particular, vinylphenol concentrations (the malodorous substances that arise from free hydroxycinnamic acid decarboxylation) in juices stored at 4°C and at 25°C for over 4 months exceeded the odor threshold value. Moshonas and Shaw (1989) found that the hedonic flavor of commercial orange juice decreased most rapidly during the first week or two of storage. Higher storage temperatures produced the greatest decrease in flavor scores. Obenland et al. (2008) have characterized the aroma-active volatiles of navel oranges using GC-olfactometry as well as the soluble solids concentration (SSC), TA, ethanol concentration, percent juice recovery, and sensory quality (freshness, tartness, sweetness, and likeability). Freshness and likeability decreased as a result of storage only in the packed fruits. They concluded that commercial packing and storage of navel oranges alters the aroma volatiles and reduces their flavor quality.

Carbon dioxide-stored (at 5°C) strawberry fruits (cv. Diamante) had a better shelf life (11 days) than those stored in air (9 days) when evaluated for flavor components such as sugars, organic acids, aroma compounds, and fermentative metabolites (Pelayo et al. 2003). Bagging of peach (cv. Hakuho) fruits (15 days before harvest) has been shown to improve the fruit skin color through the reduction of chlorophyll content and increased fruit flavor through the increase in aroma volatile content (Jia et al. 2005). Effect of hyperbaric and CA storage and prestorage treatment with UV radiations on the volatiles of peach fruit have been studied by Yang et al. (2009). About 65 volatiles have been indentified in fresh peach fruit and after 4 weeks of storage. The concentration of total volatiles and esters had increased by 32.5- and 36.5-fold during storage, respectively. The effect of CA storage on the volatile composition of "Hayward" kiwifruit has been investigated by Burdon et al. (2005). They suggested that the alcohol metabolism contributed significantly to the ripe fruit volatile profile of kiwifruits, especially the ester production.

Thirty-eight volatile compounds have been reported in "Bartlett" pear fruits treated with 2,4-dichlorophenoxypropionic acid with esters being the most prevalent compounds and butyl, ethyl, and hexyl acetate were produced in the largest amounts (Kondo et al. 2006). In case of blackcurrants (*Ribes nigrum* L. cv. "Titania") stored in air and under CA, 53 volatile compounds have been reported using GC-MS techniques (Harb et al. 2008). The air-stored fruits synthesized more of total terpene volatiles, and the nonterpene compounds, mainly esters and alcohols, also increased under these storage conditions. In blackcurrants juice, terpenes together with esters and alcohols are the major groups of aroma compounds. Hanekom et al. (2010) have investigated the effect of sulfur dioxide fumigation, modified atmosphere packaging (MAP), and CA packaging on the changes in volatiles and sensory characteristics of litchi fruit. Citronellol and geraniol are responsible for the fruity, floral, rose, and citrus aroma in "Mauritius" litchi fruit. The retention of these aroma volatiles in litchi fruit during storage followed the trend: MAP $>$ CA $>$ SO_2 $>$ SO_2–HCl dip.

The MAP packed litchi fruit showed no decay and reduced pericarp browning with acceptable marketability.

Flavor and Packaging Interactions

In commercial products, initial flavor has little meaning if that same flavor is not present when the product is consumed. The flavor changes that occur between production and consumption are of enormous interest to the food and flavor industry. Many factors have to be considered. Unfortunately, many flavor-active components are also highly chemically reactive and will react with each other, other product components, or with the packaging they come in contact with. Moshonas and Shaw (1989) reported that the flavor score decreased during 6-week storage of commercial orange juice due to increased levels of ethyl acetate, which they speculated may have come from the laminated multilayered package liner.

Imai et al. (1990) monitored the sorption of d-limonene, neral, and geraial from orange juice into three sealant films during 24-day contact at 22°C. They found the copolyester had less sorption of the organic volatiles than ethylene vinyl copolymer or commercial low density polyethylene. Konczal et al. (1992) carried out a similar study with apple juice; however, they used dynamic head space to determine sorption. Sorption of the apple juice volatiles was most significant for the low density polyethylene than with the two developmental polymers.

Sadler et al. (1995) discussed the interaction of orange juice with various packaging polymers. They found that d-limonene absorption increased microbial proliferation and accelerated vitamin C degradation. They were able to calculate the time required for identifiable flavor loss using diffusion, solubility, and permeation data. Two inexpensive methods for evaluating the interaction between volatile organic compounds and packaging polymers were also presented.

Manurakchinakorn et al. (2004) reported that fresh-cut fruits with MAP treatment obtained the highest sensory scores, compared with other treatments, throughout the entire period of storage. Fresh-cut mangosteens (*Garcinia mangostana* L.) stored in MAP resulted in the best overall retention of ascorbic acid, antioxidant capacity, and sensory quality.

SENSORY EVALUATION OF FRUITS

Sensory analysis is defined as a scientific discipline of highlighting and describing the sensory properties that are perceived by sense organs. It comprises the perception of the presence, or intensity of perceived properties, or the differentiation of perception and quantitative assessment. Sensory testing has been taking place ever since there have been humans around to assess the quality of their surroundings. There are many kinds of tests that are given to evaluate sensory perceptions of a product. Descriptive sensory analysis is the most sophisticated sensory method. It is used to identify and quantify the sensory characteristics of products, usually in the order of their occurrence, through the objective descriptions of trained assessors who possess extraordinary sensory perception (Drake and Civille 2002). Sensory quality is important in assessing cultivars for fresh consumption as well as for the processing industry (Skrede 1982, Stanely 1988). Sensory fruit qualities such as color and taste/flavor are the main factors that influence consumer's acceptance. The quality of processed fruits differs considerably from that of fresh fruits, though the aim of the industry is to conserve the quality of fresh fruits in the best way. The product shall have the characteristic color, aroma, and flavor of the particular fruit.

Flavor is the sensory impression of a food or other substance and is mainly determined by the chemical senses of taste and smell. The overall flavor impression is the result of the tastes perceived by the taste buds in the mouth and the aromatic compounds detected by the epithelium in the olfactory organ in the nose. The aroma development during storage of Castlebrite apricots has been evaluated using GC, e-nose, and sensory analysis techniques (Defilippi et al. 2009). According to them, GC and e-nose were able to successfully differentiate between two different stages of apricot fruit maturity, though the sensory panel could not identify these differences.

Organic acids and sugars ratio primarily creates a sense of taste that is perceived by specialized taste buds on the tongue. Thus, sweetness due to sugar and sourness from organic acids are dominant components in the taste of many fruits (Kays 1991). Degree of ripeness, at which a fruit is tested, plays a major role in the assessment of its sensory qualities and acceptability (Mtebe et al. 2006).

A number of biochemical reactions or metabolic activities are involved in the ripening process of mango fruit such as increased respiration, ethylene production, change in structural polysaccharides causing softening, degradation of chlorophyll and synthesis of carotenoids, changes in carbohydrates or starch conversion into sugars, organic acids, lipids, phenolics, and a number of volatile compounds. All these changes lead to ripening of fruit with softening of texture to acceptable quality. These factors predominantly contribute toward developing a total sensory profile of the mango fruit (Herianus et al. 2003). Sensory profile of fruits, especially color, has a great impact on consumers' decision to buy a particular type of fruit or its products (Gössinger et al. 2008, Akhtar et al. 2009). Karlsen et al. (1999) reported that the texture is important because it affects the perception of certain properties referring to the smell and taste of the fruit. Postharvest fruit quality parameters in apple have been assessed using both instruments and an expert panel (Oraguzie et al. 2009). The instrument-sensory relationships obtained with the expert panel were similar to those of trained panelists, indicating the benefits of using expert panel for routine postharvest fruit quality assessment under limited budget.

Gunness et al. (2009) have compared the sensory analysis of individual strawberry fruit with the instrumental analysis for the purpose of quantification of fruit-to-fruit variations in sensory attributes and instrumental values. They observed a good correlation between the individual fruit flavor characteristics and the fruit biophysical properties.

Sensory evaluations of thawed highbush and rabbit-eye blueberries showed that 17 panelists preferred the color of rabbit-eye to highbush blueberries, but thawed fruit of highbush cultivars had superior taste and texture and less seediness (Makus and Morris 1993). More recent sensory evaluations of fresh highbush and rabbit-eye blueberries showed that ten trained panelists found no differences in fruit color, flavor, or skin toughness among three rabbit-eye and two highbush cultivars (Silva et al. 2005). Another trained panel of nine members found that temperature and packaging film type affected sensory scores for texture and blueberry flavor of stored fruit from the highbush cultivar, Bluecrop (Rosenfeld et al. 1999). Various postharvest treatments are being tested to maintain and/or enhance sensory quality of stored blueberries (Nunes et al. 2004, Trigo et al. 2006).

Current maturity standards for California navel oranges require that in a lot, 90% of the samples must have a ratio of SSC to TA of 8:1 and yellow-orange color on at least 25% of the peel surface (Anon 2003). Obenland et al. (2009) have suggested that this current standard for navel oranges is set at too low of value to satisfy most of the consumers of this product. The e-nose and the mass spectrometer-based e-nose (MSE-nose) have been evaluated to monitor the changes in apple fruit volatiles during 8 months of storage under three different conditions, and the results were compared with the traditional techniques used to measure volatiles (i.e., GC-MS). The MSE-nose data volatile production during storage gave comparable results with the GC-MS techniques.

Sensory studies have been extensively carried out to evaluate the influence of processing operations on the quality perception of fresh-cut fruits by either trained or untrained judges. Studies on apple (Rocha et al. 1998), pear (Senesi et al. 1999, Gorny et al. 2002), peach (Brackett 1997, Gorny et al. 1998), durian (Voon et al. 2007), melon (Qi et al. 1999, Bai et al. 2001), pineapple (Torri et al. 2010), avocado (Dorantes-Alvarez et al. 1998), and mango (Nithiya et al. 2001) investigated the shelf life of fresh-cut product from the point of view of sensory quality evaluation. Few studies have attempted to relate postharvest treatments and conditions with fruit sensory quality (Hagenmaier and Baker 1994, Mannheim and Soffer 1996, Biolatto et al. 2005, Shi et al. 2005, Marcilla and del Río 2006).

ENHANCEMENT OF SENSORY QUALITY OF FRUITS

Paz et al. (1982) reported that the postharvest application of acetaldehyde vapors to blueberries, tomatoes, and pears led to the enhancement of the fruit sensory quality, including an increase in the sugar content, sugar–acid ratio. Applied ethanol vapors led to similar but limited enhancement of fruit sensory quality. Comparative applications of ethylene were more effective in stimulating changes in the background color, including an increase in the total carotenoid content in tomato and anthocyanidins in blueberry. Ethylene, however, had little or no effect, and occasionally led to deleterious changes in the fruit sensory quality. Acetaldehyde and related volatiles may be important in the development of fruit sensory quality, as occurring normally during ripening, or as a postharvest application for the improvement of fruit sensory quality.

Nectar is a nonfermented beverage, produced from the dissolution of the edible portion of the fruit and sugars in water, for direct consumption and could be added of acid, respecting the characteristics and compositions established for each fruit, such as sensory attributes, juice content, soluble solids, total acidity, and total sugar (Brasil 2003). Fruit blends present a series of advantages, such as the possibility of combining different aromas and flavors, plus the sum of nutritionally different components. Sandhu and Sidhu (1992) have prepared multi-fruit drinks utilizing orange, guava, pineapple, and mango juices. They were able to produce highly acceptable beverages with a shelf life of more than 6 months at ambient conditions of storage.

A study of different papaya nectar formulations showed an increase in sensory acceptance with increasing pulp content (Mostafa et al. 1997). Mixed nectars of papaya and mango pulps were studied (Mostafa et al. 1997), and products with equal amounts of both pulps and a total of 30% or 40% pulp in the formulation were best accepted, as compared to those with lower levels of mango pulp. Another study involving mixed nectar formulations containing papaya pulp and passion fruit juice showed better sensory acceptance to nectars containing higher proportions of papaya pulp. The products presented an ascorbic acid content varying from 35.4 to 36.8 mg/100 g (Salomon et al. 1977).

Imungi and Choge (1996) reported that using different nectars showed best sensory acceptance for a product formulated with papaya pulp and passion fruit juice (90:10 proportion) as compared to nectars produced with mango pulp and papaya pulp, passion fruit juice and pear juice, mango pulp and pear juice, and pear juice and papaya pulp. Nectars formulated with orange and passion fruit juices had a reduction in sensory acceptance for blends with an increased proportion of passion fruit juice, which was attributed to the strong flavor of the passion fruit juice (Shaw and Wilson III 1988).

Nectars produced with guava and papaya pulp (70:30) had a high sensory quality score, mainly due to consistency and flavor and also because it contained fair amounts of vitamin C (24.7 mg/100 g; Tiwari 2000). A grape and guava juice blend was also used for jelly preparation, and products with a 40:60 ratio scored highest for color, flavor, consistency, and overall acceptance by sensory evaluation as compared with 20:80 and 60:40 ratios (Poonam et al. 1997). Acerola pulp

is rich in vitamin C but has limited sensory appeal. Different authors have studied blends of acerola juice combined with various fruit juices and pulps (Matsuura et al. 1999, Folegatti et al. 2000, Matsuura and Rolim 2002).

An optimized formulation for a mango and acerola nectar contained 9% acerola pulp, 15°Brix, and an ascorbic acid content of 76 mg/100 g (Matsuura et al. 1999). The addition of acerola pulp up to a limit of 34% to a papaya and acerola nectar did not affect the sensory acceptance of the nectar and presented approx. 170 mg/100 g ascorbic acid. The optimum level of sugar was between 8.5% and 16% (Folegatti et al. 2000). Pineapple juice (20.9 mg/100 g ascorbic acid) added of 10.0% acerola juice (1000 mg/100 g ascorbic acid) resulted in product with about five times the vitamin C content of pineapple juice, and sensorial analyses showed no difference between treatments (Matsuura and Rolim 2002).

FLAVOR OF FRUIT PRODUCTS

The introduction of new tropical fruits and their products into the market will only be successful if consumers' expectations are satisfied. Sensory characteristics, particularly taste, and health considerations play a predominant role in consumers' satisfaction and hence subsequent consumption and purchase behavior. Two patents have recently been issued on the development of fruit products containing one or more encapsulated ω-3 fatty acids (docosahexaenoic acid, eicosapentaenoic acid), and one or more fruit flavors (Rivera et al. 2009a, 2009b).

In Europe, consumers' demand for tropical fruit products is expanding due to increased health consciousness, population growth of ethnic minorities in Europe, and through international travel and global communication (FAO 2003, Centeno 2005). The food industry is also making greater use of tropical fruits as ingredients for a wide assortment of food products in order to respond to consumers' growing interest in innovative products with new and exotic flavors and tastes (Kortbech-Olesen 1996).

Prosińska and Bartels (2007) suggested that when a consumer encounters a new fruit product (fruit innovation), domain-related characteristics, such as expected and perceived taste, healthiness, and quality, would also influence his/her attitude toward it. Moreover, innovation- and domain-related characteristics may be closely interrelated; for example, a new juice taste can also be characterized in terms of its innovative characteristics. Studying consumers' reactions to innovations in terms of innovation characteristics alone, seems to be insufficient as, for example, a product with new, more convenient packaging could be evaluated well by consumers, but would not be purchased when the taste did not match their preference.

Since flavor quality involves perception of the tastes and aromas of many compounds, it is much more challenging to manipulate than other quality factors. This has been true for plant breeders in the past, and it will continue to be so with biotechnology approaches. This may be the reason that improvement of flavor quality has received much less attention from biotechnologists so far than textural quality of fruits (Vicente et al. 2006, Vicente et al. 2007). Textural quality and related sensory attributes, such as juiciness, turgidity, and crispness, do influence human perception of flavor, and future research should contribute to improved understanding of the physical and chemical changes that contribute to desirable texture and flavor of fruits. The greatest need is to produce new fruit genotypes with better flavor, which means high sugars and moderate to high acids (with balance between them), low phenolics, and enough of the desirable, odor-active volatiles for good aroma.

High priority should be given to replacing poor flavor cultivars with good flavor cultivars from among those that already exist and/or by selecting new cultivars with superior flavor and good textural quality. Flavor is a complex, multigenic trait providing unique challenges to breeders and has not been a high priority. Selection for yield, fruit size, and shelf life characteristics in particular has had unintended negative consequences on fruit flavor (Goff and Klee 2006). Baldwin (2008) concluded that the bottom line for flavor quality is still genetic. Breeders need more information and analytical tools in order to select for flavor quality. Use of wild material may be necessary in breeding programs to regain flavor characteristics that have been lost from some commodities. Use of molecular markers that relate to flavor may help identify important enzymes in flavor pathways (Baldwin 2008).

Peaches volatiles have been extensively investigated and more than 100 compounds have been identified. The quantitative distribution of volatile compounds in the skin, top mesocarp, middle mesocarp, bottom mesocarp, inner mesocarp, and outer mesocarp of white-fleshed peach (cv. Maura) have been extracted using liquid–liquid microextraction and analyzed by GC-FID and GC-MS by Aubert and Milhet (2007). According to them, the levels of volatiles in skin were significantly higher than the other parts of the fruit. The top and bottom mesocarp were discriminated by opposite concentration in saturated lactones and C_6-compounds. The higher concentrations of benzaldehyde were found to be located mainly close to the stone, suggesting that in peach, this compound may be derived from the enzymatic hydrolysis of amygdalin. Ascorbic acid is used as an antibrowning agent in the apple juice. Use of increased concentration of ascorbic acid in apple juice has been reported to increase the green and unnatural odors and decrease the fresh, fruity, and apple-like odors (Komthong et al. 2007). They have identified 23 volatile compounds in apple juice by using GC analysis. The aroma values of hexanal and trans-2-hexanal in the apple juice with 0.2% w/v ascorbic acid increased about 4- and 5-fold from those of ascorbic acid-free apple juice, respectively, and the aroma values of these aldehydes corresponded well with the green color in the apple juice with added ascorbic acid. In an another study using GC-MS

and HPLC, Zhang et al. (2010) have identified and quantified 12 carbohydrates, 8 organic acids, 20 amino acids, and 18 phenolic compounds in "Honeycrisp" apple flesh. Satora et al. (2008) have studied the influence of apple variety on the polyphenol profile, volatile composition, and sensory characteristics of apple wines. On the basis of their sensory evaluation results, wines produced from Idared apples scored the highest value for overall quality.

Cooked grape must is required for the production of many traditional Italian foods and beverages. The effect of cooking on the concentration of many constituents, such as sugars, organic acids, nitrogen compounds, metal ions, and polyphenols, has been studied by Piva et al. (2008). They observed the formation of many new compounds like hydroxymethylfurfural and melanoidins that gave to the must the typical brown color and caramel-like odor. Upon cooking, the formation of condensed tannins decreased the antioxidant activity of the phenolic fraction; however, the formation of melanoidins improved the total antioxidant capacity of the cooked grape must. While comparing the thawed half strawberries and fresh berries, most of the esters like hexyl acetate, ethyl methyl hexanoate, and methyl acetate increased significantly by the week-long and not the overnight freeze/thaw treatments (Modise 2008). However, the abundance of acetaldehyde compounds increased significantly in naturally thawed strawberries compared to the force-thawed berries. The composition of the essential oils derived from the peel of four selected Tunisian citrus species has been reported by Hosni et al. (2010). Using GC and GC-MS techniques, they have identified 70 different compounds in the essential oils obtained from sweet orange (*Citrus sinensis* Osbeck.), mandarin (*Citrus reticulata* Blanco), sour orange (*Citrus aurantium* L.), and pummel (*Citrus grandis* Osbeck) grown under similar climatic and cultural conditions. They concluded that the observed variability between the studied species and cultivars has originated from the genetic variability only.

FRUIT FLAVOR IN PROCESSED FOOD PRODUCTS

In commercially processed fruit products, initial flavor has little meaning, if that same flavor is not present when the product is consumed. The flavor changes that occur between production and consumption are of enormous interest to the food and flavor industry. Many factors have to be considered. Because of their commercial importance, most of the work in this area has been done with apple or orange juice. Little work in this area has been done with tropical fruits.

FUTURE RESEARCH NEEDS

Future research should continue to identify the biochemical pathways responsible for the production of the odor-active component for each commodity and the key enzymes involved and their controlling genes. Such information can be used by geneticists in their programs to select genotypes with superior flavor. In addition, future research is needed to identify optimal integrated crop management practices that maximize flavor quality. Continued research is needed to match aroma sensory and instrumental data and to elucidate texture–aroma interactions and odor–taste interactions in flavor perception. One example is the work of Greger and Schieberle (2007), who concluded that odor-active components in a complex aroma profile can be elucidated using approaches of molecular sensory science, including aroma reconstitution experiments based on the results of quantitative data. They found that the responses of the human odorant receptors toward apricot aroma can be closely mimicked by a mixture of 18 volatiles of identical concentrations to those present in the apricot fruit. Similar studies should be conducted on other fruits for which such information is not available.

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4
Microbiology of Fresh and Processed Fruits

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Abstract: Fruits are an integral component of the balanced diet system. The microbiological profile (microbial richness and count) of the fruit surface and internal tissues reflects the processing, storage conditions, and contamination load of the fruits and hence varies among fruit types. There exists an array of factors that govern the occurrence of diverse microbes in/on fruits/fruit products; and the microbial quality and spoilage affects the shelf life of the fruit/fruit-based products. The fruit spoilage could be caused both by true spoilage as well as by opportunistic pathogens like bacteria and fungi. Generally, the extent of spoilage is increased by the use of inappropriate or contaminated fruit processing equipments/protocols and abiotic conditions during storage. The true spoilage pathogens may help create specific niches/microenvironments to harbor even human pathogenic microbes. There are diverse analytical assays such as conventional direct microscopy and viable cell counts, modified conventional, DNA/protein-based and other unconventional

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systems, biology/biosensor/nanotechnology-based techniques, that decipher the microbiological profile of fruit/fruit-based products to ensure the quality and consumption safety criteria.

INTRODUCTION

The term "microbes" represents viruses, unicellular prokaryotic bacteria, eukaryotic multicellular fungi, and protists. The omnipresent microbes found on external surfaces of plants, particularly on skins of fruits and vegetables, unless effectively removed, can lead to spoilage and foodborne diseases.

Fruits and vegetables provide essential vitamins, minerals, fiber, and health-promoting phytochemicals. The polyphenols and flavanoids in fruits positively affect gut microecology by inhibiting the adherence of pathogenic microbes to gut surface and by increasing the number of beneficial microflora (Parker et al. 2008). Nyanga et al. (2007) indicated that unripe, ripe, and unprocessed fruits possess enormous microbial diversity. The natural microflora of fruits includes lactic acid bacteria, streptococci, certain yeasts, and yeast-like fungi (Rezende et al. 2009). Certain microbes in fermented beverages, probiotics (*Lactobacillus* on apple/quince pieces), and cultures (*Lactobacillus*/*Saccharomyces* in commercial fruit juices) are particularly helpful to our health (Betoret et al. 2003, Kourkoutas et al. 2005).

Fruit juices contain antimicrobial compounds that can limit growth of several pathogenic microbes, viz, *Listeria monocytogenes*, *Salmonella enteritidis,* and *Escherichia coli* O157:H7 by causing significant damage to cell cytoplasm as revealed by transmission electron micrographs (Raybaudi-Massilia et al. 2009). However, reports have described incidences of foodborne diseases due to consumption of raw fruits and vegetables, and foods in general (Hedberg et al. 1994, Altekruse and Swerdlow 1996, Altekruse et al. 1997, Bean et al. 1997, Potter et al. 1997).

A healthy fruit surface can harbor diverse types of microbes such as plant pathogens, opportunistic pathogens, or nonplant pathogenic species (Hanklin and Lacy 1992, Nguyen-the and Carlin 1994). According to Center for Disease Control and Prevention, among documented outbreaks of infections associated with raw fruits, vegetables, and unpasteurized fruit juices, more than 50% of outbreaks were due to unidentified etiological agents. The outbreaks of fresh-produce-related food poisoning included *E. coli* O157:H7, *Salmonella*, *Shigella*, *Cyclospora*, hepatitis A virus, and Norwalk disease virus. Erickson and Kornacki (2003) suggested *Bacillus anthracis* as a potential food contaminant.

The microbiology of fruits was discussed in the first edition of this book (Kalia and Gupta 2006). This updated chapter contains new information including types of microbes on fruit surfaces and in minimally processed and processed fruit products, novel methods for detection of foodborne pathogens, fruit safety issues, and implementation of the Hazard Analysis and Critical Control Points (HACCP) protocols.

MICROBIOLOGY OF FRESH AND MINIMALLY PROCESSED FRUITS

The microflora of fruits comprises microorganisms unintentionally inoculated on produce surface during pre- and postharvest operations (Nguyen-the and Carlin 1994). In order to achieve microbiological quality, good agricultural production and distribution practices are important. The normal microflora of the outer surface of fresh fruits would vary according to the stringency of the above practices and on microbiologically safe conditions/practices followed during handling, processing, storage, and distribution (Scheper et al. 2007).

Normal Microflora of Whole Fresh Fruits

Although fresh fruit skin is an inhospitable environment for most microbes, microbes clinging to fruit surfaces may exist as vegetative cells or spores (exo- or endospores, cysts, other bodies). However, the fruit surfaces mainly consist of nonpathogenic epiphytic microbes, which may belong to subsets of microbial world, include the bacteria, yeast, molds, and viruses (Hanklin and Lacy 1992). The general bacteria associated with the fruit outer surfaces include both the gram-positive as well as gram-negative bacteria spanning over varied morphological structures such as bacillary rods to spherical coccoid cells. The predominant gram-negative bacteria include the genera belonging to family Pseudomonadaceae, *Pseudomonas* and *Xanthomonas* (Lindow et al. 1998); Enterobacteriaceae, *Enterobacter, Aerobacter cloacae, E. intermedza,* and *Erwinia*; Cornybacteriaceae, *Corynybacterium;* Achromobacteriaceae, *Flavobacterium* (Samish et al. 1961); gram-positive rods belonging to family Bacillaceae, *Bacillus* and *Lactobacillus;* the coccoid bacterial genera include the members of Micrococcaceae, *Micrococcus;* Stapylococcaceae, *Staphylococcus;* Streptococcaceae, *Streptococcus equines, S. salviarus, S. faecalis, S. mitis,* and sarcinae (Smeall 1932).

Normal fungal microflora of fruits is as diverse as the bacterial forms and includes hyphal fungi or molds like *Rhizopus*, *Aspergillus*, *Penicillum*, *Eurotium*, *Wallemia,* and the single cell yeasts such as *Saccharomyces*, *Zygosaccharomyces*, *Hanseniaspora*, *Candida*, *Debaryomyces*, and *Pichia* sp.

The normal microflora imparts certain advantages to fruits rearing these microbes, such as inhibition of the attachment, survival, and multiplication of the opportunistic microbes, particularly the human pathogens on the fruit surfaces. Ukuku et al. (2004) showed positive effect of native microflora in inhibiting growth of *L. monocytogenes* in fresh-cut melons. Similarly, Teixido et al. (1998) showed antagonistic effect of normal yeast (*Candida sake)* on molds (*Cladosporium* and *Penicillium).*

Opportunistic and Spoilage Microflora of Whole Fresh Fruits

The nonstringent or unsafe practices during growing, handling, and packaging of the fresh produce can inoculate the surface of fruits with human and plant pathogens. Thus, the surface flora of fresh produce reflects the environmental flora where the products are grown, quality of irrigation water, use of partially processed compost or manure, insects (particularly fruit flies, domestic flies), conditions of harvesting and processing equipment, etc. The bacterial flora may range from common bacteria often isolated from soil, water, and vegetation such as *Bacillus* spp., *Enterobacter* spp., *Klebsiella* spp., *Rahnella aquatilis,* and *Serratia* spp., which are not considered to be of hygienic importance, to potentially pathogenic bacteria, including the *Shigella*, *Salmonella*, *E. coli* O157:H7, *Bacillus cereus*, *L. monocytogenes, Yersinia enterocolitica,* and *Campylobacter* spp. that inhabit animal and human intestine. The gram-positive cocci such as toxinogenic *Staphylococcus aureus* can be inoculated on the fruit surfaces during distribution and handling (Johannessen et al. 2002). These organisms, which are natural inhabitants of human skin and nasal membranes, are responsible for foodborne diseases due to consumption of infected whole or cut fruits and vegetables. Apart from these bacterial species, certain viruses such as hepatitis A virus, rotavirus, and Norwalk disease viruses, which are the causative agents of waterborne diseases, can be transmitted by consumption of raw fruits. The protistian parasites like *Cryptosporidium parvum, Giardia lamblia*, *Cyclospora caytanensis,* and *Toxiplasma gondii* could also be isolated from the fresh produce (Tauxe et al. 1997) and are one of the major causes of antibiotic-resistant diarrhea and gastroenteritis.

The spoilage molds like certain strains of *Aspergillus* are known to produce mycotoxins that have bad impacts on vital organs of body, viz., liver, kidney, and lungs. Moldy fruits can also initiate allergic reactions in hypersensitive individuals due to production of large numbers of conidia (Tournas and Katsoudas 2005).

The disease-causing capacity of the human pathogenic microbes as well as spoilage microbes is dose-dependent, but the microbial counts required for causing disease symptoms are much less than those required for causing spoilage and off-odors (Ragaert et al. 2007).

Microflora of Minimally Processed Fruits

Fresh-cut, minimally processed fruits are essentially peeled, trimmed, cut or sliced, and packaged and offer 100% usable product with high nutrition, flavor, freshness, and convenience (Lamikanra 2002). However, fresh-cut fruits are highly perishable due to biochemical, physiological, and microbial changes and require refrigeration or chilled storage (Garcia and Barrett 2002). As minimally processed fresh fruits and vegetables are not heat treated, regardless of additives or packaging, they should be handled and stored at refrigerated temperatures (5°C or less) in order to achieve microbiological safety and shelf life. The inner tissues of fruits and vegetables are usually regarded as sterile (Lund 1992). However, microbes may be present in low numbers as a result of the uptake of water through certain irrigation or washing procedures, particularly involving human pathogenic bacteria and viruses. Rinsing of fresh produce with contaminated water or reusing processed water adds *E. coli* O157:H7, *Enterobacter*, *Shigella*, *Salmonella* sp., *Vibrio chloreae*, *C. parvum*, *G. lamblia*, *Cyclospora caytanensis*, *T. gondii*, and other causative agents of foodborne illnesses, thus increasing the microbial load of the fresh produce that undergo further processing, along with the undesirable pathogens from the crop.

Fruits are more acidic than other types of fresh produce. Acidity helps in inhibition of microbial growth, particularly on storage at low temperatures. The fresh-cut fruits (apple, peach, orange, mango, and pineapple) harbored small microbial populations with predominance of yeasts and molds (Abadias et al. 2008). Tournas et al. (2006) have found higher yeasts and mold counts in several fruit salad preparations (cantaloupe, honeydew melon, citrus fruit, pineapple, strawberry, watermelon, and mixtures of these fruits). The processing protocols followed during minimal processing of fruits lead to removal of fruit's natural cuticle, creating easy access to opportunistic microflora. These microbes may cling to the bruised surfaces and enter newer tissue niches and may persist there as harmless commensals. Human pathogenic microbes such as *L. monocytogenes, Y. enterocolitica, Salmonella* spp., and *Aeromonas hydrophila* may survive and even proliferate at low temperatures in fresh-cut fruits even though there are little environmental conditions available for the multiplication of these pathogens (Brackett 1994). Minimally processed fruits contain psychrotrophic microbes like pectinolytic pseudomonads, *Listeria, Salmonella, Clostridium botulinum, Y. enterocolitica, V. parahaemolyticus,* and *E. coli,* which have a competitive advantage over other pathogens (Laurila and Ahvenainen 2002). The potent sources of contamination in fresh-cut fruits are cutters and slicers, which provide inaccessible sites for harboring microbes, particularly bacteria. The presence of cut surfaces provides an increased surface area for contamination and growth and allows microbial infiltration of the tissues. Gorny and Kader (1996) observed that pear slices cut with a freshly sharpened knife retained visual quality longer than the fruits cut with a dull hand slicer.

MICROFLORA OF PROCESSED FRUIT PRODUCTS

The processed or canned fruits and fruit products exhibit predominance of entirely different type of microbes than the fresh or minimally processed fruits. Since postharvest processing methods include diverse range of physical and

chemical treatments to enhance the shelf life of fresh produce, the processed fruits or fruit products are dominated by temperature-tolerant (high or low) microbes, particularly the bacterial and fungal spores, due to application of thermal processes or refrigeration during processing. Fruit concentrates, jellies, jams, preserves, and syrups have reduced water activity (a_w) achieved by concentration, sugar addition, and heating to 60–82°C and this inhibits xerotolerant fungi as well as restrains the growth of bacteria. Pasteurized fruit juices and nectars lose most vegetative bacteria, yeasts, and molds while retaining heat-resistant ascospores or sclerotia producing *Paecilomyces* sp., *Aspergillus* sp., and *Penicillum* sp. (Splittstoesser 1991). *Alicyclobacillus acidoterrestris* is the most commonly isolated heat tolerant, endospore-forming spoilage microorganism in canned commercially pasteurized orange, grapefruit, and apple juices (Silva and Gibbs 2001). Walls and Chuyate (2000) also reported occurrence of *Alicyclobacillus acidoterrestris*, an endospore-forming bacteria in pasteurized orange and apple juices. Walker and Phillips (2009) showed the occurrence of psychrotolerant *Propionibacterium cyclohexanicum* in pasteurized orange, apple, grapefruit, pineapple, cranberry, and tomato juices.

FACTORS AFFECTING MICROBIAL GROWTH

Fruits are composed of polysaccharides, sugars, organic acids, vitamins, and minerals, which function as reservoirs or substrates for microbial growth. Fresh fruits exhibit the presence of a mixed microbial population, and the growth rate of each microbial type would depend upon an array of factors listed below.

Intrinsic Factors

These factors are an inherent part of the plant tissues (Mossel and Ingram 1955) and are characteristics of the growth substrates. They include the following.

Hydrogen Ion Concentration (pH)

Microbial cells lack the ability to adjust their internal pH, and most microorganisms grow best around neutral pH. Bacteria exhibit a narrow pH range, pathogenic bacteria being the most fastidious; yeasts and molds are more acid-tolerant than bacteria. Typically, fruits possess acidic pH (<4.0), favoring growth of yeasts and molds. Microbes, in general, experience increased lag and generation times at either extremes of the optimum pH range. However, small fluctuations in pH impact microbial growth rates, and the pH changes become more profound if the substrate has low buffering capabilities, leading to rapid changes in response to metabolites produced by microorganisms (Table 4.1).

The intracellular pH of microbial cytoplasm remains reasonably constant due to relative impermeability of cell membrane to hydrogen (H^+) and hydroxyl (OH^-) ions as key cellular compounds such as ATP and DNA require neutrality (Brown 1964). The pH changes also affect the morphology of some microbes such as *Penicillum chrysogenum* that show decreased length of hyphae at pH above 6.0. Corlett and Brown (1980) observed varying ability of organic acids as microbial growth inhibitors in relation to pH changes.

Table 4.1. Approximate pH Values of Some Fresh Fruits

Fruits	pH Values
Apples	2.9–3.3
Bananas	4.5–4.7
Grape fruit	3.4–4.5
Watermelons	5.2–5.6
Oranges	3.6–4.3
Limes	1.8–2.0
Melons	6.3–6.7
Figs	4.6
Plums	2.8–4.6

Water Activity (Moisture Requirement)

Water is a universal constituent required by all living cells, and microbes are no exceptions, but the exact amount of water required for growth of microorganisms varies. Hence, several preservation methods involve drying or desiccation of the produce (Worbo and Padilla-Zakour 1999). The water requirement of microbes is defined as water activity (a_w) or ratio of water vapor pressure of food substrate to that of vapor pressure of pure water at the same temperature,

$$a_w = \frac{p}{p_o},$$

where p is the vapor pressure of the solution and p_o is the vapor pressure of the solvent.

Christian (1963) related water activity (Table 4.2) to relative humidity (RH) as

$$RH = 100 \times a_w.$$

Table 4.2. Lower Limit a_w Values of Certain Microorganisms

Bacteria	Minimum a_w Values	Fungi	Minimum a_w Values
Pseudomonas	0.97	*Mucor*	0.62 (0.94)
E. coli	0.96	*Rhizopus*	0.62
Staphylococcus aureus	0.86	*Botyritis*	0.62
Bacillus subtilis	0.95	*Aspergillus*	0.85
Clostridium botulinum	0.93	*Penicillum*	0.95
Enterbacter aerogenes	0.94		

In general, most fresh produce has a_w value above 0.99, which is sufficient for the growth of both bacteria and molds; however, bacteria, particularly gram-negative, are more stringent regarding a_w changes, while molds could grow at a_w as low as 0.80. The lowest range of a_w for halophilic bacteria, xerophilic fungi, and osmophilic yeasts is 0.75–0.61. Morris (1962) elaborated the interaction of a_w values with temperature and nutrition and observed that at optimum temperature, range of a_w values remain wide, while lowering/narrowing a_w values reduces growth and multiplication of microbes, and nutritive properties of substrate increase the range of a_w over which microorganisms can survive.

Each microbe has a characteristic a_w range for optimum growth and multiplication. The a_w is affected by temperature, pH, oxygen, nutritive properties of substrate, and organic acids or other secondary metabolites performing inhibitory action. Thus, narrowing the a_w range decreases microbial growth (Wodzinsky and Frazier 1961). Lowering of water activity builds up stress and exerts adverse influence on all vital metabolic activities that require aqueous environment. Charlang and Horowitz (1974) observed the appearance of nonlethal alterations in cell membrane permeability of *Neurospora crassa* cells, resulting in loss of various essential molecules, as the dynamic cell membrane should remain in fluid state.

The exception to normal a_w requirements are halophilic (salt tolerant) bacteria that grow under low a_w values by accumulating potassium ions in the cell (Csonka 1989), while osmophilic yeasts concentrate polyols as osmoregulators and enzyme protectors (Sperber 1983). Brown (1976) reported proline accumulation in response to low a_w in halotolerant *Staphylococcus aureus* strains. Xerotolerant fungi accumulate polyhydric alcohols (Troller 1986). Microbes thus attempt to compensate for increased stress by accumulating compatible solutes.

Redox (Oxidation–Reduction) Potential

Microbial growth depends upon oxidation–reduction (O/R) potential of a substrate or its ability to lose or gain electrons. Aerobic microbes require oxidized (positive Eh values) substrate for growth, and it is opposite for the anaerobes (Walden and Hentges 1975). Fruits contain sugars and ascorbic acid for maintaining reduced conditions, though plant foods tend to have positive Eh values (300–400 mV). Hence, aerobic bacteria and molds most commonly spoil fruits and fruit products. The O/R potential of food can be determined by

- pH of food,
- Poising capacity,
- Oxygen tension of the atmosphere,
- Atmospheric access of food.

Poising capacity alters the ability of the living tissues to metabolize oxygen at specifically low Eh values that exist in the vacuum-packed foods. Aerobic microbes include bacilli, micrococci, pseudomonas, and actinobacters and require positive Eh values, while anaerobes such as clostridia and bacteriodes require negative Eh values. However, most yeast and molds are aerobic and few tend to be facultative anaerobes. In the presence of limited amount of oxygen, aerobic or facultative microbes may produce incompletely oxidized organic acids. Pasteurization of fruit juices would render microbes lose reducing substances, but this would not limit yeast growth.

Available Nutrients

Each microbe has a definite range of food requirements, with some species having wide range and ability to grow on a variety of substrates, while others having narrow range and fastidious requirement, allowing growth on limited substrates. Fruits are a reservoir of sugars (source of energy), water, minerals, vitamins, and other growth-promoting factors, but the protein content or nitrogen source is not as high. Microorganisms have varied nutrient requirements, which are influenced by temperature, pH, and Eh values. The microbes become more demanding at reduced temperatures, while at optimum temperature, nutrients control microbial growth. Thus, pectinolytic bacteria such as *Erwinia cartovora*, *Pseudomonas* sp., or pectinolytic molds grow best on fruits and vegetables.

Nitrogen requirement is usually met by proteolysis of protein present in substrates, use of amino acids, nucleotides, certain polysaccharides, and fats under usual microbe-specific conditions. The accessory food substances or vitamins are to be furnished by substrate since microorganisms are unable to synthesize essential vitamins. In general, gram-positive bacteria are least synthetic and require supply of certain vitamins before growth, while gram-negative bacteria and molds are relatively independent and can synthesize most of the vitamins. Thus, these two groups of microbes grow profusely on foods relatively low in B-complex vitamins, such as fruits under the influence of usual low pH and positive Eh values.

Antimicrobial Factors

Certain naturally occurring substances in food work against the microbes, thus maintaining stability of food; however, these are directed toward a specific group of microorganism and have weak activity. Song et al. (1996) reported that the presence of aroma precursor hexal readily gets converted to aroma volatiles *in vivo* by fresh-cut apple slices. Hexal acts as antibrowning agent as well as inhibits growth of molds, yeasts, mesophilic, and psychrotropic bacteria (Lanciotti et al. 1999). Hexanal and (*E*)-hexenal in modified atmosphere packaging (MAP) of sliced apples reduce spoilage microbe populations (Corbo et al. 2000).

Spices contain essential oils such as eugenol (clove), allicin (garlic), cinnamic aldehyde and eugenol (cinnamon), allyl isothiocynate (mustard), eugenol and thymol (sage),

thymol, and isothymol (oregano) that have antimicrobial activity (Shelef 1983). Buta and Molin (1998) observed reduction in mold growth on fresh-cut peppers by exogenous application of methyl jasmonate.

The antimicrobial compounds may originally be present in food, added purposely or developed by associated microbial growth, or by processing methods. Certain antifungal compounds applied to fruits include benomyl, biphenyl, and other phenylic compounds that exist in small quantities as by-product of phenol synthesis pathways. Beuchat (1976) observed that essential oils of oregano, thyme, and sassafras have bacteriocidal activity, at 100 ppm, to *V. parahaemolyticus* in broth, while cinnamon and clove oils at 200–300 ppm inhibit growth and aflatoxin production by *Aspergillus parasiticus* (Bullerman et al. 1977). The hydroxy-cinnamic acid derivatives such as *p*-coumaric, ferulic, caffeic, and chlorogenic acids and benzoic acid in cranberries have antibacterial and antifungal activities and are present in most plant products including fruits.

Extrinsic Factors

Extrinsic factors imposed from the external environment during storage can affect food and the microbes that tend to develop on it. These factors include the following.

Temperature

Microbes grow over a wide range of temperature, and change in temperature at both extremes lengthens the generation time and lag periods. The temperature required for microbial growth varies from –34°C to 90°C. The following is the list of microbes based on temperature requirements.

1. *Psychrotrophs*: These microorganisms can grow well at 7°C or below, with temperature optima ranging from 20°C to 30°C. For example, *Lactobacillus*, *Micrococcus*, *Pseudomonas*, *Enterococcus*, *Psychrobacter*, *Rhodotorula*, *Candida* and *Saccharomyces* (yeasts), *Mucor*, *Penicillum*, *Rhizopus* (molds) and *Clostridium botulinum*, *L. monocytogenes*, *Y. enterocolitica*, and *Bacillus cereus* (pathogenic psychrotrophs). The groups of microbes, which grow from –10°C to 20°C with the optima of 10–20°C, are included as *Psychrophiles* and include certain genera mentioned above.
2. *Mesophiles:* These include microbes growing best between 20°C and 45°C, with optimum range of 30–40°C. For example, *Enterococcus faecalis*, *Streptococcus*, *Staphylococcus*, and *Leuconostoc*.
3. *Thermophiles:* Microbes, which grow well above 45°C with the optima ranging between 55°C and 65°C and with maximum of above 60–85°C, are known as thermotolerant thermophiles. For example, *Thermus* sp. (extreme thermophile), *Bacillus sternothermophilus*, *Bacillus coagulans*, and *Clostridium thermosaccharolyticum* are endospore-forming thermotolerants and grow between 40°C and 60°C and create major problems in the canning industry.
4. *Thermotrophs:* This group includes microbes similar to mesophiles but with slightly higher temperature optima and includes pathogenic bacteria in foods. For example, *Salmonella*, *Shigella*, enterovirulent *E. coli*, *Campylobacter*, toxigenic *Bacillus cereus*, *Staphylococcus aureus*, and *Clostridium perfringens*. The relationship between temperature and growth rate of microorganisms between minimum and maximum temperature is given by the following equation:

   $$\sqrt{r} = b(T - T_0),$$

   where r is the growth rate, b is the slope of regression line, T is temperature, and T_0 is the conceptual temperature of no metabolic significance (Ratowsky et al. 1982).

Relative Humidity of Environment

Success of a storage temperature depends on the RH of the environment surrounding the food. Thus, RH affects a_w within a processed food and microbial growth at surfaces. A low a_w food kept at high RH value tends to pick up moisture until equilibrium is reached, and foods with high a_w lose moisture in a low-humidity environment. Fruits and vegetables undergo a variety of surface growth by yeasts and molds as well as bacteria, and thus are liable to spoilage during storage at low RH conditions. However, this practice may cause certain undesirable attributes, such as firmness and texture loss.

Modified Atmosphere Storage

Altering the gaseous composition of the environment, which retards the surface spoilage without reducing humidity includes the general practice of increasing CO_2 (to 10%) is referred as "controlled or modified atmosphere packaging" (CAP or MAP). CAP/MAP retard senescence, lower respiration rates, and slow the rate of tissue softening or texture loss (Wright and Kader 1997a, Qi et al. 1999, Rattanapanone and Watada 2000). CAP/MAP storage has been employed for fruits (apples and pears) with CO_2 applied mechanically or as dry ice, and this retards fungal rotting of fruits probably by acting as competitive inhibitor of ethylene action (Wright and Kader 1997b, Gil et al. 1998).

The inhibitory effect increases with decrease in temperature due to increase in solubility of CO_2 at lower temperatures (Bett et al. 2001). Elevated CO_2 levels are generally more microbiostatic than microbiocidal, probably due to the phenomena of catabolite repression. However, an alternative to CO_2 application includes the use of ozone gas at low ppm concentrations, which acts as ethylene antagonist as well as a strong oxidizer that retards microbial growth. Sarig et al. (1996) and Palou et al. (2002) reported control of

postharvest decay of table grapes caused by *Rhizopus stolonifera*. A similar report on effect of ozone and storage temperature on postharvest diseases of carrots was observed by Liew and Prange (1994). In general, gaseous ozone introduction to postharvest storage facilities or refrigerated shipping and temporary storage containers is reported to be optimal at cooler temperatures and high RH (85–95%; Graham 1997). The most reproducible benefits of such storage are substantial reduction of spore production on the surface of infected produce and the exclusion of secondary spread from infected to adjacent produce (Kim et al. 1999, Khadre and Yousef 2001).

MAP is the most commonly used for fresh-cut fruits (Jayas and Jeyamkondan 2002, Soliva-Fortuny and Martin-Belloso 2003, Ayhan and Esturk 2009). Timon (2005) reported better product quality and enhanced shelf life of the fresh-cut fruits by using approximately 3–5% O_2 and 5–10% CO_2 within the package. MAP technique has been used in combination with physical, chemical, or radiation techniques. The texture and quality of fresh fruits packed by MAP technique can be enhanced by treating with essential oils having antimicrobial properties. A study of fresh sweet cherry fruits revealed that treatment with antifungal essential oils like eugenol, thymol, or menthol imparts certain positive benefits on several quality parameters. The treated fruits had less weight loss, color degradation, and texture softness than the control fruits (Serranoa et al. 2005). Aromatic compounds (e.g., hexanal, 2-(*E*)-hexenal and hexyl acetate) have been reported to have antimicrobial effects on gram-negative bacteria (Lanciotti et al. 2004).

Implicit Factors

While growing in a food substrate, microorganisms may produce one or more inhibitory substances such as acids, alcohols, peroxides, and antibiotics that affect the growth of other microorganisms.

General Interference

Normal microflora of fresh produce helps prevent the colonization of pathogens and succeeds in overcoming the contaminant number by overgrowth and efficient utilization of available nutrients.

Production of Inhibitory Substances

Some microbes can produce inhibitory substances, including "bacteriocins," for example, "nisin" produced by certain strains of *Lactobacillus lactis*. As an inhibitor of spore-forming *Clostridium* spp., which causes cheese blowing due to undesirable gas production, nisin was the first bacteriocin produced by lactic acid bacteria to be isolated and approved for use in cheese spreads. Other bacteriocins produced by lactic acid bacteria include lactococcins, lacticins, lactacins, diplococcin, sakacins, acidophilocins, pediocins, and leuconosins. Although mostly active against gram-positive bacteria, bacteriocins can be microbiocidal under certain conditions, even toward gram-negative bacteria and yeasts. The antimicrobial action of nisin and of similar bacteriocins is believed to involve cell membrane depolarization, leading to leakage of cellular components and to loss of electrical potential across the membrane. *Propioniobacterium* produces propionic acid that has inhibitory effect on other bacteria.

The bacteriocins may be of broad or narrow spectrum depending on the kind of microbe. Narrow-spectrum bacteriocins selectively inhibit high-risk bacteria in foods like *L. monocytogenes* without affecting harmless microorganisms; this is of importance for extending shelf life of high sugar and high moisture fruits like honeydew melons, berries, apple, etc. (Leverentz et al. 2003). Thus, these peptides have a future as preservatives, shelf-life extenders, additives, or ingredients that could be produced in situ by bacteriocinogenic starters, adjunct, or protective cultures (Galvez et al. 2007). Certain bacteriocins, which are available for commercial applications, are nisin, pediocin PA-1/AcH, lacticin 3147, enterocin AS-48 or variacin, and many more. Penney et al. (2004), however, reported that nisin did not prevent growth of spoilage-causing microbes in fruit yogurt made with minimally processed wild blueberries. They advocated application of phytopreservatives such as vanillin as "natural" antimicrobial agents in minimally processed fruit yogurt.

Certain microorganisms can produce a wide-spectrum antimicrobial substances or secondary metabolites called "antibiotics," capable of killing or inhibiting a wide range of microbes. Further, growth of one kind of microbe can lower pH and make the environment unsuitable for other microbes to grow. Organic acid production or hydrogen peroxide formation can also interfere with the growth of microbial population (Jay 1992).

Biofilm Formation

Most of the gram-negative bacteria exhibit quorum sensing or a cell-to-cell communication phenomena leading to formation of a multicellular structure that provides protection to bacterial species from deleterious environment by precipitation. Adoption of biofilm formation involves release of autoinducers, particularly called the *N*-acyl homoserine lactones that either activate or repress the target genes involved in biofilm formation (Surette et al. 1999). Quorum sensing can regulate prime events such as spore germination, virulence factor production, and biofilm formation on surfaces (Frank 2000b).

Bacterial cells, which have slow growth on biofilm, are more resistant to heat, chemicals, and sanitizers due to the diffusional barrier created (Costerton 1995). Morris et al. (1997) reported certain methods for observing microbial biofilms directly on leaf surfaces and also to recover the constituent microbes for isolation of cultivable microorganisms. Biofilm

formation has emerged as a challenge for routine decontamination techniques used in the food and beverage industries (Frank 2000a).

FACTORS AFFECTING MICROBIAL QUALITY AND FRUIT SPOILAGE

Factors that affect the microbial quality of fruits include the following.

Preharvest Factors

These factors basically involve production practices that have effect on the microbial quality of fruits. Management practices can affect product quality since stressed produce or mechanical injuries permit microbial contamination. Mold growth and decay on winter squash caused by *Rhizoctoina* result from fruits lying on the ground. Food safety begins in field as a number of foodborne disease outbreaks have potential sources in field, which can contaminate the produce, for example, the use of partially treated manure, irrigation with livestock-used pond water, or storage near roosting birds (Trevor 1997). Wallace et al. (1997) reported the presence of verocytotoxin producing *E. coli* O157:H7 from wild birds.

Postharvest Handling and Processing

Improper or harsh handling of produce causes bruises, leading to increased chances of microbial damage. The postharvest rots are most prevalent in damaged or bruised fruits (Sanderson and Spotts 1995, Bachmann and Earles 2000). The processing involves heating, cooling, moisture, and ethylene control, thus include the extrinsic parameters discussed earlier.

FRUIT SPOILAGE

Microbial spoilage affects quality of fruits and renders them inedible. Fresh fruits possess effective defense, including a thicker epidermal tissue and relatively higher concentration of antimicrobial organic acids. However, the higher the water activity, the higher the sugar content, and more acidic pH (<4.4) of fresh fruits favor the growth of xerotolerant fungi or osmophilic yeasts. Lamikarna et al. (2000) have reported bacterial spoilage in neutral pH fruits.

Normal microflora of fruits is diverse and includes bacteria such as *Pseudomonas*, *Erwinia*, *Enterobacter*, and *Lactobacillus* sp. (Pao and Petracek 1997) and a variety of yeasts and molds. These microbes remain adhered to outer skin of fruits. They can be from several sources, such as air, soil, compost, and insect infestation. Brackett (1987) reported inoculation of *Rhizopus* sp. spores by egg laying in ruptured epidermal fissures of fruits by *Drosophila melanogaster* (the common fruit fly). The microbial load of the fresh produce can be reduced by rinsing with water (Splittstoesser 1987). However, the source and quality of water dictate the potential for human pathogen contamination upon contact with the harvested produce.

Lund and Snowdon (2000) reported certain common molds such as *Penicillum* sp., *Aspergillus* sp., *Eurotium* sp., *Alternaria* sp., *Cladosporium* sp., and *Botrytis cinerea* involved in spoilage of fresh and dried fruits. Molds producing heat-resistant ascospores or sclerotia, such as *Paecilomyces fulvus*, *P. niveus*, *Aspergillus fischeri*, *Penicillum vermiculatum*, *and P. dangeardii,* were observed to cause spoilage of thermally processed fruits or the fruit products. These products had off-flavors, visible mold growth, and texture breakdown (Splittstoesser 1991, Beuchat and Pitt 1992).

Fruit safety risks could be increased by certain spoilage types that create microenvironments suitable for the growth of human pathogens, as the primary spoilage by one group of phytopathogens produces substances required for nurturing growth and development of human pathogens. Wade and Beuchat (2003) reported role of proteolytic fungi and the associated changes in pH of the decayed and damaged raw fruits on survival and growth of various foodborne pathogens. *Botrytis* or *Rhizopus* spoilage of fruits can help create environment for proliferation of *Salmonella enterica* serovar *Typhimurium* (Wells and Butterfield 1997). Dingman (2000) observed the growth of *E. coli* O157:H7 in bruised apple tissues. Similar reports by Riordan et al. (2000) and Conway et al. (2000) depicted the impact of prior mold contamination of wounded apples by *Penicillum expansum* and *Glomerella cingulata* on survival of *E. coli* O157:H7 and *L. monocytogenes*.

True Pathogens

These microbes possess the ability to actively infect plant tissues as they produce one or several kinds of cellulytic or pectinolytic and other degradative enzymes to overcome tough and impervious outer covering of fruits, which acts as the first and the foremost effective external protective system, thus causing active invasion and active spoilage in fruits. The degradative enzyme list includes the following.

Pectinases

These enzymes depolymerize the pectin, which is a polymer of α-1,4-linked D-galactopyranosyluronic acid units interspersed with 1,2-linked rhamnopyranose units. On the basis of site and type of reaction on the pectin polymer, pectinases are of three main types, i.e., pectin methyl esterases produced by *Botrytis cinerea*, *Monilinia fructicola*, *Penicillum citrinum*, *and Erwinia cartovora* (Cheeson 1980); polygalacturonase; and pectin lyase.

Cellulases

Several types of cellulase enzymes attack the native cellulose and cleave the cross-linkage between β-D-glucose into

shorter chains. Cellulases contribute toward tissue softening and maceration as well as yield glucose, making it available to opportunistic microflora.

Proteases

These enzymes degrade the protein content of fresh produce, giving simpler units of polypeptides, i.e., amino acids. The action of proteases is limiting in fruit spoilage as fruits are not rich in proteins.

Phosphatidases

These enzymes cleave the phosphorylated compounds present in cell cytoplasm, and the energy released is utilized to cope with the increased respiration rates.

Dehydrogenases

These enzymes dehydrogenate the compounds, thus increasing the amount of reduced products that may lead to increased fermentation under microaerobic/anaerobic conditions.

Opportunistic Pathogens

These microorganisms lack the degradative enzymes and thus gain access only when the normal plant defense system weakens. For example, mechanical injury or cuticular damage caused by insect infestation or natural openings presents on the surface of the fresh produce. Thus, an opportunistic pathogen slips in through the damage caused by biotic and abiotic stresses on the produce and generally moves via natural gateways as the lenticels, stomata, hydathodes, or the other pores/lesions caused by insect infestation or invasion by true pathogens. Damage of the product during harvesting or by postharvest processing techniques and equipments enables opportunistic microflora to invade the internal unarmed tissue and cause spoilage.

Modes of Fruit Spoilage

Fruit spoilage occurs as a result of relatively strong interdependent abiotic and biotic stresses posed particularly during the postharvest handling of produce. Harvested fruits continue to respire by utilizing the stored available sugars and adjunct organic acids culminating in significant increase in stress-related/stress-induced carbon dioxide and ethylene production that leads to rapid senescence (Brecht 1995). Moreover, postharvest processing, which involves washing, rinsing, peeling, and other treatments, results in major protective epidermal tissue damage and disruption, which in turn leads to unsheathing of the vacuole-sequestered enzymes and related substrates and their amalgamation with the cytoplasmic contents. Cutting/dicing increases surface area and stress-induced ethylene production, which can accelerate water loss; the sugar availability enhances microbial growth (Wiley 1994, Watada and Qi 1999). The physiological state of fruit also determines the pattern of spoilage to be followed, as with increase in age/maturity, the normal defense tactics of the plant produce deteriorates. Harvested produce loses water by transpiration, thus gets dehydrated, followed by climacteric ripening and enzymatic discoloration of cut surfaces to senescence, thus increasing possibilities of damage by microflora. Harsh handling and ill-maintained equipment during processing lead to increased damage or removal of the outer cuticle, leading to tissue disruption that provokes stress-induced increased respiration and microbial decay (Gorny and Kader 1996). Spanier et al. (1998) reported the development of off-flavors in fresh-cut pineapple, which appeared undamaged physically, in lower portion of container kept at 4°C for 7–10 days. Walls and Chuyate (2000) reported survival of acid- and heat-tolerant *Alicyclobacillus acidoterrestris* that produces 2-methoxy phenol or guaiacol, imparting phenolic off-flavor in pasteurized orange and apple juices. Jay (1992) reported osmophilic yeasts to be associated primarily with the spoilage of cut fruits due to their ability to grow faster than the molds, and this usually includes the genera such as *Cryptococcus*, *Rhodotorula*, and *Saccharomyces* sp. in fresh fruits, and *Zygosaccharomyces rouxii*, *Hanseniaspora*, *Candida*, *Debaryomyces*, and *Pichia* sp. in dried fruits.

Thus, senescence and spoilage depend on product type, abiotic factors, and microbes involved in the deterioration process. A common approach is to name the spoilage type by symptomatological appearance, such as soft rot or black rot. However, this definitely results in discrepancy in ascertaining the causal pathogen of spoilage, and this ambiguity could be overruled by classifying on the basis of causal microbe such as *Rhizopus* rot, *Cladosporium* rot, etc.

METHODS TO EVALUATE MICROBIAL QUALITY

Food quality and safety are ensured by analysis of food for the presence of microbes, and such microbial analyses are routinely performed as quarantine/regulatory procedures. The methods employed for adjudging the quality of food include an array of microbiological to biochemical assays to ascertain the acceptability or unacceptability of a food product for human consumption or a processing/handling practice that needs to be followed. Thus, enumerating the microbial load of the produce could help in determining the quality as well as the related safety aspects of the product and the effectiveness of the processing technique employed to kill spoilage microbes.

Microbiological methods for pathogen identification primarily involve conventional cultural techniques of growing microbes on culture media and observing the ability to form

viable countable colonies showing characteristic growth on such media as well as the direct microscopic methods for various groups of microbes.

Hence, microbiological criteria are specifically employed to assess:

- Safety of food,
- Shelf life of perishable products,
- Suitability of food or ingredient for specific purpose,
- Adherence to general manufacturing practices.

The routine culturing techniques require longer time to obtain results. To overcome this hurdle, indicator organisms that provide rapid, simple, and reliable information without isolation and identification of specific pathogens are used. However, such tests can be used as presumptive test with the confirmation provided by a battery of biochemical tests and may include specialized serological typing (Swaminathan and Feng 1994). The microbiological techniques are summarized below.

Conventional Techniques

Direct Microscopic Count

This method involves the microscopic examination for evaluating the viable or nonviable microbes present in a given sample. The direct microscopic count ushers little value for the determination of microbiological status of a food sample as usually total cell counts exceed 10^5 CFU per g or mL of the sample. New variations of microscopes render the capability to predict the presence of pathogens clinging on surfaces of fruits or attached to internal surfaces. For example, confocal scanning laser microscopy has shown the presence of *E. coli* O157:H7 on surfaces and internal structures of apple (Burnett et al. 2000).

Drawbacks: This technique does indicate the type of bacteria present in a sample, and it does not differentiate between normal and pathogen-causing microorganisms.

Aerobic Plate Counts or Total Plate Counts

It is the most practical method to determine the presence of cultivatable microbes in a food sample. This technique, thus, reveals the total number of microbes in a food product under a particular set of incubation temperature, time, or culture media and can be used to preferentially screen out a specific group of microbes in a given set of conditions, thereby helping in determining the utility of food or food ingredient added for specific purpose. For example, psychrophilic microbes would be the predominant spoilage microflora for refrigerated fruit/fruit products. The aerobic plate counts (APC) of the refrigerated fruits/fruit products indicate utensil or equipment conditions prevailing during storage and distribution of the product.

Drawbacks: Though APC bacterial count is the most practical and easy technique, it suffers from the following inherent drawbacks :

- It provides the viable cell count that does not reflect the quality of raw material used for processing.
- It is unable to indicate the extent of quality loss at low count levels.
- It provides little information regarding organoleptic quality that is degraded at low counts.
- It requires scrupulous researcher to interpret APC results.

Certain variations to APC method are now available to classify according to the type of microbes as molds, yeasts, or thermophilic spore counts. These counts are basically used for microbiological analysis of the canned fruits/fruit products.

1. *Howard mold count*. This technique involves the enumeration of molds in products such as canned fruits.
2. *Yeasts and mold counts*. The high sugar products such as fruit drinks or fruit beverages are prone to contamination by yeasts and molds and thus enumeration of these microbes gives a presumptive glimpse of the microbiological status of these products. A similar kind of count involves the heat-resistant mold count providing the presence of molds such as *Aspergillus fischeri* and *Byssochlamys fulva* in heat-processed fruit products such as the fruit concentrates.
3. *Thermophilic spore count*. The technique advocates the presence of spore-forming bacteria as the major contaminants of canned fruits, pasteurized fruit juices, etc.

New Methods for Rapid Analysis

The physical characteristics of food can cause a nonuniform distribution of microbes and thus a (nonuniform) sample preparation may not provide consistent and reproducible microbiological data. The drawbacks of the conventional microbiological analysis criteria are as follows:

- Requirement of the selective or enrichment media for isolation of foodborne pathogen requires several days to provide results.
- Normal microflora can interfere with the isolation and identification of low infectious (dose and number) pathogens that may be sublethally injured during processing. These microorganisms can exist in a state of shock after vigorous heat/chemical/radiation treatments and require specific enriched culture media. Zhao and Doyle (2001) reported use of a universal preenrichment broth for growth of heat-injured pathogens in food.

Rapid methods shorten the assay time by a simple modification of conventional methods or may involve an array

of molecular assay formats and diverse technologies that are quite specific and more sensitive (Mermelstein et al. 2002). Some of the assays involved in the rapid enumeration of pathogens in foods are as follows.

Modification of Conventional Techniques

- *Miniaturized biochemical assays*: Biochemical test kits for identification of pure cultures of bacterial isolates deliver results in less than 1 day with 90–99% accuracy (Hartman et al. 1992).
- *Modified process/specialized media*: Petrifilms (Curiale et al. 1991) and hydrophobic grid membrane filters eliminate the need for media preparation, thus economizes storage and incubation space as well as simplifies disposal after analysis. Chromogenic [o-nitrophenyl-beta-D-galactopyranoside (ONPG)/5-bromo-4-chloro-3-indolyl-beta-D-galactopyranoside (X-gal)] or fluorogenic [4-methylumbelliferyl-beta-D-glucuronide (MUG)/glucuronidase enzyme (GUD)] substances provide quick measure of specific enzyme activities to ascertain presence of a specific microbe. A bioluminescence assay can provide quick assessment of direct live cell counts with sensitivity within a few minutes.

DNA-based Assays

A DNA-based probe has been developed for the detection of most foodborne pathogens, which detects the target gene sequence specific to a particular pathogenic microbe in a sample with unique sensitivity and reproducibility (Saiki et al. 1988, Lampel et al. 1992, Schaad et al. 1995, Feng et al. 1996, Guo et al. 2000). The DNA–DNA hybridization, DNA–RNA hybridization, and DNA–protein hybridizations are the types of DNA-based probing techniques.

DNA-based Polymerase Chain Reaction If the target DNA contains several targets, then polymerase chain reaction (PCR) assays can be used in a multiplex format that ensures the elimination of culturing steps (Jones and Bej 1994, Hill 1996, Chen and Griffiths 2001). PCR protocols can detect very small number or a few cells of particular pathogens and have been successfully developed for various fastidious/uncultivatable pathogens (Guo et al. 2000, 2002). DNA fingerprinting methods are the most recent for detection of pathogens in fresh produce, and a semi-automated fluorescent (amplified fragment length polymorphism or AFLP) technique for genomic typing of *E. coli* O157:H7 has been developed (Zhao et al. 2000). A report of occurrence of *Acidovorax avenae* subsp. *citrulli* in watermelon seeds has been provided by Walcott and Gitaitis (2000).

The DNA-based PCR techniques exhibit attributes like speed, high throughput, sensitivity, and reproducibility, which are prerequisite for accurate identification of pathogens present in very low amounts (Kalia and Gupta 2006). With the sequencing of the microbial genomes, novel specific sequences are now available for correct identification of pathogenic microbes from a variety of food samples (Alvarez 2004). Moreover, automation of the technique had resulted in analysis of several hundred of samples within a short period of time with near accurate reproducibility. The PCR techniques have another edge for better identification of microbes present in very low numbers or showing unculturable or fastidious culture behaviors for the identification of novel fruit spoilage or human pathogenic microbes from samples (Guo et al. 2002, Krtinic et al. 2010). The common DNA-based PCR assays for the identification of phytopathogenic as well as human pathogenic microbes from a fruit or fruit-based product include the rep-PCR, real-time or qPCR, multiplex PCR, 16s/23s r-DNA PCR followed by sequence comparison (phylogenetic typing), nested PCR, cooperational PCR, fluorescent AFLP (fAFLP), and more recent DNA microarray or DNA/biochip techniques. Microbes, particularly the bacteria, contain certain repetitive elements located in distinct, intergenic positions in both orientations all around the genome, including the 35–40 bp repetitive extragenic palindromic (REP) sequence, the 124–127 bp enterobacterial repetitive intergenic consensus (ERIC) sequence, and the 154 bp BOX element (Versalovic et al. 1994). Performing PCR of primers based on above sequences leads to the selective amplification of distinct genomic regions located between REP, ERIC, or BOX sequences to yield a characteristic fingerprint of the bacterial species (Janse 2010). Real-Time PCR is a technique that provides fast, precise, accurate, and highly sensitive detection of PCR amplification and kinetics of the reaction during the early log phase that allows for more accurate DNA/RNA quantitation without requirement of the laborious post-PCR methods like agarose gel electrophoresis. The 16s/23s r-DNA PCR is based on the principle of DNA amplification using universal primers designed on the basis of the sequence knowledge of the conservative regions of the small (16s) and large (23s) subunits ribosomal DNA followed by its sequence analysis and comparison for identification (Jeng et al. 2001). Nested PCR involves the use of two pairs of primers to amplify single locus-specific sequences of DNA from a large complex mixture of DNA and thus is useful in accurate amplification of the known DNA sequence for correct detection of particular microbes (Ma et al. 2003). The cooperative PCR, on the other hand, involves simultaneous annealing of three or four primers to the same target using one amplification round only without requiring two different annealing temperatures and provides highly sensitive detection of the RNA viral phytopathogens (Olmos et al. 2002, Caruso et al. 2003). The microarray or chip technologies allow to test the presence of a wide variety of microbes from a sample simultaneously, i.e., multiplex detection (Lopez et al. 2008).

Janse (2010) has described the benefits of utilization of several molecular tools with special mention of the PCR-based real-time PCR, rep-PCR, and fAFLP techniques for the detection and identification of plant pathogenic bacteria

of stone fruit, pistachio, and mango. Moore et al. (2002) have reported a novel gram-negative bacillary acetic acid bacteria that caused spoilage of fruit-flavored bottled water, which was sharing phenotypic and biochemical characters to that of *Pasturella* and could only be identified on basis of molecular identification using 16s r-DNA PCR followed by sequencing. The human pathogens exist in numbers much smaller to be detected by the conventional phenetic system (requiring morphological, biochemical, and functional characterization), and both DNA fingerprinting techniques using the arbitrary primer PCR like fAFLP as well as real-time PCR could be employed for rapid and accurate detection (Walcott and Gitaitis 2000, Schena et al. 2004, Vincente et al. 2009). Spotts et al. (2009) have reported the development of PCR primers based on sequencing of 581 bp intertranscribed spacer of r-RNA gene for qPCR that can not only identify but also quantify the number of biocontrol yeast cells present on the surfaces of various fruits.

Antibody-based Assays

These include the classical agglutination assays as well as the immunodiffusion techniques that are rather simple, quick, and useful methods for confirmation of microbial isolates from sample but possess low sensitivity. Hence, the new immunological protocols hail the use of enzyme-linked immuno sorbent assay scoring high sensitivity (Candish 1991) and immunoprecipitation techniques that provide the results within a few minutes as these are automated.

Other Techniques

These rather unconventional methods involve the use of immunomagnetic separations, chromatographic detection of certain organic acids produced by the pathogen during growth and recent techniques such as the flow cytometery for deciphering the survival and growth of human fecal–oral pathogens in raw produce. The magnetic separation technique is now being employed in both clinical and food microbiology (Olsvik et al. 1994, Bennett et al. 1996, Safarik and Safarikova 1999). Jung et al. (2003) have used immunomagnetic separation technique in conjunction with flow cytometery to detect the presence of *L. monocytogenes* in food.

Chromatography–Mass Spectrometry Techniques Besides PCR-based techniques, other methods including the identification of microbes by identifying volatile compounds, signature peptides, glycoproteins, glycan, etc., by chromatographic and mass spectrometry techniques are looked at. Bianchi et al. (2010) have reported application of gas chromatography–mass spectrometry of volatile compound profile for early detection of *Alicyclobacillus acidoterrestris* in spoiled juice. Another type of spectroscopic technique, the Fourier transform infrared spectroscopy, could be used to correctly identify the pure as well as mixed cultures of several spoilage-causing *Alicyclobacillus* spp. and human pathogenic *E. coli* microbes in fruit juice samples on the basis of unique spectral features of various components of the microbial cells (Al-Qadiri et al. 2006). Orr et al. (2000) have detected the presence of *Alicyclobacillus acidoterrestris* in apple juice by sensory and chromatographic analysis of compounds produced by bacteria.

Predictive Microbiology Predictive microbiology is a subdiscipline of microbiology dealing with development of models for predicting the responses of microbial populations with respect to environmental factors (Membre and Kubaczka 1998). The technique, though conceptualized in the late 1980s was resuscitated and gained momentum in the late 1990s, is now a foremost proactive technique among other HACCP protocols, which do not demand end point or end product estimation of microbiological quality and safety of food. It involves estimation of microbial numbers for useful predictions and analyses (McMeekin and Ross 2002). Predictive microbiology provides mathematical tools in the form of primary, secondary, and tertiary models to estimate the consequences of food handling and processing operations on growth, survival, and inactivation of microbes such as the foodborne pathogens (McMeekin et al. 2008) and thus help in describing the microbial behavior in order to prevent food spoilage and food-borne illnesses (Table 4.3). The technique has been used to predict the cell numbers of bacteria (Valdramidis et al. 2006), yeast (Tchango et al. 1997, Wang et al. 2004), fungi (Gibson and Hocking 1997), and viruses (Deboosere et al. 2010) in food matrices. Although the technique is versatile and proactive, it suffers from certain limitations due to the complexity encountered at two levels, i.e., complexity of the microbial behavior as well as of the food matrix. New models in system biology are available, which account for both the complexities and improves the quantitative predictions of microbial behavior in a particular sample by utilizing elaborate sequential structure-linked equations to provide graphical interface.

Biosensors A biosensor is a special sensor device that integrates a biological/biochemical element with a physiochemical transducer to produce an electronic signal proportional to a single analyte, which is conveyed to a detector. Thus, biosensor typically consists of three basic components, viz, bioreceptor (could be a microorganism, tissue, cell, organelle, cellular macromolecules like nucleic acid, i.e., DNA or RNA, enzyme, enzyme component, receptor, antibody, etc.), transducer (acts as an interface, measuring the physical change that occurs with the reaction at the bioreceptor, which is transformed into measurable electrical output and includes electrode, thermistor, photon counter, piezoelectric device, etc.), and the detector (a microprocessor that amplifies and analyzes the signals sent by transducer and transfers data to data displayer or storage unit and includes piezoelectric,

Table 4.3. Predictive Microbiological Methods for Detection of Spoilage and Contaminating Pathogenic Microbes in Different Food Materials

Fruit/Fruit Product	Microorganism	Cellular Entity	Remarks	References
Bacteria				
Raw vegetables and meat	*Clostridium botulinum, Clostridium perfringens, Bacillus subtilis*	Spores	Risk assessment is a valuable tool to justify the implementation of management options.	Augustin (2011)
Water	*Escherichia coli* K12 MG1655	Vegetative cells	Use of a dynamic microbial modeling approach for considering microbial adaptive responses is an important step toward avoiding process-induced adaptive responses, allowing pathogenic microorganisms to persist during storage of foods.	Valdramidis et al. (2006)
Vegetable juice	*Chryseomonas luteola*	Pectinolytic vegetative cells	Modified Ratkowsky model used to predict the interaction factors specific microbial growth, stability phase, and alteration percentage.	Membre and Kubaczka (1998)
Fungi				
Cold-filled ready-to-drink beverages	*Saccharomyces cerevisiae, Zygosaccharomyces bailii*, and *Candida lipolytica*	Vegetative cells	Predictive microbiological models showed the pH, sodium benzoate, and potassium sorbate concentrations to be significant factors controlling the probability of yeast growth.	Battey et al. (2002)
Apple cider	*Saccharomyces cerevisiae* strain CCTCC M201022	Vegetative cells	Nonlinear kinetic model predicted glucophilic nature of *Saccharomyces cerevisiae* strain CCTCC M201022 during an apple wine fermentation.	Wang et al. (2004)
Guava nectar	*Candida pelliculosa*	Vegetative cells and spores	A quadratic polynomial model used to predict the effects and interactions of pH and temperature.	Tchango et al. (1997)
Viruses				
Strawberry products	Hepatitis A virus (HAV)	Viral particles	Modeling approach using response surface methodology provides a rapid answer to heat resistance evaluation of a food-borne virus as a function of specific physical and chemical parameters of specific food products	Deboosere et al. (2004)
Red berries and acidified raspberries	Hepatitis A virus (HAV)	Viral particles	Excellent predictions were obtained in most cases, while failed predictions provided safe results, with the model predicting higher residual virus titers than what was observed.	Deboosere et al. (2010)

electrochemical, optical, and calorimetric detectors). A variety of biosensors could be developed by combining different types of three basic components. However, biosensors could be classified into five basic types on the basis of the type of detector: calorimetric, potentiometric, amperometric, optical, and acoustic wave biosensors. In food analysis, preservation, and processing industries, biosensors have elaborate applications as reviewed by a number of researchers (Milardovi et al. 2000, Prodromidis and Karayannis 2002, Valadez et al. 2009, Viswanathan et al. 2009). Bacteriophages have also

been used as tools for detecting pathogenic bacteria throughout the food chain (Garcia et al. 2009).

MAINTAINING MICROBIAL QUALITY OF FRUITS

Fruit variety, abiotic, or environmental factors such as soil type, temperature, frost, and rainy weather at harvest may adversely affect the storage life and quality of produce. Fresh produce, which has been stressed by too much or too little water, high rates of nitrogen application, or mechanical injury (scrapes, bruises, abrasions), is particularly susceptible to postharvest diseases. Mold decay on winter squash, caused by the fungus *Rhizoctonia*, results from the fruits lying on the ground, which can be alleviated by using mulch. A number of outbreaks of foodborne illnesses have been traced to contamination of produce in the field. Management practices such as unscrupulous picking and harsh handling of the fresh produce markedly affect the quality of fruits. Crops destined for storage should be as free as possible from skin breaks, bruises, spots, rots, decay, and other deterioration. Bruises and other mechanical damage not only affect appearance, but also provide entrance to the decay organisms as well. Postharvest rots are more prevalent in fruits that are bruised or damaged.

Postharvest and Storage Considerations

After harvesting, fresh produce is stored before shipment. This is a critical period for microbial decay and spoilage of produce. Storage temperature and water activity play an important role during this.

Temperature

Temperature is the single most important factor in maintaining fruit quality after harvest. Refrigerated storage retards the following elements of deterioration in perishable crops:

- Aging due to ripening, softening, and textural/color changes,
- Undesirable metabolic changes and respiratory heat production,
- Moisture loss/wilting,
- Spoilage due to invasion by bacteria/fungi/yeasts.

Refrigeration controls the respiration rate of crop, which is evil enough as this generates heat due to oxidation of sugars, fats, and proteins in the cells, resulting in loss of these stored food reserves, leading to decreased food value, loss of flavor, loss of saleable weight, and more rapid deterioration. Sharma et al. (2001) have provided the insight about the fate of *Salmonellae* in calcium-supplemented orange juice at refrigeration temperature. Since the respiration rate of fruits strongly determines their transit and postharvest life, a constant cold temperature maintained over a span of storage period decreases the deterioration; however, the produce has to be precooled to relieve the field heat by room cooling, forced air cooling, vacuum cooling, hydrocooling, and top or ice cooling.

However, during refrigerated storage, certain fruits having higher water content can undergo chilling injury, but store best at 45–55°F. The effect of chilling injury may be cumulative in some crops with the appearance of chilling symptoms becoming evident as pitting or other skin blemishes, internal discoloration, or failure to ripen. Fruits such as muskmelons, peppers, winter squash, tomatoes, and watermelons are moderately sensitive to chilling injury; however, if tomatoes, squash, and peppers are overchilled, then they may particularly become more susceptible to decay by fungal genera such as by *Alternaria*.

Water Activity

Transpiration rates are determined by the moisture content of the air, which is usually expressed as RH. Water loss at low RH values can severely degrade quality, since sugar-rich perishable fruits such as grapes may break loose from clusters due to drying out of their stems and this would decrease the aesthetic value of the product as well as saleable weight loss, culminating in reduced profits. Thus, the RH of the storage unit directly influences water loss in fresh produce. Most fruit and vegetable crops retain better quality at higher RH (80–95%), maintaining saleable weight, appearance, nutritional quality and flavor, and reduction in wilting, softening, and juiciness, but it encourages disease growth. This situation can be overruled by storage at cool temperatures, but stringent sanitary preventative protocols have to be enforced. Unfortunately, refrigeration inevitably extracts moisture from fruit surfaces, thus necessitating the use of proper packaging.

Control of Respiration and Ethylene Production

Ethylene, a natural phytohormone, produced by some fruits upon ripening promotes additional ripening of produce exposed to it (Gorny et al. 1999). Damaged or diseased apples produce high levels of ethylene and stimulate the other apples to ripen too quickly, making them more susceptible to diseases. Ethylene "producers" such as apple, apricot, avocado, ripening banana, cantaloupe, honeydew melon, ripe kiwifruit, nectarine, papaya, passion fruit, peach, pear, persimmon, plantain, plum, prune, quince, and tomato show decreased quality and reduced shelf life with appearance of specific symptoms of injury (Gorny et al. 2000, 2002). Respiration-induced ethylene production causes the following:

- Softening and development of off-flavor in watermelons,
- Increased ripening and softening of mature green tomatoes,
- Shattering of raspberries and blackberries.

Packaging

This process is crucial in preventing contamination by microbes as it restricts the inward movement of light and air, thus keeping produce dry/moist, and this prevents any changes in the textural integrity of produce along with convenient division of the produce in suitable portions needed for transportation, handling, and sale.

Application of Biocontrol Agents

The major percentage of postharvest fruit decay caused by the microbial pathogens of stored fruits is primarily by the multicellular fungi, which are controlled by treatment of fruits with synthetic fungicides (Sharma et al. 2009). However, with the evolution of resistant strains and species of contaminating fruit pathogens as well as growing concern for the avoidance of application of pesticides, either the use of obsolete physical and chemical processes of microbial eradication have to be revised or fresh, environmentally benign alternatives like use of biological control agents have to be searched for (Mari et al. 2007). The pH and other biochemical properties of fruits are helpful in maintaining a wide diversity of inoculated microflora (biocontrol, opportunistic, or pathogenic microflora). Several microbes have been reported to act as potential postharvest microbial control agents that decrease or even eliminate the postharvest decay of fruits by antagonism, either active, i.e., curbing the growth of other microbial pathogens due to secretion of antimicrobial compounds like antibiotics, cell wall degrading enzymes, and induction of host resistance, or passive, i.e., by competing for space and nutrition with pathogens (Janisiewicz and Korsten 2002, Chan and Tian 2005, Sharma et al. 2009).

A report by Xu et al. (2008) showed the biocontrol potential of a variety of yeasts genera (*Pichia membranaefaciens, Candida guilliermondii, Cryptococcus laurentii,* and *Rhodotorula glutinis*). They reported control of postharvest decay of peach fruits by spraying cultures of above yeast genera by regulation of the protein carbonylation levels and also mitigation of the oxidative damage induced by fungal pathogen *Monilinia fructicola*. Spotts et al. (2009) reported biocontrol action of naturally occurring saprophytic yeast *Cystofilobasidium infirmominiatum* to control a variety of postharvest crop/pathogen systems, including gray mold, side rot, mucor rot, blue mold, and bull's-eye rot of pear (Chand-Goyal and Spotts 1997, Gholamnejad et al. 2010, Pimenta et al. 2010). The effectiveness of biological control yeasts is closely related to the concentration of yeast cells in the treatment suspension (Fan and Tian 2001, He et al. 2003, Spotts et al. 2009). The fruit's outer surface comprises cutin, a plant cuticle that is chemically a rigid lipid meshwork polymer formed by embedding of esterified hydroxyl fatty acids in a layer of wax. The compositional differences in the type of fatty acids and the waxes considerably alter the physical and chemical properties and thereby the surface interaction properties like adhesiveness to and removal of materials from the fruit surfaces, among different fruits (Pierzynowska-Korniak et al. 2002). Moreover, the epicuticular wax quantities and uniformity of thickness of the cutin coating also significantly affect the surface toughness provided for the absorption of inoculated/contaminating microbes on surface (Spotts et al. 2009).

FRUIT SAFETY

Several incidences of transmission of infection by consumption of raw fruits and vegetables have been documented, such as *Salmonella typhi* infection by consuming a variety of fresh products (Pixley 1913, Sanchez et al. 2002), *Salmonella* and *E. coli* in fruit juices, as well as certain parasitic helminths primarily *Fasciola hepatica* and *Fasciolopsis buski* have been observed to encyst on plants and cause human illnesses. Recently, viruses following the fecal–oral route as hepatitis A virus and Norwalk disease virus have been observed to be associated with consumption of raw fruits such as raspberries, strawberries, and melons.

Associated Pathogens and Sources of Contamination

Bacteria such as *Clostridium botulinum*, *Bacillus cereus*, and *L. monocytogenes* are normal inhabitants of soil, whereas *Salmonella*, *Shigella*, *E. coli*, and *Campylobacter* are resident microflora of the rumen of ruminant animals and stomachs of human beings, which can potentially contaminate raw fruits and vegetables through contact with feces, sewage, untreated irrigation water, or surface water, while viruses of the fecal–oral route and parasites in form of cysts of liver flukes, tapeworms, and *Giaradia lamblia* contaminate produce by contact with sewage, feces, and irrigation water (Mead et al. 1999, King et al. 2000, Buck et al. 2003). Food pathogens such as *Clostridium*, *Yersinia*, and *Listeria* can potentially develop on minimally processed fruits and vegetables under refrigerated or high-moisture conditions (Doyle 2000a, 2000b, 2000c, Meng and Doyle 2002). Beuchat (2002) has reviewed several ecological factors that influence the growth and survival of human pathogens in raw fruits and vegetables.

Microbiology Safety Issues and HACCP

There is a need for setting standards defining the best microbiological quality of the product on sale counters (FDA 2000). The food safety issues have resulted in identification of certain critical control points that can be easily modulated to reduce or eliminate the risks of physical, chemical, or biological hazards. This approach has been based on utilizing the preventive measures to decrease or eliminate

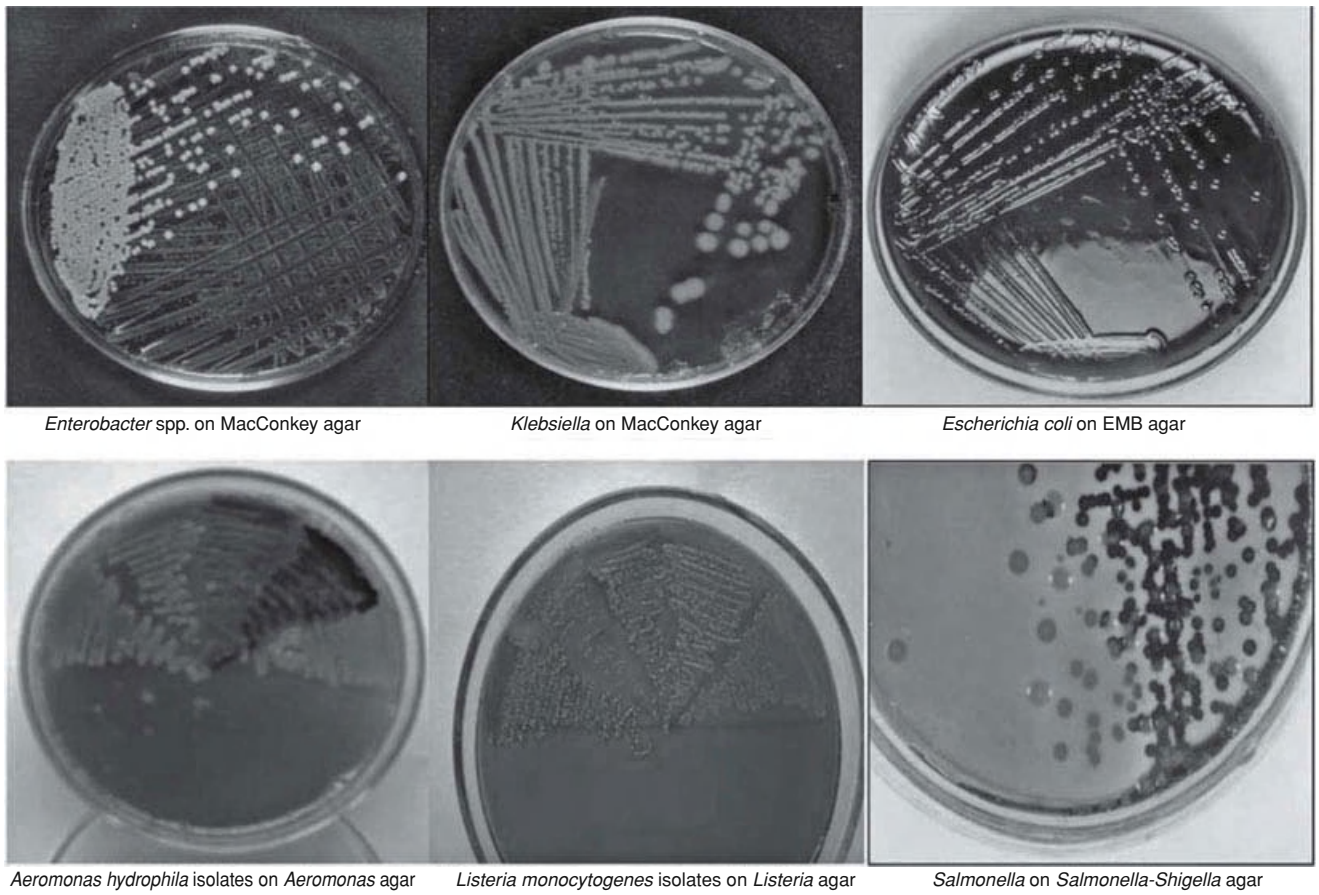

Figure 4.1. Colonies of several human pathogenic bacterial isolates on solid agar-based media isolated from fruits or fruit products.

growth of spoilage or foodborne pathogens in foods. The fresh-cut or minimally processed fruit industry requires the stringent implementation of this approach though it is being used voluntarily in this sector in spite of mandatory HACCP programs for fruit juice industry by FDA. The whole raw fruits, diced/sliced/skinned/shredded or minimally processed fruit products and unpasteurized fruit juices have been associated predominately with millions of cases of foodborne illnesses annually, particularly the gastrointestinal illnesses of bacterial etiology followed by protozoal parasite-caused outbreaks. Varzakas and Arvanitoyannis (2007) have compared the HACCP protocols with the new Food Safety Management System termed ISO22000 and concluded that the ISO22000 is more flexible due to introduction of less number of CCP in comparison to HACCP and thus provides rapid prediction of microbial growth behaviors. Tapia et al. (2009) have reviewed the implementation of HACCP strategies for production of safe fresh-cut fruits and vegetables in particular.

HEALTH IMPLICATIONS

Human pathogens such as enteric bacteria (Fig. 4.1) and viruses cause illnesses exhibiting initial symptoms such as diarrhea, nausea, vomiting, altered peristaltic movement of the intestine, fever that may debilitate patient's health and could aggravate toward certain advanced complications, or group of ailments/syndrome sometimes resulting in death of vulnerable age/immunocompromised patients.

E. coli: *E. coli* O157:H7 causes abdominal cramps and watery diarrhea/bloody diarrhea (hemorrhagic colitis) along with fever and vomiting and the incidence recovery within 10 days. However, infection of *E. coli* O157:H7 in young children and elderly patients results in life-threatening complications such as hemolytic uremic syndrome (HUS), which is characterized by acute renal failure, hemolytic anemia, and thrombocytopenia.

Salmonella enteritidis/*Salmonella typhimurium*: The symptoms share the similarity to *E. coli* infection along with

abdominal pain and cholera-like disease and subside within 2–4 days or may result in prolonged enteritis with passage of mucus and pus in feces and typhoidal speticaemic fever.

Shigella sp.: This bacterium causes shigellosis/bacillary dysentery upon ingestion at very less infective dose by forming shiga toxin and produces inflammation of intestine, capillary thrombosis leading to transverse ulceration, or bacteremia manifested as bloody, mucoid scanty feces with tenesmus, fever, and vomiting. HUS may also appear as a rare complication in certain cases.

FUTURE PERSPECTIVES

The future era in fruit microbiology connotes the advent of fully automatized packaging, detection, and status analyzers. Tailor-made packaging, particularly the bioactive packaging and film coatings, would help extend the shelf life of minimally processed fruits. A novel bioactive packaging module is the use of bacteriophages (Listex™ P100 to combat *Listeria* in fruit juices (EBI press release 2010)) to control growth of specific pathogenic microbes though the commercialization is a real challenge (Greer 2005, Strauch et al. 2007, Garcia et al. 2008, Guenther et al. 2009, Coffey et al. 2010, Heringa et al. 2010).

Novel rapid pathogen identification (cfu or PCR-based) methods have ensured detection of pathogenic microbes in variety of fruits/fruit products (Kalia and Gupta 2006) though new candidates are emerging such as use of phages (Garcia et al. 2009). Nanosensors are more recent, sensitive, and portable alternatives for rapid detection of microbial pathogens *in vivo* though there is little commercial success, considering the release/intimate interaction of the nanomaterial with the product (Bosoon et al. 2007, Sozer and Kokini 2008). Innovative and intelligent packaging materials can fulfill the existing gap in knowledge and safety regulation criteria. The role of fruit microbiology is expected to expand with commercialization of new preservation and processing techniques.

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5
Nutritional Quality of Fruits

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Abstract: A nutrient is defined as a substance obtained from food and used in the body to promote growth, maintenance, and repair of body tissues, or simply as a substance that provides nourishment. Nutrients are classified into two groups, namely, macronutrients (also called energy-producing nutrients or energy-yielding nutrients) and micronutrients (which are characterized by their essentiality for human health and the low quantities in which they need to be ingested). Energy-producing nutrients include carbohydrates, fats, and proteins. Micronutrients often refer to vitamins and minerals. Phytochemicals, also called bioactive compounds, are substances present in foods in low levels that may have a role in health maintenance in humans. Fruits have proved to be essential for a balanced diet. This is believed to be mainly due to their content of vitamins, fiber, and phytochemicals, the last being responsible in part for the antioxidant properties of fruits and foods of fruit origin. Manufacturing processes can modify the nutritional properties of some foods. This chapter reviews the content and nutritional recommendations for micronutrients, macronutrients, and bioactive compounds present in fruits and how the different processing methods used in the food industry may modify their contents, structure, and biological activity in humans.

INTRODUCTION

Nutrients are critical for our life and health. Derived from foods, they are essential for growth, maintenance, and restoration of body tissues. Broadly speaking, nutrients are classified into two groups, namely, macronutrients (also called energy-producing nutrients or calorie-providing nutrients) and micronutrients (which are essential for our health and are needed in low quantities for various body functions). The energy-producing macronutrients are carbohydrates, fats, and proteins. Water is a non-energy-producing macronutrient. The micronutrients are water- and fat-soluble vitamins and minerals.

Phytochemicals, also called bioactive compounds, are substances present in foods in low levels, have emerged important as natural antioxidants for minimizing the risk of various degenerative diseases including heart disease, cancer, and aging.

Fruits are essential for a balanced diet as they are natural sources of various vitamins, minerals, fibers, and phytochemicals, the last being responsible in part for the antioxidant properties of fruits and foods of plant origin.

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Manufacturing processes can affect nutritional properties of some foods. For instance, partial hydrogenation of vegetable oil results in the formation of *trans*-fatty acids, and heat treatment of protein solutions in an alkali environment results in the formation of lysinoalanine. Both of these have been shown to have detrimental health effects. On the other hand, some nutrients and bioactive compounds, which are naturally present in fruits, may undergo transformations during food processing that decreases neither their nutritional value nor bioactive value but may increase it by favoring their absorption and metabolism in the human body.

In general, vitamins, minerals, water, and fibers are considered to be the main nutrients contributed by fruits to a balanced diet, and thus, special attention is given to this group of nutrients (Villarino-Rodríguez et al. 2003).

In this chapter, we review the contribution of fruits to human nutrition. We also discuss the effect of processing on nutrients in fruits.

MACRONUTRIENTS

Water

As a nutrient that does not contribute to any calorie in our diet, water has two central roles: (1) protective and regulatory function—by being a substrate of biological reactions or acting as the matrix or vehicle in which these reactions take place—and (2) an essential function as the temperature and pH regulator in our body. Water also has a plastic function through the maintenance of the cell and tissue integrity. Approximately two-thirds of the human body is composed of water, and in general, the higher the metabolic activity of a given tissue, the higher its percentage of water.

Most of the body water is found within three body compartments: (1) intracellular fluid, which contains approximately 70% water; (2) extracellular fluid, which is the interstitial fluid; and (3) blood plasma. The last two compartments contain approximately 27% water. The body controls the amount of water in each compartment by controlling the ion concentrations in those compartments. Therefore, gains or losses of electrolytes are usually followed by shifts of fluid to restore osmotic equilibrium.

Although a low intake of water has been associated with some chronic diseases, this evidence is insufficient to establish water intake recommendations. Instead, an adequate intake of water has been set by the Food and Nutrition Board of the Institute of Medicine in the United States, to prevent deleterious effects of dehydration. This adequate intake of total water is 3.7 liters (L) for men and 2.7 L for women. Fluids should represent 81% of the total intake, and water contained in foods represents the other 19% (IM 2004).

The body has three sources of water: (1) ingested water and beverages, including fruit juices; (2) the water content of solid foods; and (3) metabolic water. Fruits have a high percentage of water that ranges from 70% to 95% of its composition (Table 5.1). For this reason, they are, together with vegetables, a very good source of water in the diet within the solid foods. The content of water in a fruit may be greatly affected by the processing, and in fact, some technologies used to increase the shelf life of fruits do so through the reduction of their water content. It is important to bear in mind that the water content of a fruit also changes during maturation; therefore, the optimum degree of maturation of a fruit for a given processing technology may be different than for another processing technology. This will also affect the water content in the final product.

Table 5.1. Fruit Composition (Grams per 100 g of Edible Portion)

Fruit	Water	Carbohydrates	Protein	Fat	Fiber
Apple	86	12.0	0.3	T_r	2.0
Apricot	88	9.5	0.8	T_r	2.1
Avocado	79	5.9	1.5	12	1.8
Banana	75	20.0	1.2	0.3	3.4
Cherry	80	17.0	1.3	0.3	1.2
Grape	82	16.1	0.6	T_r	0.9
Guava	82	15.7	1.1	0.4	5.3
Kiwi fruit	84	9.1	1.0	0.4	2.1
Mango	84	15.0	0.6	0.2	1.0
Melon	92	6.0	0.1	T_r	1.0
Orange	87	10.6	1.0	T_r	1.8
Papaya	89	9.8	0.6	0.1	1.8
Peach	89	9.0	0.6	T_r	1.4
Pear	86	11.5	0.3	T_r	2.1
Pineapple	84	12.0	1.2	T_r	1.2
Plum	84	9.6	0.8	T_r	2.2
Raspberry	86	11.9	1.2	0.6	6.5
Strawberry	91	5.1	0.7	0.3	2.2
Watermelon	93	8.0	1.0	T_r	0.6

Source: Moreiras et al. (2001).

Carbohydrates

Energy is required for all body processes, growth, and physical activity. Carbohydrates are the main source of energy in the human diet, contributing to 4 kcal/g. The energy produced from carbohydrate metabolism may be used directly to cover the immediate energy needs or be transformed into an energy deposit in the body in the form of fat. Carbohydrates also have a regulatory function, for instance, by selecting the microflora present in the intestines. Fructose has been known to increase plasma urate levels due to rapid fructokinase-mediated metabolism to fructose 1-phosphate. This increase in plasma urate levels is reported to cause an increase in plasma antioxidant capacity in humans (Lotito and Frei 2004).

In general, the carbohydrates are classified into three groups: (1) monosaccharides, (2) oligosaccharides, and (3)

Table 5.2. Sugar Contents of Fruits (Grams per 100 g of Edible Portion)

Fruit	Fructose	Glucose	Sucrose	Maltose	Total Sugar
Apple	5.6	1.8	2.6	–	10.0
Apricot	0.4	1.9	4.4	–	6.7
Avocado	0.1	0.1	–	–	0.2
Banana	2.9	2.4	5.9	–	11.3
Cherry	6.1	5.5	–	–	11.6
Grapefruit	1.6	1.5	2.3	0.1	5.7
Grape	6.7	6.0	0.0	0.0	12.9
Mango	3.8	0.6	8.2	–	12.7
Orange	2.0	1.8	4.4	–	8.3
Peach	4.0	4.5	0.2	–	8.7
Pear	5.3	4.2	1.2	–	10.7
Plum	3.2	5.1	0.1	0.1	8.6
Strawberry	2.3	2.6	1.3	–	6.2
Watermelon	2.7	0.6	2.8	–	6.2

Source: Belitz and Grosch (1997) and Li et al. (2002).

polysaccharides. Monosaccharides include pentoses (arabinose, xylose, and ribose) and hexoses (glucose, fructose, and galactose). Oligosaccharides are sucrose, maltose, lactose, raffinose, and stachyose. Polysaccharides include starch (composed of amylose and amylopectin, both polymers of glucose), glycogen, and other polysaccharides, which form part of fiber reviewed in the following section.

Carbohydrates should represent 45–65% of the total energy consumed per day (IM 2002). After water, carbohydrates are the main component of fruits and vegetables and represent more than 90% of their dry matter. The main monosaccharides are glucose and fructose. Their concentration may vary depending on the degree of maturation of the fruit. The relative abundance of glucose and fructose also changes from one fruit to another (Table 5.2). For instance, in peaches, plums, and apricots, there is more glucose than fructose and the opposite occurs in the case of apples or pears. Other monosaccharides, such as galactose, arabinose, and xylose, are present in nominal amounts in some fruits, especially orange, lemon, or grapefruit. Fruits such as plums, pears, and cherries also contain the sugar alcohol sorbitol, which acts as a laxative because of osmotic transfer of water into the bowel.

Sucrose is the most abundant oligosaccharide in fruits; however, there are others such as maltose, melibiose, raffinose, or stachyose that have been described in grapes, and 1-kestose in bananas. Other oligosaccharides are rare in fruits. Starch is present in very low amounts in fruits, since its concentration decreases during maturation. The only exception is banana that may have concentrations of starch higher than 3% (Belitz and Grosch 1997).

During food processing, carbohydrates are mainly involved in two kinds of reactions: (1) on heating, they darken in color or caramelize and (2) some of them combine with proteins to give dark colors known as the browning reaction.

Fiber

Fiber is a generic term that includes those plant constituents that are resistant to digestion by secretions of the human gastrointestinal tract. The role of fiber in human health is mainly protective against disease, for example, diseases of the gastrointestinal tract, circulation-related diseases, and metabolic diseases (Saura-Calixto 1987). Dietary fiber may be classified as water-soluble fiber and insoluble fiber. Gums, mucilages, some hemicelluloses, and pectins are part of the soluble fiber. Celluloses, hemicelluloses, and lignins are insoluble fibers. Fruits are good sources of both classes of fibers, especially soluble fiber.

There are several fiber-associated substances that are found in fruit fiber, which may have some nutritional interest. Among them are phytates, saponins, tannins, lectins, and enzyme inhibitors. Saponins, which are mainly present in some tropical fruits, may enhance the binding of bile acids to fiber and reduce cholesterol absorption. Tannins are polyphenolic compounds widely distributed in fruits, which can bind proteins and metals and reduce their absorption. Lectins, which are present in bananas and some berries, are glycoproteins that can bind specific sugars and affect the absorption of other nutrients.

The recommended dietary allowance (RDA) for fiber is 25–30 g/day, depending on age and sex, except in the case of children from 1 to 3 years, in which case it is 19 g/day.

Dietary fiber is present in fruits in amounts that may be as high as 7% of the eatable part of the fruit (Table 5.1). Within fiber, the most common components in fruits are celluloses, hemicelluloses, and pectins. Pectins are important in processing, since they may be modified, and this modification not only has an influence on the nutritional value of the final food but also has an impact on the texture and palatability of the product.

Fats

Fat has three important roles as a nutrient. (1) It is a highly concentrated source of energy, giving 9 kcal/g. (2) It serves as a carrier for fat-soluble vitamins; some fatty acids that are essential nutrients can only be obtained from ingested fat. (3) It also serves as a carrier for some of the bioactive compounds present in fruits such as phytoestrogens and carotenoids that are lypophylic.

Fatty acids are part of triglycerides, which are the principal form in which fat occurs. Fatty acids are needed to form cell structures and to act as precursors of prostaglandins. Fatty acids may occur naturally with various chain lengths and different numbers of double bonds. They may be saturated (butyric, caproic, caprylic, capric, lauric, palmitic, stearic, and myristic acids), monounsaturated (oleic and palmitoleic acid), and polyunsaturated (linoleic, linolenic, and arachidonic acids) also known as polyunsaturated fatty acids (PUFAs). Linoleic and linolenic acids cannot be synthesized

in the body and are known as essential fatty acids. They are needed to build and repair cell structures, such as the cell wall and, notably, tissues in the central nervous system, and to form the raw material for prostaglandin production. Inflammatory and other chronic diseases are noted for exhibiting a deficiency of PUFAs in the bloodstream. Fatty acids that contain double carbon bonds can exist in either of two geometrically isomeric forms: *cis* and *trans*. *trans*-Fatty acids are produced in the hydrogenation process in the food industry and may play a role in atherosclerotic vascular disease (Sardesai 1998).

In general, fat should represent between 20% and 35% of the total energy consumed per day in order to reduce risk of chronic disease while providing intakes of essential nutrients.

Fat content in fruits is in general very low (Table 5.1). However, in cherimoya (1%) and avocado (12–16%), the lipid levels are higher. In avocado, the most abundant fatty acids are palmitic, palmitoleic, stearic, oleic, linoleic, and linolenic acids, but the amounts may vary with the variety, maturity, processing, and storage conditions (Ansorena-Artieda 2000).

Proteins

Proteins are a source of amino acids (AA) (some of which are essential because the human body cannot synthesize them) in our diet and provide 4 kcal/g. There are 20 amino acids that are part of the structure of proteins, almost half of these amino acids are considered as essential amino acids, including isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The RDA for proteins is 34–56 g/day, depending on age and sex, and in the case of pregnancy and lactation, it is 71 g/day. With respect to the total energy consumed per day, proteins should represent 10–35%.

Proteins are essential structural components of all cells and are needed by the human body to build and repair tissues, for the synthesis of enzymes, hormones, and others. They are also involved in the immune system, coagulation, etc. Therefore, proteins play both regulatory and plastic roles in the human body.

Proteins are made up of a long chain of AAs, sometimes modified by the addition of heme, sugars, or phosphates. Proteins have primary, secondary, tertiary, and quaternary structures, all of which may be essential for the protein to be active. The primary structure of a protein is its AA sequence and the disulfide bridges, that is, all covalent connections in a protein. The secondary structure is a small part, spatially near in the linear sequence of a protein, folds up into α-helix or β-pleated sheets. The tertiary structure is the way the secondary structures fold onto themselves to form a protein or a subunit of a more complex protein. The quaternary structure is the arrangement of polypeptide subunits within complex proteins made up of two or more subunits, sometimes associated with nonprotein groups. Food processing may affect these four structures, thus modifying the activity of the protein and also its nutritional value. AAs and proteins containing lysine or arginine as their terminal AAs are involved in the Maillard reactions that have a nutritional and sensory impact on processed foods.

Nitrogenated compounds are present in fruits in low percentages (0.1–1.5%). From a quantitative point of view, fruits are not a good source of proteins; however, in general, berries are a better source than the rest of the fruits. Cherimoya and avocado present higher levels of proteins than other fruits (Torija-Isasa and Cámara-Hurtado 1999).

There are some free AAs that may be characteristic of a certain fruit. This is the case of proline, which is characteristic of oranges but not in strawberries or bananas.

MICRONUTRIENTS

Vitamins

Thirteen vitamins have been discovered to date, each vitamin has a specific function. Vitamins must be supplied in adequate amounts in order to achieve maximum health benefit.

Vitamin C

Antioxidants have important roles in cell function and have been implicated in processes that have their origins in oxidative stress, including vascular processes, inflammatory damage, and cancer. L-Ascorbic acid (L-AA, vitamin C, ascorbate) is the most effective and least toxic antioxidant. Vitamin C may also contribute to the maintenance of a healthy vasculature and to a reduction in atherogenesis through the regulation of collagen synthesis, prostacyclin production, and nitric oxide (Davey et al. 2000; Sánchez-Moreno et al. 2003a, 2003b). The second US National Health and Nutrition Examination Survey indicated that a low intake of vitamin C is associated with blood concentrations of vitamin C = 0.3 mg/dL, whereas blood concentrations in well-nourished persons fluctuate between 0.8 and 1.3 mg/dL. An increase in intake of vitamin C is associated with health status (Simon et al. 2001).

Vitamin C is an essential nutrient for humans; unlike most mammals, we cannot synthesize vitamin C, and therefore, must acquire it from foods and supplements. For adults, dietary needs are met by a minimum intake of 60 mg/day. However, the preventative functions of vitamin C in aging-related diseases provide compelling arguments for an increase in dietary intakes and RDAs. Men and women who consumed four daily vegetable and fruit servings had mean vitamin C intakes of 75 and 77 mg, respectively. Men and women who consumed five daily vegetable and fruit servings averaged 87 and 90 mg vitamin C, respectively (Taylor et al. 2000).

The primary contributors to daily vitamin intake are fruit juices (21% of total), whereas all fruits together contributed nearly 45% of total vitamin C intake. Relatively high amounts of vitamin C are found in strawberries and citrus fruits,

although the availability of vitamin C within these food sources will be influenced by numerous factors. Virtually all of the vitamin C in Western diets is derived from fruits and vegetables. In general, fruits tend to be the best food sources of the vitamin. Particularly rich sources of vitamin C are blackcurrant (200 mg/100 g), strawberry (60 mg/100 g), and citrus fruits (30–50 mg/100 g). Not all fruits contain such levels, and apples, pears, and plums represent only a very modest source of vitamin C (3–5 mg/100 g). However, much fruit is eaten raw and the low pH of fruits stabilizes the vitamin during storage (Davey et al. 2000).

A summary of the average vitamin C content of certain fruits (mg per 100 g of edible portion) is given in Table 5.3.

Vitamin E

Vitamin E is the generic term for a family of related compounds known as tocopherols and tocotrienols. Naturally occurring structures include four tocopherols (α-, β-, γ-, and δ-) and four tocotrienols (α-, β-, γ-, and δ-). Of the eight naturally occurring forms of α-tocopherol (*RRR*-, *RSR*-, *RRS*-, *RSS*-, *SRR*-, *SSR*-, *SRS*-, and *SSS*-), only one form, *RRR*-α-tocopherol, is maintained in human plasma and, therefore, is the active form of vitamin E (Trumbo et al. 2003).

α-Tocopherol is the predominant tocopherol form found naturally in foods, except in vegetable oils and nuts, which may contain high proportions of γ-tocopherol (Bramley et al. 2000).

The vitamin E activity of tocopherols is calculated in international units (IUs), with 1 IU defined as the biological activity of 1 mg *all-rac*-α-tocopheryl acetate. Recently, the US National Research Council has suggested that vitamin E activity could be expressed as *RRR*-α-tocopherol equivalents (α-TE). One α-TE is defined as the biological activity of 1 mg *RRR*-α-tocopherol. One IU is equal to 0.67 α-TE (Brigelius-Flohé et al. 2002).

Recent research indicated the role of vitamin E in reducing the risk of developing degenerative disease. This role is suggested on the hypothesis that preventing free radical-mediated tissue damage (e.g., to cellular lipids, proteins, or deoxyribonucleic acid (DNA)) may play a key role in delaying the pathogenesis of a variety of degenerative diseases (Bramley et al. 2000; Sánchez-Moreno et al. 2003b).

There is some controversy about the optimum range of vitamin E intake for health benefits. Some authors recommend intakes of 130–150 IU/day or about ten times the US Food and Nutritional Board (15 mg/day) on the basis of the protection in relation to cardiovascular disease. Other authors indicate that the optimal plasma α-tocopherol concentration for protection against cardiovascular disease and cancer is >30 mmol/L at common plasma lipid concentrations. A daily dietary intake of only about 15–30 mg α-tocopherol would be sufficient to maintain this plasma level, an amount that could be obtained from the diet (Bramley et al. 2000).

The richest sources of vitamin E are vegetable oils and the products made from them, followed by bread and bakery products and nuts. Vegetables and fruits contain little amount of vitamin E (Bramley et al. 2000).

Table 5.3 shows the range of (mg per 100 g of edible portion) of vitamin E (α-tocopherol) from certain fruits.

Table 5.3. Vitamin Content of Fruits (Value per 100 g of Edible Portion)

Fruit	Vitamin C (mg)	Vitamin E (mg) (α-Tocopherol)	Vitamin A (μg RAE)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Pyridoxine (mg)	Folate (μg)
Apple	4.6	0.18	3	0.017	0.026	0.091	0.041	3
Apricot	10.0	0.89	96	0.030	0.040	0.600	0.054	9
Avocado	10.0	2.07	7	0.067	0.130	1.738	0.257	58
Banana	8.7	0.10	3	0.031	0.073	0.665	0.367	20
Cherry	7.0	0.07	3	0.027	0.033	0.154	0.049	4
Grape	10.8	0.19	3	0.069	0.070	0.188	0.086	2
Guava	183.5	0.73	31	0.050	0.050	1.200	0.143	14
Kiwi fruit	75.0	–	9	0.020	0.050	0.500	–	–
Orange	53.2	0.18	11	0.087	0.040	0.282	0.060	30
Papaya	61.8	0.73	55	0.027	0.032	0.338	0.019	38
Passion fruit	30.0	0.02	64	0.000	0.130	1.500	0.100	14
Peach	6.6	0.73	16	0.024	0.031	0.806	0.025	4
Pear	4.2	0.12	1	0.012	0.025	0.157	0.028	7
Pineapple	36.2	0.02	3	0.079	0.031	0.489	0.110	15
Plum	9.5	0.26	17	0.028	0.026	0.417	0.029	5
Raspberry	26.2	0.87	2	0.032	0.038	0.598	0.055	21
Strawberry	58.8	0.29	1	0.024	0.022	0.386	0.047	24

Source: USDA (2004).
RAE, retinol activity equivalents.

Vitamin B1, B2, B3, B6, Folate

Thiamin (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), and pyridoxine (vitamin B6) are used as coenzymes in the body. They participate in the metabolism of fats, carbohydrates, and proteins. They are important for the structure and function of the nervous system (IM 1998; ASNS 2004; Lukaski 2004).

Thiamin diphosphate is the active form of thiamin. It serves as a cofactor for several enzymes involved in carbohydrate catabolism. Thiamin requirement depends on energy intake, thus the suggested RDA is 0.5 mg/1000 kcal.

Riboflavin is required for oxidative energy production. Because riboflavin is found in a variety of foods, either from animal or vegetable origin, riboflavin deficiency is uncommon in Western countries. Recommendations for riboflavin intake are based on energy intake. It is suggested that an intake of 0.6 mg/1000 kcal will meet the needs of most of the healthy adults. The current RDA is 1.2 mg/day.

Niacin (nicotinic acid and nicotinamide). Nicotinamide is a precursor of nicotinamide adenine (NAD), nucleotide, and nicotinamide adenine dinucleotide phosphate (NADP), in which the nicotinamide moiety acts as electron acceptor or hydrogen donor, respectively, in many biological redox reactions. The RDA is expressed in milligram niacin equivalents (NEs) in which 1 mg NE = 1 mg niacin or 60 mg tryptophan. For individuals above 13 years of age, the RDA is 16 mg NE/day for males and 14 mg NE/day for females.

The chemical name of vitamin B6 is pyridoxine hydrochloride. Other forms of vitamin B6 include pyridoxal, and pyridoxamine. Vitamin B6 is one of the most versatile enzyme cofactors. Vitamin B6 in the form of pyridoxal phosphate acts as a cofactor for transferases, transaminases, and decarboxylases, used in transformations of AAs. The RDA for vitamin B6 is 1.6 mg/day.

Folate is an essential vitamin that is also known as folic acid and folacin. The metabolic role of folate is as an acceptor and donor of one-carbon units in a variety of reactions involved in AA and nucleotide metabolism. The RDA for folate is 400 μg/day. Excellent food sources of folate from fruits (>55 μg/day) include citrus fruits and juices.

Table 5.3 shows the range of concentrations (amount per 100 g of edible portion) of thiamin, riboflavin, niacin, pyridoxine, and folate from selected fruits.

Minerals

An adequate intake of minerals is essential for a high nutritional quality of the diet, and it also contributes to the prevention of chronic nutrition-related diseases. However, even in Western societies, intake of some minerals such as calcium, iron, and zinc is often marginal in particular population groups, for example, small children or female adolescents, while the intake of sodium or magnesium, reach or exceed the recommendations.

Table 5.4 shows the mineral content (amount per 100 g of edible portion) from certain fruits.

Iron

Iron (Fe) is an essential nutrient that carries oxygen and forms part of the oxygen-carrying proteins, hemoglobin in red blood cells, and myoglobin in muscle. It is also a necessary component of various enzymes. Body iron is concentrated in the storage forms, ferritin and hemosiderin, in bone marrow,

Table 5.4. Mineral Content of Fruits (Value per 100 g of Edible Portion)

Fruit	Fe (mg)	Ca (mg)	P (mg)	Mg (mg)	K (mg)	Na (mg)	Zn (mg)	Cu (mg)	Se (μg)
Apple	0.12	6	11	5	107	1	0.04	0.027	0.0
Apricot	0.39	13	23	10	259	1	0.20	0.078	0.1
Avocado	0.55	12	52	29	485	7	0.64	0.190	0.4
Banana	0.26	5	22	27	358	1	0.15	0.078	1.0
Cherry	0.36	13	21	11	222	0	0.07	0.060	0.0
Grape	0.36	10	20	7	191	2	0.07	0.127	0.1
Guava	0.31	20	25	10	284	3	0.23	0.103	0.6
Kiwi fruit	0.41	26	40	30	332	5	–	–	–
Orange	0.10	40	14	10	181	0	0.07	0.045	0.5
Papaya	0.10	24	5	10	257	3	0.07	0.016	0.6
Passion fruit	1.60	12	68	29	348	28	0.10	0.086	0.6
Peach	0.25	6	20	9	190	0	0.17	0.068	0.11
Pear	0.17	9	11	7	119	1	0.10	0.082	0.1
Pineapple	0.28	13	8	12	115	1	0.10	0.099	0.1
Plum	0.17	6	16	7	157	0	0.10	0.057	0.0
Raspberry	0.69	25	29	22	151	1	0.42	0.090	0.2
Strawberry	0.42	16	24	13	153	1	0.14	0.048	0.4

Source: USDA (2004).

liver, and spleen. Body iron stores can usually be estimated from the amount of ferritin protein in serum. Transferrin protein in the blood transports and delivers iron to cells (Lukaski 2004).

The body normally regulates iron absorption in order to replace the obligatory iron losses of about 1–1.5 mg/day. The RDAs for iron are 10 mg for men over 10 years and for women over 50 years, and 15 mg for 11–50-year-old females (ASNS 2004).

Nonheme iron is the source of iron in the diet from plant foods. The absorption of nonheme iron is strongly influenced by dietary components, which bind iron in the intestinal lumen. Nonheme iron absorption is usually from 1% to 20%. The main inhibitory substances are phytic acid from cereal grains and legumes such as soy, and polyphenol compounds from beverages such as tea and coffee. The main enhancers of iron absorption are ascorbic acid from fruits and vegetables, and the partially digested peptides from muscle tissues (Frossard et al. 2000; Lukaski 2004).

Calcium

Calcium (Ca) is the most common mineral in the human body. Calcium is a nutrient in the news because adequate intakes are an important determinant of bone health and reduced risk of fracture or osteoporosis (Frossard et al. 2000).

Approximately 99% of total body calcium is in the skeleton and teeth, and 1% is in the blood and soft tissues. Calcium has the following major biological functions: (a) structural as stores in the skeleton, (b) electrophysiological—carries a charge during an action potential across membranes, (c) intracellular regulator, and (d) as a cofactor for extracellular enzymes and regulatory proteins (Frossard et al. 2000; ASNS 2004).

The dietary recommendations vary with age. An amount of 1300 mg/day for individuals aged 9–18 years, 1000 mg/day for individuals aged 19–50 years, and 1200 mg/day for individuals over the age of 51 years. The recommended upper level of calcium is 2500 mg/day (IM 1997; ASNS 2004).

Calcium is present in variable amounts in all the foods and water we consume, although vegetables are one of the main sources. Of course, dairy products are excellent sources of calcium.

Phosphorus

Phosphorus (P) is an essential mineral that is found in all cells within the body. The body of the human adult contains about 400–500 g. The greatest amount of body phosphorus can be found primarily in bone (85%) and muscle (14%). Phosphorus is primarily found as phosphate (PO_4^{2-}). The nucleic acids—DNA and ribonucleic acid (RNA)—are polymers based on phosphate ester monomers. The high-energy phosphate bond of ATP is the major energy currency of living organisms. Cell membranes are composed largely of phospholipids. The inorganic constituents of bone are primarily a calcium phosphate salt. The metabolism of all major metabolic substrates depends on the functioning of phosphorus as a cofactor in a variety of enzymes and as the principal reservoir for metabolic energy (ASNS 2004).

The RDAs for phosphorus (mg/day) are based on life stage groups. Among others, for youth 9–18 years, the RDA is 1250 mg, which indicates the higher need for phosphorus during the adolescent growth. Adults 19 years and older have a RDA of 700 mg (IM 1997; ASNS 2004).

Magnesium

Magnesium (Mg) is the fourth most abundant cation in the body, with 60% in the bone and 40% distributed equally between muscle and nonmuscular soft tissue. Only 1% of magnesium is extracellular. Magnesium has an important role in at least 300 fundamental enzymatic reactions, including the transfer of phosphate groups, the acylation of coenzyme A in the initiation of fatty acid oxidation, and the hydrolysis of phosphate and pyrophosphate. In addition, it has a key role in neurotransmission and immune function. Magnesium acts as a calcium antagonist and interacts with nutrients, such as potassium, vitamin B6, and boron (Lukaski 2004; ASNS 2004).

The RDA, from the US Food and Nutrition Board, vary according to age and sex. The RDAs for magnesium are 320 and 420 mg/day for women and men (adults over 30 years), respectively (IM 1997; ASNS, 2004).

Potassium

Potassium (K) in the form of K^+ is the most essential cation of the cells. Its high intracellular concentration is regulated by the cell membrane through the sodium–potassium pump. Most of the total body potassium is found in muscle tissue (ASNS 2004).

The estimated minimum requirement for potassium for adolescents and adults is 2000 mg or 50 mEq/day. The usual dietary intake for adults is about 100 mEq/day. Most foods contain potassium. The best food sources are fruits, vegetables, and juices (IM 2004; ASNS 2004).

Sodium

Sodium (Na) is the predominant cation in extracellular fluid and its concentration is under tight homeostatic control. Excess dietary sodium is excreted in the urine. Sodium acts in consort with potassium to maintain proper body water distribution and blood pressure. Sodium is also important in maintaining the proper acid–base balance and in the transmission of nerve impulses (ASNS 2004).

The RDAs for sodium ranges from 120 mg/day for infants to 500 mg/day for adults and children above 10 years. Recommendations for the maximum amount of sodium that

can be incorporated into a healthy diet range from 2400 to 3000 mg/day. The current recommendation for the general healthy population to reduce sodium intake has been a matter of debate in the scientific community (Kumanyika and Cutler 1997; IM 2004; ASNS 2004).

Zinc

Zinc (Zn) acts as a stabilizer of the structures of membranes and cellular components. Its biochemical function is as an essential component of a large number of zinc-dependent enzymes, particularly in the synthesis and degradation of carbohydrates, lipids, proteins, and nucleic acids. Zinc also plays a major role in gene expression (Frossard et al. 2000; Lukaski 2004).

The RDAs for zinc are 8 and 11 mg/day for women and men, respectively (ASNS 2004).

Copper

Copper (Cu) is utilized by most cells as a component of enzymes that are involved in energy production (cytochrome oxidase), and in the protection of cells from free radical damage (superoxide dismutase). Copper is also involved with an enzyme that strengthens connective tissue (lysyl oxidase) and in brain neurotransmitters (dopamine hydroxylase) (ASNS 2004).

The estimated safe and adequate intake for copper is 1.5–3.0 mg/day (ASNS 2004).

Selenium

Selenium (Se) is an essential trace element that functions as a component of enzymes involved in antioxidant protection and thyroid hormone metabolism (ASNS 2004).

The RDAs are 70 μg/day for adult males and 55 μg/day for adult females. Foods of low-protein content, including most fruits and vegetables, provide little selenium. Food selenium is absorbed with efficiencies of 60–80% (ASNS 2004).

BIOACTIVE COMPOUNDS

Carotenoids

Carotenoids are lipid-soluble plant pigments common in photosynthetic plants. The term carotenoid summarizes a class of structurally related pigments, mainly found in plants. At present, more than 600 different carotenoids have been identified, although only about two dozens are regularly consumed by humans. The most prominent member of this group is β-carotene. Most carotenoids are structurally arranged as two substituted or unsubstituted ionone rings separated by four isoprene units containing nine conjugated double bonds, such as α- and β-carotene, lutein, and zeaxanthin, and α- and β-cryptoxanthin (Goodwin and Merce 1983; van den Berg et al. 2000). These carotenoids, along with lycopene, an acylic biosynthetic precursor of β-carotene, are most commonly consumed and are most prevalent in human plasma (Castenmiller and West 1998).

All carotenoids can be derived from an acyclic $C_{40}H_{56}$ unit by hydrogenation, dehydrogenation, cyclization, and/or oxidation reactions (Fig. 5.1). All specific names are based on the stem name carotene, which corresponds to the structure and numbering in Figure 5.1 (Shahidi et al. 1998).

The system of conjugated double bonds influences their physical, biochemical, and chemical properties. On the basis of their composition, carotenoids are subdivided into two groups. Those containing only carbon and hydrogen atoms are collectively assigned as carotenes, for example, β-carotene, α-carotene, and lycopene. The majority of natural carotenoids containing at least one oxygen function, such as keto, hydroxy, or epoxy groups are referred to as xanthophylls or oxocarotenoids. In their natural sources, carotenoids mainly occur in the *all-trans* configuration (Goodwin and Merce 1983; Van den Berg et al. 2000).

Carotenoids are of physiological interest in human nutrition, since some of them are vitamin A precursors, especially β-carotene. α-Carotene, and α- and β-cryptoxanthin possess provitamin A activity, but to a lesser extent than β-carotene. On the basis of epidemiological studies, diet rich in fruits

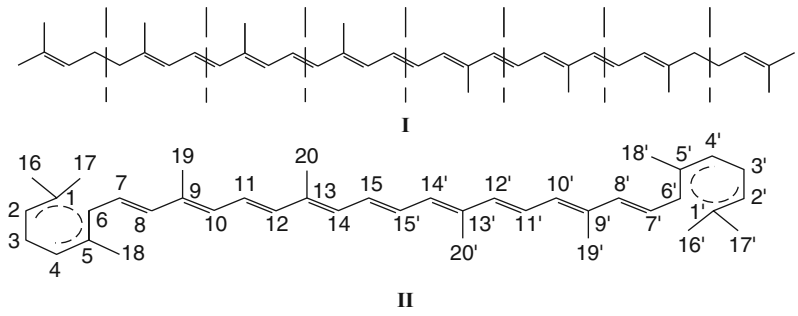

Figure 5.1. Structure and numbering of the carotenoid carbon skeleton (Shahidi et al. 1998).

and vegetables containing carotenoids is suggested to protect against degenerative diseases such as cancer, cardiovascular diseases, and macular degeneration. Recent clinical trials on supplemental β-carotene have reported a lack of protection against degenerative diseases. Much of the evidence has supported the hypothesis that lipid oxidation or oxidative stress is the underlying mechanism in such diseases. To date, carotenoids are known to act as antioxidants in vitro. In addition to quenching of singlet oxygen, carotenoids may react with radical species either by addition reactions or through electron transfer reactions, which results in the formation of the carotenoid radical cation (Canfield et al. 1992; Sies and Krinsky 1995; Van den Berg et al. 2000; Sánchez-Moreno et al. 2003c).

Carotenoid intake assessment is complicated mainly because of the inconsistencies in food-composition tables and databases. Thus, there is a need for more information about individual carotenoids. The estimated dietary intake of carotenoids in Western countries is in the range of 9.5–16.1 mg/day. To ensure the intake of a sufficient quantity of antioxidants, the human diet, which realistically contains 100–500 g/day of fruit and vegetables, should contain a high proportion of carotenoid-rich products. No formal diet recommendation for carotenoids has yet been established, but some experts suggest intake of 5–6 mg/day, which is about twice the average daily US intake. In the case of vitamin A, for adult human males, the RDA is 1000 μg retinyl Eq/day, and for adult females, 800 μg retinyl Eq/day (O'Neill et al. 2001; Trumbo et al. 2003).

Citrus fruits are the major source of β-cryptoxanthin in the Western diet. The major fruit contributors to the carotenoid intake in Western diets are orange (β-cryptoxanthin and zeaxanthin), tangerine (β-cryptoxanthin), peach (β-cryptoxanthin and zeaxanthin), watermelon (lycopene), and banana (α-carotene). Other relatively minor contributors are kiwi fruit, lemon, apple, pear, apricot, cherry, melon, strawberry, and grape (Granado et al. 1996; O'Neill et al. 2001).

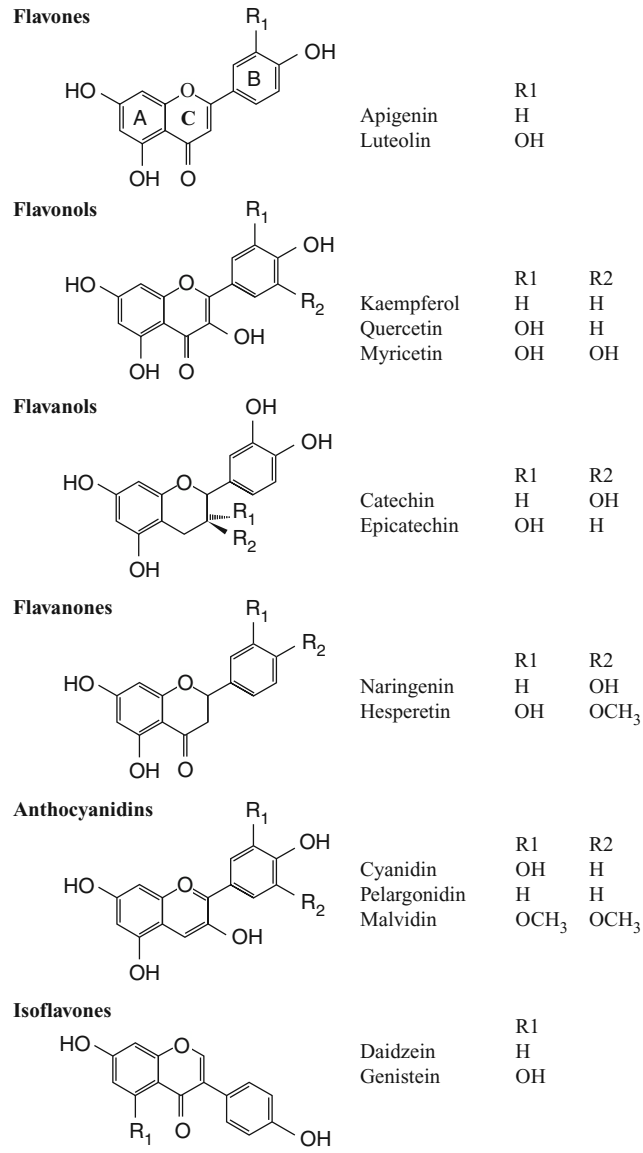

Figure 5.2. Structures of the main flavonoids in fruits.

Flavonoids

Flavonoids are the most common and widely distributed group of plant phenolics. Over 5000 different flavonoids have been described to date and they are classified into at least ten chemical groups. Among them, flavones, flavonols, flavanols, flavanones, anthocyanins, and isoflavones are particularly common in fruits (Fig. 5.2). The most-studied members of these groups are included in Table 5.5, along with some of their fruit sources (Bravo 1998).

Numerous epidemiological studies support the concept that regular consumption of foods and beverages rich in antioxidant flavonoids is associated with a decreased risk of cardiovascular disease mortality. There is also scientific evidence that flavonoids may protect against some cancers. It has been shown in the past that flavonoid content and structure may change with technological processes increasing or decreasing their contents and biological activity (García-Alonso et al. 2004).

Most of the existing flavonoids in fruits have shown antioxidant activity in in vitro studies, and almost all the fruits, which have been screened for their antioxidant activity, have shown to a lower or higher extent some antioxidant and radical scavenger activity.

Other biological activities of flavonoids seem to be independent of their antioxidant activity. This is the case of the estrogen-like activity showed by isoflavones. Isoflavones have also shown an effect on total and high-density lipoprotein cholesterol levels in blood.

Table 5.5. Classification of Flavonoids and Their Presence in Fruits

Subclasses	Flavonoids	Fruits
Flavones	Apigenin, luteolin	Apples, blueberries, grapefruit, grapes, oranges
Flavonols	Quercetin, kaempferol, myricetin	Apples, berries, plums
Flavanols	Catechin, epicatechin, epigallocatechin gallate	Apples, berries, grapes, plums
Flavanones	Hesperetin, naringenin	Citrus fruits
Anthocyanins	Cyanidin, pelargonidin, malvidin	Berries, grapes
Isoflavones	Genistein, daidzein	Currants, passion fruit

Source: De Pascual-Teresa et al. (2000) and Franke et al. (2004).

Anthocyanins have shown to be effective in decreasing capillary permeability and fragility and also have anti-inflammatory and antiedema activities.

Flavonols inhibit COX-2 activity and thus may play a role in the prevention of inflammatory diseases and cancer (De Pascual-Teresa et al. 2004).

Factors like modification on the flavonoid structure or substitution by different sugars or acids may deeply affect the biological activity of flavonoids, and in this sense, different processing of the fruits may also influence their beneficial properties for human health.

Phytosterols

Plant-based foods contain a large number of plant sterols, also called phytosterols, as minor lipid components. Plant sterols have been reported to include over 250 different sterols and related compounds. The most common sterols in fruits are β-sitosterol and its 22-dehydro analog stigmasterol, campesterol, and avenasterol (4-desmethylsterols). Chemical structures of these sterols are similar to cholesterol differing in the side chain (Fig. 5.3). β-sitosterol and stigmasterol have ethyl groups at C-24, and campesterol has a methyl group at the same position. Plant sterols can exist as free plant sterols, and as bound conjugates: esterified plant sterols (C-16 and C-18 fatty acid esters, and phenolic esters), plant steryl glycosides (β-D-glucose), and acylated plant steryl glycosides (esterified at the 6-hydroxy group of the sugar moiety). All of these forms are integrated into plant cell membranes (Piironen et al. 2000, 2003).

Plant sterols are not endogenously synthesized in humans; therefore, they are derived from the diet entering the body only via intestinal absorption. Since plant sterols competitively inhibit cholesterol intestinal uptake, a major metabolic effect of dietary plant sterols is the inhibition of absorption and subsequent compensatory stimulation of the synthesis of cholesterol. The ultimate effect is the lowering of serum cholesterol owing to the enhanced elimination of cholesterol in stools. Consequently, the higher the dietary intake of plant sterols from the diet, the lower is the cholesterol absorption and the lower is the serum cholesterol level (Ling and Jones 1995; De Jong et al. 2003; Trautwein et al. 2003).

The usual human diet contains currently around 145–405 mg/day of plant sterols. Dietary intake values depend on type of food intake. Intakes, especially that of β-sitosterol, are increased two- to threefold in vegetarians. For healthy humans, the absorption rate of plant sterols is usually less than 5% of dietary levels. Serum sterol levels of around 350–270 μg/dL in nonvegetarians have been observed (Ling and Jones 1995; Piironen et al. 2000).

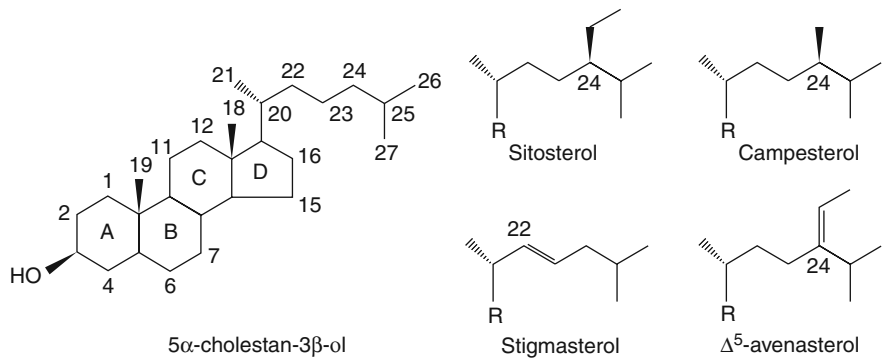

Figure 5.3. Structures of cholesterol (5α-cholestan-3β-ol), sitosterol, campesterol, stigmasterol, and Δ^5-avenasterol (Piironen et al. 2003).

Vegetables and fruits are generally not regarded as good a source of sterols as cereals or vegetable oils. The plant sterol content in a food may vary depending on many factors, such as genetic background, growing conditions, tissue maturity, and postharvest changes (Piironen et al. 2000). There are scarce data available on the content of plant sterols in the edible portion of fruits (Wiehrauch and Gardner, 1978; Morton et al. 1995). Recently, fruits, more commonly consumed in Finland, have been analyzed. Total sterols ranged from 6 mg/100 g (red currant) to 22 mg/100 g (lingonberry) of fresh weight, in all fruits, except avocado, which contained significantly more sterols, 75 mg/100 g. The content on dry weight basis was above 100 mg/100 g in most products. Peels and seeds were shown to contain more sterols than edible parts (Piironen et al. 2003). In Sweden, the range of plant sterol for 14 fruits is 1.3–44 mg/100 g (fresh weight), only passion fruit contains more than 30 mg/100 g (Normen et al. 1999). Among the fruits found in both reports, orange shows the highest plant sterol content and banana the lowest. In all the items analyzed, β-sitosterol occurred at the highest concentrations, followed by campesterol or stigmasterol. Detectable amounts of 5-saturated plant stanols, sitostanol, and campestanol, were found in specific fruits such as pineapple.

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Part 2
Postharvest Handling and Preservation Technologies

6
Postharvest Storage Systems: Biology, Physical Factors, Storage, and Transport

N. R. Bhat

Abstract: The fresh produce market has experienced rapid changes in recent years due to increasing consumer demands and sophistication. To remain profitable in today's competitive environment, there is a need to cut costs, streamline postharvest operations, expand product range throughout the year and improve customer services. Sophisticated postharvest handling and storage technologies along with efficient marketing strategies have ensured year-round supply of most food crops even in places that are far away from the places of production. Innovations in quality and its management strategies have become important strategic tools to gain access to new markets while retaining share in the current market. With increasing globalization, sophistication of markets and increasing consumer demands for better products and services, there is a consistent need for new quality management models. Cooperation among researchers, produce handlers, consumers, and other stakeholders as well as a continuous flow of technological innovations will be crucial in the successful management of quality and safety of fresh produce in the postharvest chain and in retaining competitive edge in an era of increasing global competition. The chapter compares various storage systems and their relevance to total quality management of fresh fruits and vegetables.

INTRODUCTION

Fruits are essential components of a balanced human diet as they provide sugars, salts, organic acids, minerals, water-soluble pigments, vitamins, and nondigestible carbohydrates (Ansorena 1999, Belitz et al. 2004, Pajk et al. 2006). Approximately 75–90% of the total mass of fruits is water. The final water content usually depends on the structural differences of individual fruits and vegetables (Vicente et al. 2009). Carbohydrates are the next most abundant constituents in fruits, representing 50–80% of the total dry weight. Glucose, fructose, and sucrose are water-soluble sugars, and together, they account for most of the sugars associated with the sweet taste of fruits and vegetables. While the most abundant organic acids found in fruits and vegetables are citric and malic (both aliphatic) acids, significant amounts of tartaric acid are present in grapes (Vicente et al. 2009). Several fruits and vegetables also contain aromatic acids (e.g., benzoic acid in cranberries, quinic acid in bananas, and chlorogenic acid in potatoes) at low concentrations. Citrus fruits such as oranges, lemons, and grapefruits are excellent sources of ascorbic acid (Ansorena 1999, Belitz et al. 2004). These acids play an important role in the sugar to acid ratio.

Proteins represent $<1\%$ of the fresh mass of fruit and vegetable tissues, although certain dried legume seeds contain higher amounts. Fruits, vegetables, and legumes account for approximately 1.2%, 5.5%, and 6.1%, respectively, of the protein in the US food supply (Hiza and Bente 2007).

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

The fat content is usually <1% in most fruits (grape, 0.2%; banana, 0.1%; and apple, 0.06%) and vegetables, but some products contain greater amounts (e.g., avocado, 35–70%; olive, 30–70%; Vicente et al. 2009). Fruits and vegetables are also an abundant source of minerals such as potassium, iron, calcium, sodium, and magnesium (Belitz et al. 2004). The vitamin content of vegetables may depend on the cultivar and climate. In addition to these nutrients, fruits and vegetables are a good source of several minor components known as phytonutrients and antioxidants, which reduce risks of one or more chronic diseases in mammals (Beecher 1999, Blomhoff et al. 2006). Fruits such as berries and nuts, some seeds, vegetables, and some beverages (red wine and fruit juices) are good sources of antioxidants, which strengthen antioxidant defense system in humans and work in a synergistic way to protect cells from damage (Blasa et al. 2010).

BIOLOGY OF FRUITS

Molecular and genetic analysis of fruit development, especially ripening of fleshy fruits, has resulted in significant advances in recent years (Giovannoni 2001). Kidd and West's discovery of the climacteric phenomenon and Blackman's classic studies on respiration in apples formed the foundation for the postharvest physiology research, which led to several breakthroughs in our understanding of ethylene biosynthesis and response, cell wall metabolism, and environmental factors such as light that impact ripening (Grierson 1987, Seymour et al. 1993, Laties 1995, Saltveit et al. 1998, Giovannoni 2001, Kader 2003).

Unlike other perishable foods (e.g., meat), fruits and vegetables are living tissues and continue to respire and transpire after detachment from plant (Kader 1987, Zagory and Kader 1988, Lee et al. 1995, 1996a, Paul and Clarke 2002). Prior to their harvest, substrate and water losses are replaced by continuous flow of photosynthates, minerals, and water within the parent plant; but these losses are not replaced in the postharvest channel. Consequently, these products begin to deteriorate and eventually die, thereby reducing the shelf life and quality of these commodities. Respiration involves a complex set of biochemical reactions through which starch, sugars, proteins, fats, and organic acids are broken down into water and carbon dioxide, heat, and metabolic energy. The rate of these biochemical reactions may change naturally as the products go through ripening, maturity, and senescence stages or artificially when the storage environment is altered (Paul and Clarke 2002). The rate of deterioration depends on a number of factors, some internal or intrinsic (type of commodity, cultivar, internal tissue conditions at the time of harvest) and some external or extrinsic (storage conditions such as temperature, relative humidity (RH), levels of ethylene, O_2, and CO_2) (Kader 1980, Kader et al. 1989).

In addition to physiological changes, perishable products are subjected to other types of deterioration, including tissue softening and pigment loss caused by chemical and enzymatic processes, physical damage due to faulty harvesting, handling, processing and packing, and attack by microorganisms and insects (Williamson 1963, Dennis 1984, Watada et al. 1984). Therefore, shelf life extension may require a combination of treatments to retard or inactivate the deteriorative processes.

FRUIT QUALITY

In literature, quality of fresh fruits has been described in several ways. Postharvest physiologists, producers, and handlers describe the quality in terms of specific physical or chemical product attributes such as weight, sugar content, color, or firmness (product orientation), whereas consumers, marketers, and economists describe it as a combination of characteristics that determine the degree of consumer acceptance or usefulness (superior, good, fair, or poor). While quality of a product is generally set by the first buyer in the marketing chain, its perception changes as it travels through the postharvest handling chain (Shewfelt 2000, Shewfelt and Brückner 2000, 2009). The farmer uses seeds or plants of a premium cultivar, several inputs (water, fertilizers, growth substances, and pesticides), and tries to ensure good yield and quality that is acceptable to the first buyer. At this stage, quality of a fresh product is determined by visual attributes, such as color, size, shape, and absence of defects. Established grades and standards based on these attributes are available to determine the quality of a given product at this early stage. Theoretically, the physical and physiological conditions of the commodity change (not the grade) as the product travels through the marketing channel. Perishability of a commodity is a function of how rapidly the condition of the product deteriorates under a particular storage regime. While the postharvest physiologists try to develop techniques to maintain the quality, food technologists try to optimize the quality during the marketing process.

Product quality encompasses several product attributes: sensory attributes, nutritive values, chemical constituents, mechanical properties, functional properties, and defects. Majority of the studies to determine consumer acceptance in fresh commodities have been conducted in tomato (Stern et al. 1994, Malundo et al. 1995, Auerswald et al. 1999, Sinesio et al. 2000, Causse et al. 2002). Therefore, it is important to identify product-specific set of characteristics for a given market, region, market segment (e.g., variety), or safety concerns (Hampson and Quamme 2000, Shewfelt 2000).

STORAGE SYSTEMS

In the past, fruits were consumed almost entirely near to their place of production, but because of advancements in postharvest and marketing technologies, fresh fruits are transported

to distant places and are consumed in a few to several days after their harvest. This trend clearly underscores the importance of preserving the natural qualities and freshness from farm to the distant consumer. All operations beginning with harvesting through packaging, storage, and transportation to retailing have significant impact on the storage life and the quality of fruits and vegetables. To meet these requirements, the modern storage systems has to perform functions such as quality characterization, manage the quality of the product throughout the postharvest chain, protect products from microbial attack, and present the product to the ultimate consumer in the best possible condition. The ability of supply chain to develop efficient techniques to perform these functions and, subsequently, apply them commercially to extend the useful life of the product will determine the profitability and survival in the competitive global trade.

In most developing countries, fruits after harvest are handled and marketed in simple open storage structures, especially when ambient conditions are moderate. Some storage houses in India, China, and other developing countries still use improved designs of these open structures with proper ventilation for less perishable fruits (Sangey et al. 1999). Several improved storage systems are being used commercially in developed countries. These modern storage systems include refrigerated or low-temperature storage, controlled-atmosphere storage, modified atmosphere (MA) storage, hypobaric storage, storage at chilling temperature with intermittent warming, and modified atmosphere packaging (MAP). Fruits have different optimum storage conditions depending on their tolerance to low temperatures, high humidity, low O_2, elevated CO_2, air pressure, ethylene level, and mechanical injuries.

Temperature of fruits at the time of harvest is in equilibrium with the ambient air, which is normally high. This renders these products vulnerable to rapid deterioration and microbial decay in the postharvest environment. To slow down the deteriorative process, it is important that the product is cooled to safe temperatures as quickly and efficiently as possible after harvesting (Dennis 1984). This process is known as precooling (Janick 1986). Baird and Gafney (1976) described it as the most important of all operations used in the maintenance of quality of saleable produce. If done properly, it improves the efficiency and effectiveness of the refrigeration system (Halevy et al. 1978, Farnham et al. 1979). It will also reduce production and sensitivity of produce to ethylene, which accelerates ripening and senescence (Prange 1994). Therefore, precooling is considered as the most critical postharvest treatment (Brosnan and Sun 2001).

Precooling operations are carried out at the packing houses or central cooling facilities. A variety of precooling techniques are now available, but the main methods used in the horticultural industry include room cooling, hydrocooling, forced air cooling, package cooling, vacuum cooling, and cryogenic cooling with several variations within these techniques (Brosnan and Sun 2001). The choice of a cooling technique depends on the nature of the product, packing requirements, product flow, and economic considerations. For example, strawberries and broccoli require near freezing temperatures, whereas tomatoes and squash would be damaged at this low temperatures (Table 6.1; Edeogu et al. 1997). Similarly, some crops that are susceptible to *Botrytis cinnerarea* are not suited for hydrocooling (Nowak and Rudnicki 1990). The design, package material, and the way in which the product is packed can dramatically change the rate and efficiency of cooling (Stanley 1989, Faubion and Kader 1997). Sainsbury (1961) reported that packed boxes of certain produce require several days to reach the required temperature in storage rooms. Several reviews have been written on the applications of various precooling systems in fresh fruits and vegetables (Sheehan 1960, Brosnan and Sun 2001, Shewfelt 2009). Cooling guidelines are given in Table 6.2.

Refrigerated Storage

Improvements in refrigeration, transportation, and storage facilities have enabled even the highly perishable fruits and vegetables to be shipped over a long distance, thereby allowing the consumers to expect almost a complete range of produce throughout the year. Refrigeration has also allowed marketing of fruits and vegetables for a longer duration after harvest. In the United States, commercial cold storages were started in the 1880s, while in Britain, it was started even earlier (Ladaniya 2008). Refrigerated warehouses have become a necessity for the efficient handling of fruits and vegetables.

A refrigeration or "cold-chain" encompasses all critical steps and processes that perishable food products must undergo in order to maintain the quality. Logistics in terms of planning, implementing, and controlling the storage and flow of goods, services, and information plays an important role in maintaining an efficient cold chain from field, through distribution channels, to the home refrigerator (Ezeike and Hung 2009). The intricacies of transcontinental shipments and customs requirements have added further complexities to the logistics. The supply chain is only as strong as its weakest link in the cold chain (between producer and packing house or between customer and store) and the chain is often broken at the weakest links. The most common problems noticed in the cold chain are related to poor temperature management due to lack of or insufficient refrigeration, limitations of RH, or improper handling.

Efficient cooling techniques preserve product quality by restricting respiration and metabolic activity, inhibiting the growth of decay-causing microorganisms, minimizing water loss, and reducing ethylene production and/or reducing the sensitivity of produce to ethylene action. Since tropical fruits and vegetables are susceptible to chilling injuries such as failure to ripen properly, pitting, decay, and discoloration, care must be taken not to store them below safe temperatures (Hung 1993). Intermittent warming has successfully been used to overcome chilling injuries as shown by Artés et al.

Table 6.1. Application of Precooling Techniques in Fresh Fruits and Vegetables

Precooling Techniques	Applications	Remarks	References
Room cooling	Beans, beets, cucumber, onions, peppers, tomato, potato, pumpkins, herbs, and turnip.	Requires several days to reach the required temperature in storage rooms. Removal of lids of packages improves cooling rate and efficiency.	Sainsbury 1961, Ryall and Pentzer 1982, Reid et al. 1983, Anon 1984, Mitchell 1985, Boyette et al. 1994b
Package icing	Collards, kale, Brussels sprouts, broccoli, radishes, carrots, and onions.	Ice flakes or crushed ice is placed over the product in the package. Inefficient and expensive method of cooling. May result in uneven cooling.	Hardenburg et al. 1986, Boyette and Estes 1994, Wills et al. 1998
Hydrocooling	Sweet corn, celery, asparagus, radishes, and carrots.	Involves spraying, flooding, or immersing the product in or with chilled water.	Noohorm et al. 1988, Athey and Dennis 1991, Allais and Letang 2009
Forced air cooling	Cut flowers, broccoli, Brussels sprouts, cauliflower, green beans, celery, cucumber, and tomatoes.	Cold air at high pressure is made to pass through the produce in packages to lower the temperature. Packages are stacked with vent holes placed in the direction of the moving cold air. Requires long chilling time and may result in weight loss due to evaporation from the produce.	Parsons et al. 1972, Farnham et al. 1978, Arfin and Chau 1988, Risse and Craig 1989, Rudnicki and Nowak 1990, Moras and Chapon 1992, Boyette et al. 1994a
Vacuum cooling	Lettuce	Cooling is achieved by evaporation of moisture from the produce at low pressure. Requires high surface to volume ratio.	Anon 1981, Thompson and Rumsey 1984, Grittani and Pasqualone 1988, Tambunan et al. 1994
Cryogenic cooling	Soft fruits and cut flowers	Liquid nitrogen or solid CO_2 (dry ice) is used for cooling the product. Less expensive to install, but expensive to operate. A careful control of evaporation rate is needed to maintain quality.	Gormley 1990, Brosnan and Sun 2001

Table 6.2. Cooling Guidelines

Respiration Rates	Crops	Cooling Requirements
Very high	Leaf lettuce, broccoli, mushroom, and asparagus	Cooled within 90 min after harvest
High	Strawberry, raspberry, blueberry, sweet cherry, cauliflower, snap beans	Cooled within 3 h after harvest
Moderate	Cabbage, cantaloupe, apples, peach, plum, peppers, and squash	Cooled within 4–5 h after harvest

Source: Adapted from Ezeike and Hung (2009).

(1998) in case of tomato. Recommended temperature and other storage requirements for various fruits and vegetables are indicated in Table 6.3.

The performance of refrigerated transport system is influenced by structural design (thermal bridging, location of refrigeration unit, air exchanges, door openings, and fresh air exchanges) and loading pattern of produce. Mixing of several fruits and vegetables is very common in the supply chain, but due care should be exercised to pool products having similar storage requirements in terms of temperature, RH, sensitivity to ethylene, and odor production (Wang 1990a, Thompson and Kader 2004, Boyhan et al. 2004, Katinoja and Kader 2004).

Controlled Atmosphere and Modified Atmosphere Storage

Low temperature storage is used to preserve the freshness of the perishable products. However, the maintenance of a constant optimum temperature throughout the postharvest chain is a daunting task and is not always achievable. Even when desired temperature can be achieved during storage and transportation, the transport time for international shipment is too long for highly perishable products such as strawberry. Air shipment may be an alternative to surface or ocean transport, but it involves break in the cold chain during ground operations or in transit (Edmond et al. 1996). Breakdown

Table 6.3. Recommended Temperature and Storage Times in Cold Store for Some Fruits and Vegetables

Commodity	Temp. (°C)	Relative Humidity (%)	Maximum Storage Time	Sensitivity Ethylene[a]	Temp. (°C) Below Which Chilling Injury Occurs[b]
Fruits					
Apple	0–4	90–95	26 mo		2–3
Green banana	13–15	85–90	3 wks		11.5–13
Grapes	0–2	85–95	2–6 mo	Sensitive	
Mango	13–15	85–90	3 wks		10–13
Oranges	4–5	90–95	3–4 mo		3
Papaya	7–13	85–90	1–3 wks		7
Peach	0–2	90–95	2–4 wks		Sensitive to freezing temp.
Pear	0–2	90–95	2–7 mo		
Strawberries	0–2	85–95	1–2 wks		
Vegetables					
Asparagus	0–3	>95	1 wk	Sensitive	0–2
Beans	10	85–90		Sensitive	7
Beet-topped	0	95–99	4–6 mo		
Cabbage	0–2	95–99	5–6 mo	Sensitive	
Cantaloupe	2–5	90–95	1–2 wks		2
Carrots	0–2	98–100	5–9 mo	Sensitive	
Capsicum	7–10	85–90	2–3 wks		7
Cauliflower	0	95	2–4 wks	Sensitive	
Cucumber	10–13	90–95	1–2 wks	Sensitive	7
Eggplant	8–10	90–95	1–2 wks	Sensitive	7
Leek	0	95	1–3 mo	Sensitive	
Lettuce	0–1	95–99	2–3 wks	Sensitive	
Melons	7–10	85–95	2–3wks		4–5
Onions—dry	0	65–70	1–8 mo	Sensitive	0
Peas	0–2	95	1–2 wks	Sensitive	
Pumpkin	10–13	70–75	2–5 mo		10
Radish	0–2	>95	34 wks	Sensitive	
Spinach	0	95	1–2 wks	Sensitive	
Tomatoes	12–20	85–90	1–2 wks	Sensitive	7–10
Fresh cut vegetables	0	>95	2–3 wks	Sensitive	0

[a]Ethylene-sensitive products should be stored and/or transported with care. Ethylene producers include apples, bananas, beets, cherries, figs, leeks, nectarines, peaches, pear, plum, persimmon, etc.
[b]Chilling injury depends both on temperature and duration of exposure to chilling temperature. Symptoms are visible only after the products are removed to warm temperature.
Sources: McGregor (1989), Wang (1990a), Thompson and Kader (2004), Katinoja and Kader (2004).

of cold chain or fluctuations in the temperature at any stage in the postharvest chain could have significant adverse effects on the marketability and quality of horticultural produce (Nunes et al. 1999, 2001). Under these circumstances, storage under modified gaseous composition (reduced O_2 and elevated CO_2 levels, higher nitrogen concentration) has been found effective in reducing metabolic activity and thereby improving shelf life of perishables (Zagory and Kader 1988, Ooraikul and Stiles 1991, Beaudry et al. 1992, Lee et al. 1995, Parry 1995, Beaudry 1999, Jayas and Jeyamkonda 2002, Paul and Clarke 2002, Brecht et al. 2003, Sandhya 2010). Storage under MA has also been shown to preserve natural quality of the product (Jayas and Jeyamkonda 2002). Today, MA is used in conjunction with low temperature storage to overcome any fluctuations in the storage temperature. Though optimum gaseous compositions vary widely, the general rules for modifying the atmosphere include lowering O_2 levels to reduce respiration rate, ripening, and senescence, but safe enough to prevent anaerobic fermentation and other low O_2 injuries; increasing CO_2 levels to attenuate respiration rate while preventing CO_2 injuries; maintaining high RH to reduce moisture loss from the product and maintain freshness; lowering the temperature to slow down respiration rate without causing chilling injuries; and preventing buildup of ethylene levels to suppress ripening and senescence process.

Controlled atmosphere (CA) and MA are used interchangeably, although they differ in the level of the control exercised over the composition of gases (Jayas and Jeyamkonda 2002). Gas composition in CA storage is controlled throughout the storage period, whereas it is modified initially and allowed to fluctuate in MA storage depending upon respiration in product and permeability characteristics of the packaging materials (Jayas and Jeyamkonda 2002). The overall metabolic and biochemical activities (ethylene production and action, acid catabolism, breakdown of pectic substances in the cell wall, leading to tissue softening) are reduced in both CA and MA storages. Therefore, they delay the onset of ripening and senescence processes. By inhibiting the activity of polyphenol oxidase, MA also reduces browning in certain fruits and vegetables (Wang 1990b). It has also been shown that ethylene is produced and remains active even at low temperatures (Saltveit et al. 1998). Therefore, it is important to continuously flush out ethylene from the product in all postharvest steps. This can be achieved by chemical (using potassium permanganate) oxidation or catalytic scrubbing (Blanpied 1990, Knee 1990).

CA and MA storages do not replace cold storage under certain circumstances; they overcome the negative effects of nonoptimum temperatures as shown in strawberry by Nunes et al. (1995) and in tomato by Nunes et al. (1996). These authors have shown that "Chandler" strawberries stored in 5% O_2 and 15% CO_2 concentrations lost less weight and maintained firmness and color even at relatively high storage temperatures (4°C or 10°C as against the optimum temperature of 2–3°C). In tomatoes, they reported that storage at 4% O_2 and 2% CO_2 extended the shelf life at 12°C (Nunes et al. 1996).

MA suppresses postharvest diseases both by improving host resistance and by affecting the activity of pathogenic microorganisms (Barkai-Golan 1990). By delaying the ripening process, MA increases host resistance to pathogens. Similarly, low O_2 concentrations (below 1%) inhibit the growth and activity of postharvest pathogens. Gaseous ozone treatment has been shown to have bactericidal effects on *Salmonella enteritidis* in cherry tomatoes and, hence, can be used for surface sanitation prior to long-term storage (Daş et al. 2006). However, under the normal conditions of MA storage (2–5% O_2), the growth of pathogens is only checked, not completely inhibited.

Optimum storage conditions in CA or MA vary widely among species, even within the same cultivar grown under different conditions (Smock 1979, Thompson 1998, Jayas and Jeyamkonda 2002, Brecht et al. 2003).

Modified Atmosphere Packaging

MAP is used for prolonging the shelf life of fresh or minimally processed foods. This technique relies on the modification of atmosphere surrounding the product inside the package. This is achieved by the combined effects of ongoing respiration of the product and gaseous transfer through the packaging material (Sandhya 2010). As the altered atmosphere inside the package will be rich in CO_2 and low in O_2, respiration rates, ethylene production, sensitivity, decay and physiological changes responsible for deterioration of the product are greatly reduced, leading to an extension of shelf life of perishable fruits and vegetables (Kader et al. 1989, Saltveit 1997, Gorris and Peppelenbos 1999). The exact composition of gases inside the package depends on the nature and mass of product, respiration rates under changing gaseous environment, permeability of packaging materials to gases and water vapor, and storage temperature (Fonseca et al. 2002, Sandhya 2010). Since fruits and vegetables continue to respire even after harvest, an equilibrium MA is established in the package if the permeability (for O_2 and CO_2) of the packaging film is adapted to the product respiration. Therefore, respiration modeling is central to the design of MA packages because a faulty package may have considerable negative impact on the shelf life of the product (Fonseca et al. 2002, Paul and Clarke 2002).

The equilibrium modified atmosphere packaging is the most commonly used packaging technology wherein fruits and vegetables are packaged with a gaseous atmosphere, which is usually lower O_2 and higher CO_2 levels than the normal air. The diffusion of O_2, CO_2, and C_2H_4 from the tissue depends on the concentration gradient and the amount of internal air space. The diffusion of O_2, CO_2, and C_2H_4 by three varieties of apricots stored in four plastic films of different permeabilities at 10°C was studied by Pretel et al. (2000). Reducing the O_2 levels from 21 to around 2.5% was shown to decrease the production of C_2H_4 by 50% and retard ripening process.

Since respiration and overall biological activities and also the permeability of packages to gases are influenced by temperature, effectiveness of MAP system also depends on the temperature inside the package (Sandhya 2010). While low RH in MA packages can cause desiccation, high in-package humidity can lead to condensation on the inner surface of the film. A mathematical model was developed for estimating the changes in the atmosphere and humidity within perforated packages of fresh produce (Lee et al. 2000). This model was based on the mass balances of O_2, CO_2, N_2, and H_2O vapors in the package. A procedure to maintain desired levels of O_2 and CO_2 inside packages exposed to different surrounding temperatures was designed and tested (Silva et al. 1999).

Applications of MAP

Customers demand natural, minimally processed fresh foods. MAP storage is used to maintain natural quality of food products in addition to extending shelf life. Unlike grains and meat products, fruits and vegetables continue to respire and transpire at much higher rates even after harvest. Since the natural supplies of water, photosynthates, and minerals are disrupted after harvest, they are totally dependent on the food reserves. Therefore, loss of water and other reserves

lead to loss of saleable weight of the product, and hence, direct losses to the producers or handlers. Loss of moisture also causes wilting or shriveling of product within a few hours after harvest. Release of water from transpiration of product increases RH inside the package and could promote microbial growth. Therefore, permeability to water vapor is also an important consideration in the selection of packaging materials.

Successful applications of MAP include apple, banana, beans, broccoli, Brussels sprout, cabbage, cauliflower, carrot, cucumber, corn, grapefruit, grape, lettuce, mango, fresh-cut fruits and vegetables, mushroom, onion, papaya, peach, pear, peas, prepared salads, tomato, spinach, strawberry, and peeled garlic (Lee et al. 1996a, 1996b, Artes and Martinez 1999, Lee et al. 2000, Artes et al. 2001, Villaescusa and Gil 2003, Sandhya and Singh 2004a, 2004b, Liu and Li 2006, Rai et al. 2008, Sandhya 2010). Different materials used for MAP of fruits and vegetables include ethylene vinyl alcohol, low-density polyethylene, high-density polyethylene, polypropylene, rigid polyvinyl chloride (PVC), ethyl vinyl acetate, polyurethane, plasticized PVC, and polyamide (nylon; Sandhya 2010).

MAP is used as a supplement to cold storage to delay ripening and avoid chilling injury, especially in chilling sensitive fruits (Sandhya 2010). Oxygen concentrations below 8% and CO_2 concentrations above 1% have been shown to retard fruit ripening, but O_2 concentration below 2% promotes anaerobic respiration, leading to the development of off-flavors (Plestenjak et al. 2008, Sandhya 2010). Temperature fluctuations inside the package, even if they occur once, can lead to tissue browning, loss of firmness, excessive weight loss, increase in the level of ethanol in the plant tissue, and infection and can seriously compromise the benefits of MAP.

Designing MA Packaging Materials

Models have been developed, which would allow fresh produce processors to choose packaging materials most suited to the enclosed product (Paul and Clarke 2002). A common mathematical model involves the use of what is known as a Michaelis–Menten type respiratory model to describe the influence of temperature and O_2 (and potentially CO_2) on respiration. This approach has been used for blueberries (Cameron et al. 1994), strawberries (Joles 1993), raspberries (Joles et al. 1994), and apple slices (Lakakul et al. 1999). Respiratory models are then coupled with an equation describing the temperature sensitivity of film permeability to gases (known as the Arrhenius equation) to predict package O_2 partial pressure as a function of temperature, product mass, surface area, and film thickness (Cameron et al. 1994, Lakakul et al. 1999).

MA packaging systems for products with low to medium respiration rates can potentially modify the pack atmosphere and thus result in fermentation. Therefore, there has been a considerable commercial interest in developing films with high gas transmission to allow exit or entry of O_2, CO_2, and water vapor in a controlled manner. Blends of two or three different polymers, where each polymer performs a specific function such as strength, transparency, and improved gas transmission to meet certain product descriptions, are used in the manufacture of packaging films. Similarly, laminated and perforated films have been developed to improve the keeping quality of several fruits and vegetables (Van der Steen et al. 2002).

Recent advancements in MAP include active packaging (use of scavengers for oxygen, carbon dioxide, and ethylene, and moisture absorbers to allow an interaction between pack and food product) and embedding of time–temperature indicators, sensors, radio frequency identification tags, and security tags in packages to monitor quality and/or safety of a food product in the distribution chain (d' Hont 2001).

Hypobaric Storage

Storage at subatmospheric pressures (hypo means low) has similar effects of low-O_2 MA storage. In hypobaric storage systems, a partial vacuum is created and atmospheric pressure is reduced. Benefits are achieved by a reduction in O_2 and volatiles, including ethylene. This method requires a vacuum pump to create vacuum in the storage area, a pressure regulator to regulate the leakage of air into the storage area to maintain a desired low pressure, a humidifier to saturate the storage atmosphere, and a refrigerator to control the storage temperature (Burg 1990, Li and Zhang 2006). High RH (90–100%) is maintained in the storage to prevent moisture loss from the products. The major disadvantage of this system is the higher cost of construction.

Promising results have also been achieved in the hypobaric storage of acid limes, banana, avocado, and sweet cherry (Salunkhe and Wu 1973, Spalding and Reeder 1976a, 1976b, Apelbaum et al. 1977a, 1977b) and vegetables (Bangerth 1974, Li and Zhang 2005).

FACTORS AFFECTING STORAGE OF FRESH FRUITS AND VEGETABLES

Preharvest Growing Conditions

Developing fruits and vegetables are exposed to a wide range of internal and external influences, such as rootstock-scion combinations, soil properties, planting density, training/pruning systems, application of essential nutrients, endogenous and exogenous plant growth regulators, quality and amount of water applied, type of fruit set (parthenocarpic vs. normal fruit set, embryo abortion vs. normal seed development, etc.), exposure of product to light, wind, and other environmental factors, pesticide sprays, and crop load are major factors that determine or modify fruit size and external and internal qualities and storage ability. Cultivation practices significantly influence the shelf life of fruits and vegetables. Even incidence of postharvest disorders induced by storage

conditions are influenced by preharvest environmental conditions and orchard practices. Therefore, total quality management in fruits and vegetables should take the preharvest conditions into consideration.

Harvesting

Several reviews have been written to demonstrate the importance of the harvest practices (manual vs. mechanical harvesting) and harvest maturity on subsequent postharvest quality and shelf life (Ahumada and Cantwell 1996, Crisosto et al. 1997, Dixon and Hewitt 2000, Lee and Kader 2000, Shewfelt 2000). Maturity of a crop is an assessment of physiological development. Physiological maturity is defined as the stage of development when a plant or plant part will continue ontogeny even if detached. On the other hand, commercial maturity is the stage of development when a plant or plant part is ready for utilization by consumers for a particular purpose (Watada et al. 1984). Maturity of a crop at harvest not only affects the color and size of the product (hence, its grade), but also the texture, flavor and nutrient content, and susceptibility to adverse handling and storage conditions (Prussia and Woodroof 1986). Fruits and vegetables are harvested by hand or mechanically using picking devices, mechanical harvesters, or more recently by robots (Prussia and Woodroof 1986, Edan 1995, Hayashi et al. 2002, Shewfelt and Henderson 2003, Van Henten et al. 2003).

Postharvest Heat Treatments

During the past few years, there has been an increasing interest in the use of heat treatments to control postharvest insect pests and prevent fungal rots. These treatments affect ripening or other metabolic processes. Part of this interest is because there is a growing demand to decrease the postharvest use of chemicals against pathogens and insects. There are three methods in use to heat commodities; hot water, vapor heat, and hot air. A number of reviews have dealt with specialized aspects of heat treatments (Couey 1989, Paull 1990, Barkai-Golan and Phillips 1991, Klein and Lurie 1991, Coates and Johnson 1993, Paull 1994, Paull and McDonald 1994).

Physiological Disorders

Physiological disorders caused by chilling temperatures, high CO_2 or C_2H_4 levels, low O_2 levels, water stress, high temperatures, and irradiation can result in a wide range of quality defects or disorders (O'Conner-Shaw et al. 1994, Kays and Paull 2004, Butz et al. 2005).

Grading

Machines capable of sorting by size, color, and weight are used for grading of fruits and vegetables. With consumers constantly requiring higher quality products, additional features are being included in grading machines to enhance vision inspection tools (e.g., to locate stems, to determine the main and secondary color of the skin, to detect blemishes). Size and color have long been associated with quality (Miller and Delwiche 1989, Hahn 2002, Dobrzanski and Rybczynski 2002, Leemans et al. 2002, Blasco et al. 2003, Zhou et al. 2004). Nowadays, instruments that detect the presence of long stems are being used to avoid damage to other fruits. Several techniques such as the use of structured lighting to detect concavities in apples (Yang 1993); color segmentation technique to differentiate the calyx and stem in citrus fruits (Yang 1993, Ruiz et al. 1996); and the light reflection technique in apples (Penman 2002) have been used to detect size and position of the stem.

Packing

Harvested fruits and vegetables are inspected for foreign objects, sub-substandard items, trichomes (in peaches), and damaged or infected items before they are packed. Packing operation can be performed either in the field or in specially designed packinghouses. Some commodities are also washed to remove soil and microbial load on the surface. The product in these packages is then precooled to optimum temperatures to remove field heat and slow down physiological processes (Talbott et al. 1991). While these operations ensure greater product uniformity and quality, each of these operations has the potential to cause physical damage or introduce microorganisms into the product, thereby influencing the postharvest behavior of that commodity.

Transportation

Transportation facilitates should be readily available for fresh fruits and vegetables throughout the year in markets that are removed from their place of production or where they cannot be economically grown. Transportation by truck, rail, ship, or plane is used to move the product from the field to packing facilities, from packing houses to shipping containers, by air or sea freight to various warehouses, and then to retail stores. Adequate precautions are required to minimize mechanical damage to the product, maintain optimum storage conditions, and to ensure product compatibility in the shipment or in stores (Chonhenchob and Singh 2003, Crisosto et al. 1993). Ethylene-sensitive commodities should not be shipped with ethylene generators, such as apples, banana, cherries, figs, leeks, nectarines, peaches, pear, plum, persimmon, etc. (Ashby 1995). While the most common damage during transportation is caused during load shifting and crushing of packages in containers, maximum economic loss results from inadequate temperature control (Beilock 1988).

Retail Distribution

Retail store is where the final decision on acceptance or rejection of the product is made. It is also the step in the postharvest chain where maximum consumer interaction takes place. Therefore, retail distribution is probably the most important of all handling steps, but is the least controlled step in the entire postharvest chain. In retail stores, adequate attention need to be given to storage conditions (temperature, RH, lighting), compatibility of commodities (e.g., ethylene producers with ethylene-susceptible species), length of exposure to nonoptimal conditions, and damage caused by store personnel. Practices like addition of ice and periodic misting or fogging are used to maintain quality and retain freshness of the produce.

TOTAL QUALITY MANAGEMENT

To control or manage quality, one must be able to measure quality-related attributes. Complex consumer preferences and perceptions further complicate the management of quality. Each participant in the postharvest chain (grower, packer, distributor, wholesaler, retailer, produce manager, shelf stocker, shopper, and the ultimate consumer) considers certain attributes more important than others in determining the quality of a given fresh fruit or vegetable. In the absence of proper understanding of consumer behavior, it is difficult to determine as to what values are acceptable, and what is not (Abbott 1999). Instrumental measurements are always better than sensory evaluations because they reduce variations in judgment among individuals and can provide a common language among researchers, industry, and consumers (Abbott 1999). Similarly, nondestructive instrumental methods and chemical analyses are preferred because of better reproducibility. In any case, instrumental measurements must be validated by establishing their relationship to sensory perception by experienced, trained panelists prior to their commercial application.

Besides maintaining product quality and meeting consumer expectations, every participant in the postharvest chain must follow ethical and environmental approaches while ensuring efficient delivery of safe produce. To do so, appropriate postharvest technologies must be deployed at all steps of the supply chain (Fig. 6.1).

The fresh produce market has experienced rapid changes in recent years due to increased consumer demand and sophistication. To remain profitable in today's competitive environment, there is a need to reduce costs, streamline postharvest operations, expand product range throughout the year, and improve customer services. Inventory mechanization and automation and use of specialty wholesalers and fixed contracts with suppliers are being used to cut costs and manage the product quality more efficiently. The application of sound organizational and industrial management practices to manage produces, processes, and organizational quality has now become more important than ever before. Supermarket chains have well-established produce quality assurance systems in place to maintain superior sensory qualities of the produce, to protect the public from pathogens and other harmful substances, and meet stringent national and regional food legislation requirements. Quality assurance systems also guarantee that product specifications, including safety and quality attributes are adhered to in a timely fashion, at minimal cost, and in compliance with existing regulations.

CONCLUSIONS

Crop yields have increased dramatically during the past 50 years, and consequently, agricultural enterprises have become economically more viable than before. In the past, postharvest research was conducted in isolation without much consideration to what happened before harvest (production) or after retail sale (home storage and consumption). Much of the variation observed during postharvest storage can be attributable to preharvest factors. In addition, the key to increasing the volume of an item consumed and the economic value of the item lies in understanding consumer preferences. Progress in postharvest quality management of fresh fruits and vegetables will require establishment and continuous refinement of proper criteria and procedures to determine and regulate quality at various stages in the postharvest chain, improved understanding of preharvest factors that influence storage requirements and storage life of various fruits and vegetable produce, and reliable models to predict both the storage requirements and the period of optimum marketability under a specified set of handling conditions.

The application of sophisticated postharvest handling and storage technologies and efficient marketing strategies has ensured year-round supply of most food crops even in places that are far away from the place of production. New scientific tools and business management strategies have become available, bringing with them a wide range of opportunities for managing the product quality (Garvin 1984, Opara 2000a, 2000b, 2000c, 2009, Opera et al. 2002). As a result, product quality and its management have now become important strategic tools and skills to gain access to new markets, while retaining share in the current market. With increasing globalization, sophistication of markets and increasing consumer demands for better products and services, there is a continuous need for new business and quality management models. Cooperation among researchers, produce handlers, consumers, and other stakeholders as well as a continuous flow of technological innovations will be crucial in the successful management of quality and safety of fresh produce in the postharvest chain and in retaining competitive edge in an era of increasing global competition.

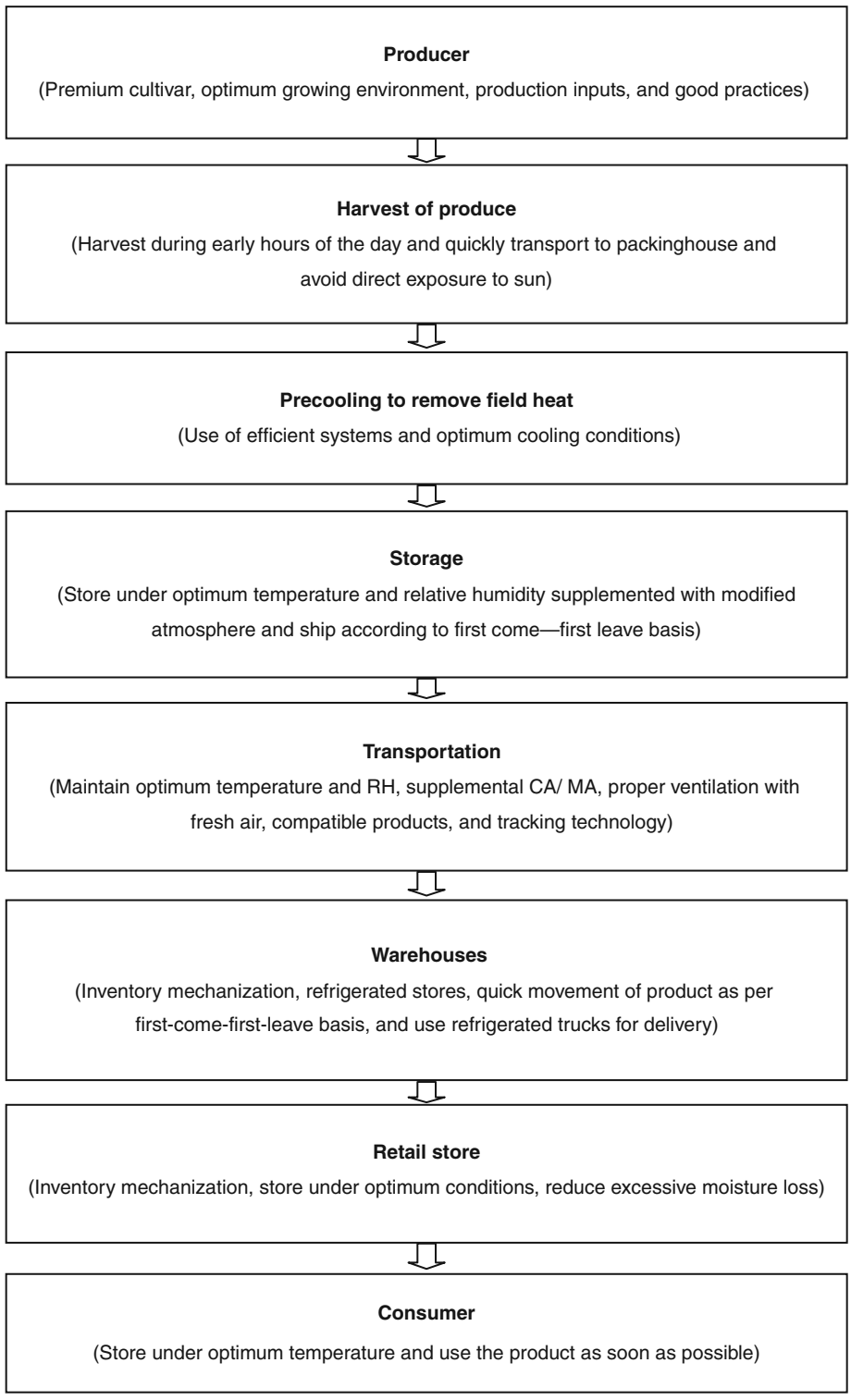

Figure 6.1. Total quality management for fresh fruits and vegetables.

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7
Freezing Preservation of Fruits

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Abstract: Freezing is one of the best methods for long-term storage of fruits. Freezing preserves the original color, flavor, and nutritive value of most fruits. Fresh fruits, when harvested, continue to undergo chemical, biochemical, and physical changes, which can cause deterioration reactions such as senescence, enzymatic decay, chemical decay, and microbial growth. The freezing process reduces the rate of these degradation reactions and inhibits the microbiological activity. However, it should be recognized that a number of physical, chemical, and biochemical reactions can still occur under frozen storage and many will be accentuated when recommended conditions of handling, production, and storage are not maintained. This chapter reviews different factors (type of fruit, varietal characteristics, stage of maturity, pretreatments, type of pack, rate of freezing) affecting safety and sensorial and nutritional quality of frozen fruit. Control freezing process, frozen storage, and thawing are critical to getting a fruit-derived products of high quality after freezing and thawing.

INTRODUCTION

Freezing is one of the fundamental methods for long-term preservation and storage of fruits. It preserves sensory (color and flavor), nutritive value, and microbial quality of most fruits. Upon harvest, fruits continue to undergo chemical, biochemical, and physical changes, which can cause quality loss and spoilage if fruits are not stored and handled properly. The freezing process reduces the rate of these degradation reactions and inhibits the microbiological activity. However, it should be recognized that a number of physical, chemical, and biochemical reactions can still occur and many will be accentuated when recommended conditions of handling, production, and storage are not maintained. Although few microorganisms grow below –10°C, it should be recognized

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that freezing and frozen storage is not a reliable biocide. The production of safe frozen fruits requires the same maximum attention to good manufacturing practices (GMP) and hazard analysis critical control points (HACCP) principles as those used in fresh products. The quality of the frozen fruits is very dependent on other factors such as the type of fruit, varietal characteristics, maturity, pretreatments, type of pack, and the rate of freezing. The freezing process reduces the fruit temperature to a storage level (–18°C), and maintaining this temperature allows the preservation of the frozen product for 1 year or more. Fruits are frozen in different shapes and styles: whole, halves, slices, cubes, in sugar syrup, with dry sugar, with no added sugar, or as juices, purees, or concentrates, depending on the end-use. The influence of freezing, frozen storage, and thawing on fruit quality has been extensively reviewed (Reid 1996, Skrede 1996, Hui et al. 2004). The objective of this chapter is to describe the main principles of manufacturing and processing of frozen fruits (selection of raw material, pretreatments, packaging, freezing process, and frozen storage) and review the current topics on the sensory and nutritional quality and safety of frozen fruits.

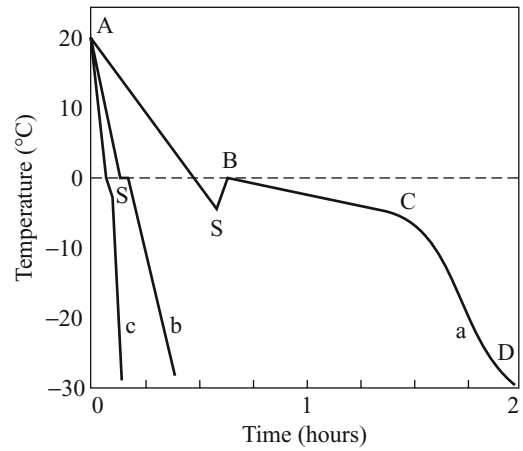

Figure 7.1. Typical freezing curves of foods at different rates: (a) very slow, (b) fast, and (c) very fast. (Adapted from Fennema 1976.)

FREEZING PRINCIPLES

The freezing process reduces food temperature until its thermal center (food location with the highest temperature at the end of freezing) reaches –18°C, with the consequent crystallization of water, the main component of plant tissues. Water constitutes 85–90% of the fruit's composition. From a physical point of view, plant and animal tissues can be considered as a dilute aqueous solution, which is the natural medium where chemical and biochemical cellular reactions take place and microorganisms grow. Crystallization of water during freezing reduces water activity (a_w) in these tissues and consequently produces a decline in chemical and biochemical reactions and microbial growth. Freezing involves the use of low temperatures at which the rate of most reactions is reduced. The study of temperature changes during freezing is basic to an understanding of how products are processed. Figure 7.1 shows typical freezing curves at different freezing rates. When the product is cooling down to 0°C, ice begins to develop (see section A–S, Fig. 7.1). The exact temperature for the formation of first ice crystal depends on the type of product and is a consequence of the constituents concentration independent of water content; for example, fruits with high water content (≈90%) have a freezing point below –2°C or –3°C, while meat with less water content (≈70%) has a freezing point of –1°C; the main difference being the high sugar and organic acid concentration in fruits. Ice formation takes place after the product reaches a temperature below its freezing point (–5°C to –9°C) for only a few seconds. This process is known as supercooling (position S in Fig. 7.1). After that, due to heat release during the first ice formation, the temperature increases until the freezing point is reached (position B in Fig. 7.1). Section B–C in Figure 7.1 corresponds to the freezing of most of the tissue water at a temperature that is practically constant, with a negative slope from a decline of the freezing point due to solute concentration. The increase of solute concentration as freezing progresses causes the unfrozen portion to undergo marked changes in such physical properties as ionic strength, pH, and viscosity. This increases the risk of enzymatic and chemical reactions, for example, enzymatic browning or oxidation–reduction, with adverse effects on frozen fruit quality. A short B–C section increases the quality of frozen fruit. This means that a fast rate freezing produces a better quality frozen fruit (see curves b and c of Fig. 7.1). Section C–D corresponds with the cooling of the product until the storage temperature, with an important increase of solute concentration in the unfrozen portion. Below –40°C, new ice formed is undetected. Up to 10% of the water can be unfrozen, mainly joined to protein or polysaccharide macromolecular structures that take part in the physical and biochemical reactions. In frozen foods, the relationship between the frozen water and the residual solution is dependent on the temperature and the initial solute concentration. The presence of ice, and an increase in solute concentration, has a significant effect on the reactions and state of the fruit matrix. The concentration of the solute increases as freezing progresses; and thus, solute concentration of the unfrozen matrix can leach out of the cellular structures, causing loss of turgor and internal damage. Solute-induced damage can occur whether freezing is fast or slow, and cryoprotectants, such as sugars, are usually added to aqueous solution to reduce the cell damage (Reid 1996, Rahman 1999).

Freezing Rate

Controlling the freezing rate is an important aspect of reducing cell damage, which causes quality losses in frozen fruits. Three types of cell damage due to freezing have been reviewed:

- Solute-induced damage
- Osmotic damage
- Structural damage.

Although solute-induced damage is present in fast and slow freezing processes, it can be minimized by slow speed. Osmotic and structural damages are dependent on the rate of freezing.

Freezing rate is the speed at which the freezing front goes from the outside to the inside of the product and depends on the freezing system used (mechanical or cryogenic), the initial temperature of the product, the size and form of the package, and the type of product. The freezing process (as a function of the rate) can be defined as follows (IIR 1996):

- Slow, 1 cm/h
- Semi-quick, 1–5 cm/h
- Quick, 5–10 cm/h
- Very quick, 10 cm/h.

Generally, quick freezing produces better quality frozen fruits. Individually quick freezing between 5 and 10 cm/h is an efficient way to obtain individual frozen fruits with high quality. The rate of freezing is very important in plant tissues because it determines the size, form, and status of the ice crystals, factors that affect cell wall integrity. If the rate of freezing is very slow, large ice crystals are formed slowly in the outer of cells and water from the cells migrate out by osmotic pressure (Fig. 7.2, up). Then, the cellular membranes are damaged during thawing, and the consequence of migration is an important drip loss.

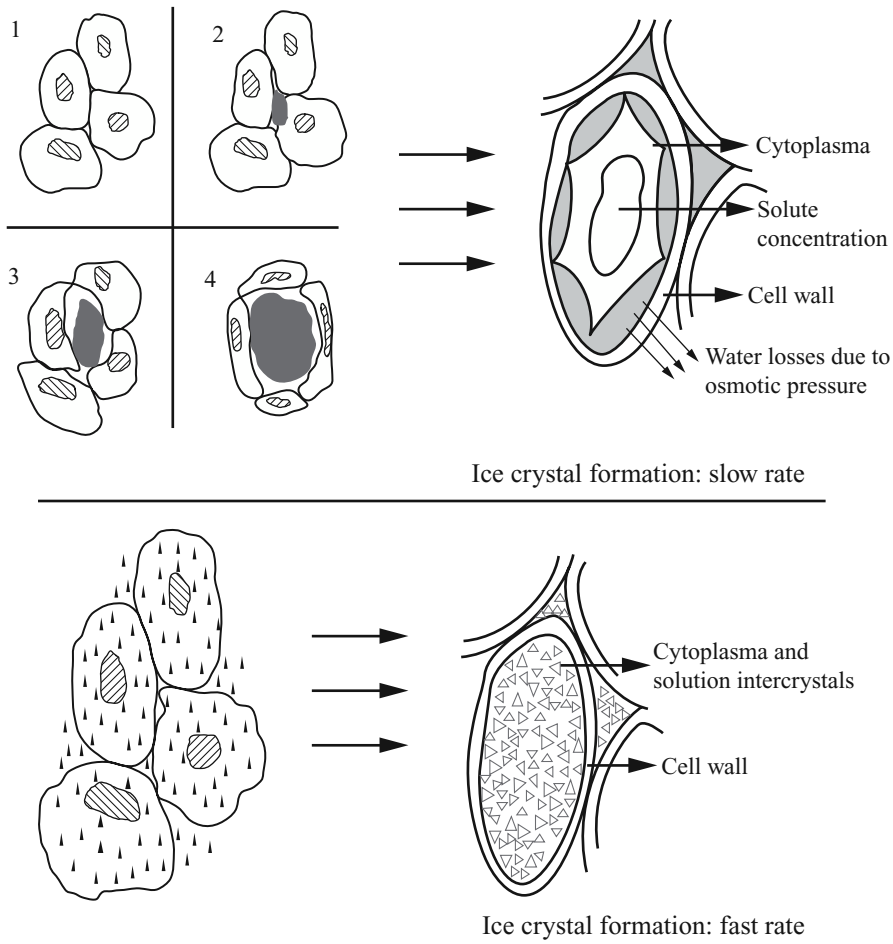

Figure 7.2. Ice crystal formation in plant tissues at slow rate (Fig. 7.2, up) and at fast rate (Fig. 7.2, down).

In slow cooling, large sharp ice crystals are formed and may cause damage to delicate organelle and membrane structure of the cell. As a consequence, enzymatic systems and their substrates may be released, leading to different effects such as off-flavors and color and textural changes, etc. These effects can be prevented by applying prefreezing treatments like the addition of chemicals or by blanching, a heat treatment that denatures the enzymes. In a rapid rate freezing process, small size and round ice crystals increase at the same time, both inside and outside of the cell, and structural and osmotic damages are minimal (Fig. 7.2, down). Although fast freezing is better than slow freezing in fruit and vegetable products, the importance of freezing speed is sometimes misleading. The initial advantage obtained by fast freezing can be lost during storage due to recrystallization as a consequence of temperature fluctuations. Also, some products, such as whole fruits, will crack if they are exposed to extremely low temperature. This is due to volume expansion, internal stress, and the contraction and expansion phenomenon (Reid 1996, Rahman 1999).

FACTORS AFFECTING FROZEN FRUIT QUALITY

The freezing of fruits slows down, but does not stop, the physical, chemical, and biochemical reactions that cause quality deterioration. There is a slow progressive change in sensory and nutritional quality during frozen storage that becomes noticeable after a period of time. Safe, high-quality frozen fruits with maximum nutritional values can be produced if diligent controls are maintained at all times. These include temperature control, extended quality shelf life, microbiological safety, and the retention of nutrients.

Two principles dominate the control of quality and safety in frozen foods: product–process–package (PPP) factors and time–temperature–tolerance (TTT) factors. PPP factors need to be considered at an early stage in the production of frozen fruits, and they are the bases of commercial success of the product. The PPP factors are as follows:

- *Product*: High-quality frozen food requires high-quality raw materials and ingredients.
- *Process*: The speed and effectiveness of the freezing operations and the use of additional processes (blanching, etc.).
- *Package*: Packaging offering physical and chemical barriers.

TTT factors maintain the quality and safety during storage. TTT concepts refer to the relationship between storage temperature and storage life. For different foods, different mechanisms govern the rate of quality degradation, and the most successful way of determining practical storage life is to subject the food to long-term storage at different temperatures. TTT relationships predict the effects of changing or fluctuating temperatures on quality shelf life (IIR 1996).

Safe, high-quality frozen fruits with maximum nutritional values can be produced if the directions given below are followed:

- Selection of suitable product for freezing
- PPP factors
- Knowledge of the effect of freezing, frozen storage, and thawing on the fruit tissues that causes physical, chemical, and biochemical changes
- Stability of frozen fruits (TTT factors)
- Thawing
- Microbiological quality and safety of frozen fruits.

Selection of Suitable Product for Freezing

High-quality frozen fruit requires high-quality raw material. Generally, quality cannot be gained from processing, but it certainly can be lost. Fruits are best when frozen fully ripe but still firm and at the peak of quality, with a pleasing color, texture, flavor, and maximum nutritional value. Large differences in frozen fruit quality exist between fruit varieties and cultivars based on chemical, biochemical, and physical characteristics that determine the sensory and nutritional quality. Differences in cell wall structure, enzyme activity, amounts of pigments, sugars, organic acids, volatile compounds, vitamins C, A, and E, and other components are factors that affect the differences in sensory and nutritional quality of raw fruits. Freezing potential of fruit varieties or cultivars are evaluated with practical trials after freezing, frozen storage, and thawing of the fruit products. The suitability of varieties or cultivars for freezing can be studied on the basis of physical (texture and color), physical–chemical (pH, acidity, and soluble solids), chemical (volatile, pigments, and polyphenol compounds), nutritional (vitamins and dietary fiber content), and sensory aspects (firmness, color, and taste). These studies have been done with different fruits such as kiwi (Cano and Marín 1992, Cano et al. 1993a), mango (Marín et al. 1992, Cano and Marín 1995), pineapple (Bartolomé et al. 1996a, 1996b, 1996c), papaya (Cano et al. 1996a, Lobo and Cano 1998), raspberry (De Ancos et al. 1999, 2000a, 2000b, González et al. 2002), and strawberry (Castro et al. 2002). Another criterion for selection of suitable variety or cultivar can be the enzymatic systems activity (polyphenoloxidase (PPO), peroxidase (POD), lipoxygenase (LOX), etc.) in raw fruit and during freezing and frozen storage. Employing varieties with low enzymatic activities could reduce the development of browning, off-flavors and off-odors, and color and textural changes (Cano et al. 1990b, 1996b, 1998, González et al. 2000).

Harvesting fruits at optimum level for freezing purposes is difficult. The need for efficient production often implies the use of mechanical harvesting at a time when the fruit has reached an acceptable maturity level to avoid mechanical

damage. Postharvest techniques allow the storage of unripe climateric fruits at specific atmosphere, temperature, and humidity conditions until they reach proper maturity levels to be frozen (Cano et al. 1990a, 1990b, Marín et al. 1992). Nonclimateric fruits (strawberries, raspberries, etc.) are harvested, preferably when fully ripe but still firm, cooled immediately after picking, and frozen as soon as possible (González et al. 2002). However, the quality advantages of immediate freezing could not be detected after a long frozen storage period (6–12 months; Plocharski 1989).

Preparing, Pretreatments, and Packaging

Successful freezing should retain the initial quality present in the raw fruit selected for freeze processing.

Preparing

Fruits must be prepared before freezing according to the frozen fruit end-use. Washing, rinsing, sorting, peeling, and cutting the fruits are not specific steps for frozen fruits; these are preparatory operations similar to other types of processing but must be carried out quickly and with great care to avoid damaging the fragile fruit tissue. Peeling, stone removal, and cutting in cubes, slices, or halves are usually mechanical operations. Size reduction before freezing results in a faster freezing and consequently a better frozen fruit quality. For economical factors, certain fruits like peaches, apricots, and plums are frozen whole immediately after harvesting and peeling; stone removal and cutting is done after a partial thawing.

Consumption of fruit juices and nectars has increased in the world due to recommendations for better nutrition and healthier diets. Fruits and fruit juices meet these recommendations. Nectars and fruit juices can be manufactured with fresh fruit, but with frozen fruit, higher yields are obtained.

At present, frozen juices represent an important segment of the international drink industry. Preparing fruit for frozen juice requires different steps: pressing, clarification, heat treatment, and concentration. Also, purees and pulps represent an important ingredient for the manufacturing industries for dairy products, cakes, ice creams, jellies, and jams (Chen 1993).

Pretreatments

The importance of enzyme content to fruit quality has been extensively reviewed (Philippon and Rouet-Mayer 1984, Robinson and Eskin 1991, Friedman 1996, Browleader et al. 1999). Enzymes, namely PPO, POD, LOX, catalase (CAT), and pectinmethylesterase, are involved in the fast deterioration of fruit during postharvest handling and processing. Enzymes not inactivated before freezing can produce off-flavors, off-odors, color changes, development of brown color, and loss of vitamin C and softness during frozen storage and thawing. Water blanching is the most common method for inactivating vegetable enzymes (Fellows 2000). It causes denaturation and, therefore, inactivation of the enzymes that also causes destruction of thermo-sensitive nutrients and losses of water-soluble compounds such as sugar, minerals, and water-soluble vitamins. Blanching is rarely used for fruits because they are usually consumed raw and heat treatment causes important textural changes. An alternative to blanching fruit is to use ingredients and chemical compounds that have the same effect as blanching.

Blanching Heat treatment to inactivate vegetable enzymes can be applied by immersion in hot water, by steam blanching or by microwave blanching. Hot water blanching is usually done between 75°C and 95°C for 1–10 minutes, depending on the size of the produce. Hot water blanching also removes tissue air and reduces the occurrence of undesirable oxidation reactions during freezing and frozen storage. Steam blanching reduces the water-soluble compounds losses and is more energy efficient than water blanching. Of all the enzymes involved in producing quality losses during processing, POD and CAT seem to be the more heat stable, and thus could be used as an index of adequate blanching. Generally, a quality blanched produce permits some POD and CAT activity. Complete POD inactivation indicates overblanching. Blanching also helps to destroy microorganisms on the surface of the produce. Blanching destroys semipermeability of cell membranes and removes cell turgor. Reduced turgor is perceived as softness and lack of crispness and juiciness. These are some of the most important sensory characteristics of fruit. Although loss of tissue firmness in blanched frozen fruits after thawing indicates that blanching is not a good pretreatment for the majority of the fruits, some results have been interesting (Reid 1996). Hot water blanching peeled bananas prior to slicing, freezing, and frozen storage produced complete PPO and POD inactivation and a product with acceptable sensory quality (Cano et al. 1990a). Microwave blanching has not been an effective pretreatment for banana slices (Cano et al. 1990b) but interesting results have been obtained with frozen banana purees (Cano et al. 1997).

Addition of Chemical Compounds Substitutes for thermal blanching have been tested with different enzymatic inhibitors. They are mainly antibrowning additives such as sulfiting agents (sulfur dioxide or inorganic sulfites salts) and ascorbic acid, which are applied by dipping or soaking the fruit in different solutions before freezing (Skrede 1996). Enzymatic browning involving the enzyme PPO is the principal cause of fruit quality losses during postharvest and processing. PPO catalyzes the oxidation of mono- and orthodiphenols to quinones, which can cyclize, undergo further oxidation, and polymerize to form brown pigments or react with amino acids and proteins that enhance the brown color produced (Fig. 7.3).

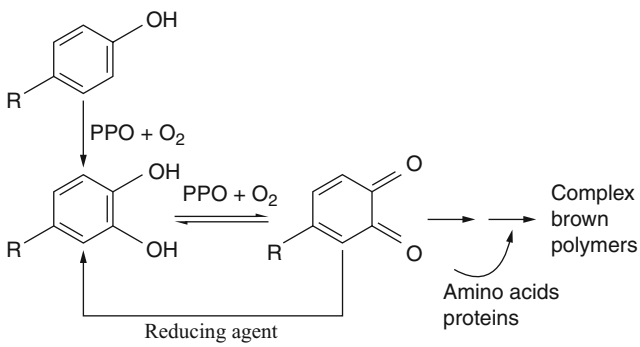

Figure 7.3. Enzyme-catalyzed initiation of browning by PPO showing the point of attack by reducing agents.

The proposed mechanisms of antibrowning additives that inhibit enzymatic browning are (1) direct inhibition of the enzyme, (2) interaction with intermediates in the browning process to prevent the reaction leading to the formation of brown pigments, or (3) to act as reducing agents, promoting the reverse reaction of the quinone back to the original phenols (Fig. 7.3; Friedman 1996, Ashie et al. 1996). Other acid treatments such as dipping in citric acid or hydrochloric acid solution (1%) could be a commercial pretreatment for browning control and quality maintenance of frozen litchi fruit (Yueming-Jiang et al. 2004). Although all the fruits contain polyphenolic compounds, some fruits as peaches, apricots, plums, prunes, cherries, bananas, apples, and pears show a greater tendency to develop browning very quickly during processing. Research efforts have been done to develop new natural antibrowning agents in order to replace sulfites, the most powerful and cheapest product until now, but they cause adverse health effects in some asthmatics. In this framework, Maillard reaction products have been recognized as a strong apple PPO inhibitor (Billaud et al. 2004). Also, some frozen fruits like apples and cherimoya are pretreated by dipping its slices in sodium chloride solutions (0.1–0.5%) in combination with ascorbic or citric acid, in order to remove intracellular air and reduce oxidative reactions (Reid 1996, Mastrocola et al. 1998).

Fruit texture is significantly altered by freezing, frozen storage, and thawing. Fruits have thin-walled cells rich in pectin substances, in particular in the middle lamella between cells, and with a large proportion of intracellular water, which can freeze, resulting in cell damage. Freezing–thawing also accelerates the release of pectin, producing de-esterification of pectins and softens the fruit tissue. Optimum freezing rate reduces tissue softening and drip loss, and the addition of calcium ions prior to freezing increases the firmness of fruit after thawing. These ions fortify the fruit by changing the pectin structure. Calcium maintains the cell wall structure in fruits by interacting with the pectic acid in the cell walls to form calcium pectate. Dipping in calcium chloride solution (0.18% Ca) or pectin solution (0.3%) improves the quality of frozen and thawed strawberries (Suutarinen et al. 2000).

Osmotic Dehydration: Addition of Sugars and Syrups

Dipping fruits in dry sugar or syrups is a traditional pretreatment to preserve color, flavor, texture, and vitamin C content and to prevent the browning of frozen–thaw fruits. Sugar or syrups are used as cryoprotectants by taking out the fruit cell water by osmosis and excluding oxygen from the tissues. Partial removal of water before freezing might reduce the freezable water content and decrease ice crystal damage, making the frozen fruit stable. Therefore, minor damage to cellular membranes occurs and oxidative reactions and enzymatic degradation reactions are minimized. The process of dehydration before freezing is known as *dehydrofreezing* (Fito and Chiralt 1995, Robbers et al. 1997, Bing and Da-Wen 2002). During osmotic dehydration, the water flows from the fruit to the osmotic solution, while osmotic solute is transferred from the solution into the product, providing an important tool to impregnate the fruit with protective solutes or functional additives. Syrup is considered a better protecting agent than dry sugar. Dry sugars are recommended for fruits, such as sliced peaches, strawberries, figs, grapes, cherries, etc., that produce enough fruit juice to dissolve the sugar. Dipping fruit, whole or cut, in syrup allows a better protection than dry sugar because the sugar solution is introduced inside the fruit. Syrup concentrations between 20% and 65% are generally employed, although 40% syrup is enough for the majority of the fruits. Sucrose is the osmotic agent most suitable for fruits although other substances, including sucrose, glucose, fructose, lactose, L-lysine, glycerol, polyols, maltodextrin, starch syrup, or combinations of these solutes can be used (Bing and Da-Wen 2002, Zhao and Xie 2004). Osmotic dehydration is carried out at atmospheric pressure or under vacuum. Among developments in osmotic treatments, vacuum impregnation may be the newest. The exchange of partial freezable water for an external solution is promoted by pressure, producing different structural changes and lower treatment time than osmotic dehydration at atmospheric pressure. Successful applications of dehydrofreezing and vacuum impregnation on fruits have been recently reviewed (Zhao and Xie 2004). Great color, flavor, and vitamin C retention have been achieved in frozen–thawed strawberries, raspberries, and other types of berries treated with a 20% or 40% syrup concentration before freezing and long-term frozen storage between 6 months and 3 years (Skrede 1996). The effects of dehydrofreezing process on the quality of kiwi, strawberry, melon, and apples have been reported (Garrote and Bertone 1989, Tregunno and Goff 1996, Spiazzi et al. 1998, Talens et al. 2002, 2003). The quality and texture of dehydrofrozen and thawed fruit has been improved by using osmotic solutions in combination with ascorbic acid solution (antibrowning treatment) and/or calcium chloride or pectin solutions (Skrede 1996, Suutarinen et al. 2000, Talens et al.

2002, 2003, Zhao and Xie 2004). Another important factor contributing to fruit quality improvement is vacuum impregnation, which is useful in introducing functional ingredients into the fruit tissue structure, conveniently modifying their original composition for development of new frozen products enriched with minerals, vitamins, or other physiologically active nutritional components (Zhao and Xie 2004).

Packaging

Packaging of frozen fruits plays a key role in protecting the product from air and oxygen that produce oxidative degradation, contamination by external sources, and damage during shipping. Package barrier properties protect the frozen fruit from oxygen, light, and water vapor, each of which can result in deterioration of colors, oxidation of lipids and unsaturated fats, denaturation of proteins, degradation of ascorbic acid, and a general loss of characteristic sensory and nutritional qualities. Similarly, barrier properties protect against the loss of moisture from the frozen food to the external environment to avoid external dehydration or "freezer burn" and weight loss. The primary function of food packaging is to protect the food from external hazards. In addition, packaging materials should have a high heat transfer rate to facilitate rapid freezing. Also, the package material should not affect the food in any way, as indicated by European Directives on food contact materials, including migration limits (EC Directives 1990, 2002) and the Code of Federal Regulations in the United States regarding food contact substances (CFR 2004). A wide range of materials has been used for packaging of frozen fruits, including plastic, metals, and paper/cardboard, or polyethylene bags. Laminates can provide a combination of "ideal" package properties. Board and paper packages are often laminated with synthetic plastics to improve the barrier properties. Table 7.1 shows some comparisons of barrier properties for a range of common package materials. Fruit products can be packaged before freezing (fruits with sugar or syrup, purees and juices concentrated or not) or after freezing (whole or cut fruits). The importance of packaging material to the stability of frozen fruits has been reviewed (Skrede 1996). In general, quality differences (pigment content, ascorbic acid retention, color, and consistency) between frozen products packaged in different types of packages are mainly detected after a long period of frozen storage (>3 months) and at temperatures over –18°C.

Effect of Freezing, Frozen Storage, and Thawing on Fruit Tissues: Physical, Chemical, and Biochemical Changes

Plant Cell Structure

Understanding the effect of freezing on fruit requires a short review of plant cell structure. A relationship between cell structure properties and freezing cell damage has been extensively reviewed (Reid 1996, Skrede 1996). Plant cells are surrounded by a membrane and interspersed with extensive membrane systems that structure the interior of the cell into numerous compartments. The plasmalemma or plasma membrane encloses the plasma of the cell and is the interface between the cell and the extracellular surroundings. Contrary to animal cells, plant cells are almost always surrounded by a cell wall and many of them contain a special group of organelles inside: the plastids (chloroplasts, leucoplasts, amyloplasts, or chromoplasts; Fig. 7.4).

An important property of the plant cell is its extensive vacuole. It is located in the center of the cell and makes up the largest part of the cells volume and is responsible for the turgor. It helps to maintain the high osmotic pressure of the cell and the content of different compounds in the cell, among which are inorganic ions, organic acids, sugars, amino acids, lipids, oligosaccharides, tannins, anthocyanins, flavonoids, and more. Vacuoles are surrounded by a special type of membrane, the tonoplast. The cell wall of plants consists of several stacked cellulose microfibrils embedded in a

Table 7.1. Relative Oxygen and Water Vapor Permeabilities of Some Food Packaging Materials (References Values Measured at 23°C and 85% RH)

	Relative Permeability	
Package Material	Oxygen (mL m^{-2} day^{-1} atm^{-1})	Water Vapor (g m^{-2} day^{-1})
Aluminum	<50 (very high barrier)	<10 (very high barrier) variable
Ethylene vinyl acetate (EVOH)	<50 (very high barrier)	
Polyester (PET)	50–200 (high barrier)	10–30 (high barrier)
Polycarbonate (PC)	200–5000 (low barrier)	100–200 (medium barrier)
Polyethylene (PE)		
High density (HDPE)	200–5000 (low barrier)	<10 (very high barrier)
Low density (LDPE)	5000–10,000 (very low barrier)	10–30 (high barrier)
Polypropylene (PP)	200–5000 (low barrier)	10–30 (high barrier)

Source: Atmosphere Controle 2000 (http://atmosphere-controle.fr/permeability.html).

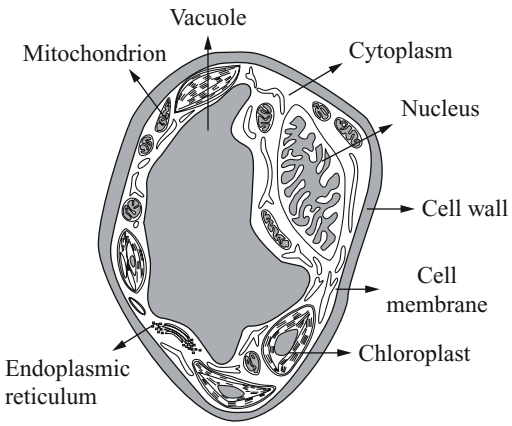

Figure 7.4. Cross-section of a plant cell.

polysaccharide matrix able to store water, thereby increasing the cell volume (hydration and absorbtion). According to their capacity to bind or store water, the polysaccharides involved in the matrix can be classified as follows: pectin > hemicellulose > cellulose > lignin.

Pectins are mainly polygalacturonic acids with differing degrees of G-galactosyl, L-arabinosyl, or L-rhanmosyl residue and are predominant in the middle lamella, the layer between cells. The de-esterification process of pectin is related to the softness of fruit tissues during ripening and processing.

Physical Changes and Quality

Volume Expansion The first factor that produces mechanical damage to the cell is the volume expansion due to the formation of ice that affects the integrity of cell membrane.

Recrystallization Ice crystals can change the quality of frozen fruits in different ways. First, the speed of freezing affects frozen–thaw fruit quality. Slow speed freezing produces large and sharp ice crystals that can produce mechanical damage to the fragile plants cell membranes, causing the cell organelles to collapse and lose their contents (sugars, vitamins, pigments, volatile compounds, phenol, enzymes, etc.) and a breakdown of the pectin fraction in the cell wall, which affects fruit tissue texture. During frozen storage, retail-display, or the carry-home period, fluctuations in product temperature produces ice recrystallization that affects the number, size, form, and position of the ice crystal formed during freezing. Frequent large fluctuation produces partial fusion of ice and the reforming of large and irregular ice crystals that can damage cellular membranes and produce a freeze-dried product, allowing sublimed or evaporated water to escape.

Sublimation: Freezer Burn The sublimation of the ice may occur during frozen storage if the packaging product is unsuitable. Moisture loss by evaporation from the surface of the product leads to "freezer burn," which is recognized as a light-colored zone on the surface of the product. Dehydration of the product can be avoided by improving the type of package, increasing humidity, and decreasing the storage temperature.

The recrystallization and freezer burn dehydration increase with temperature fluctuations, but the harmful effect of these two processes on frozen fruit quality can be decreased by lowering the storage temperature below –18°C (IIR 1996).

Chemical and Biochemical Changes and Quality

The chemical and biochemical reactions related to sensory and nutritional quality changes of fruits are delayed but not completely stopped at subzero temperature. Quality changes, such as loss of the original fruit color or browning, development of off-odor and off-taste, texture changes, and oxidation of ascorbic acid, are the main changes caused by chemical and biochemical mechanisms that affect fruit quality. Also, pH changes in fruit tissues detected during freezing and frozen storage can be a consequence of these degradation reactions.

Color Changes Color is the most important quality characteristic of fruits because it is the first attribute perceived by the consumers and is the basis for judging the product acceptability. The most important color changes in fruits are related to chemical, biochemical, and physicochemical mechanisms: (a) breakdown of cellular chloroplasts and chromoplasts, (b) changes in natural pigments (chlorophylls, carotenoids, and anthocyanins), and (c) development of enzymatic browning.

Mechanical damage (ice crystals and volume expansion) caused by the freezing process can disintegrate the fragile membrane of chloroplasts and chromoplasts, releasing chlorophylls and carotenoids, and facilitating their oxidative or enzymatic degradation. Also, volume expansion increases the loss of anthocyanins by lixiviation due to disruption of cell vacuoles.

Chlorophylls Chlorophylls are the green pigment of vegetables and fruits, and their structures are composed of tetrapyrroles with a magnesium ion at their center. Freezing and frozen storage of green vegetables and fruits cause a green color loss due to degradation of chlorophylls (a and b) and transformation in pheophytins, which transfers a brownish color to the plant product (Cano 1996). One example is kiwi fruit slices that show a decrease in chlorophyll concentration between 40% and 60%, depending on cultivar, after freezing and frozen storage at –20°C for 300 days (Cano et al. 1993a). Different mechanisms can cause chlorophyll degradation: loss of Mg due to heat and/or acid, which transforms chlorophylls into pheophytins, or loss of the phytol group through the action of the enzyme chlorophyllase (EC 3.1.1.14), which transforms chlorophyll into pheophorbide.

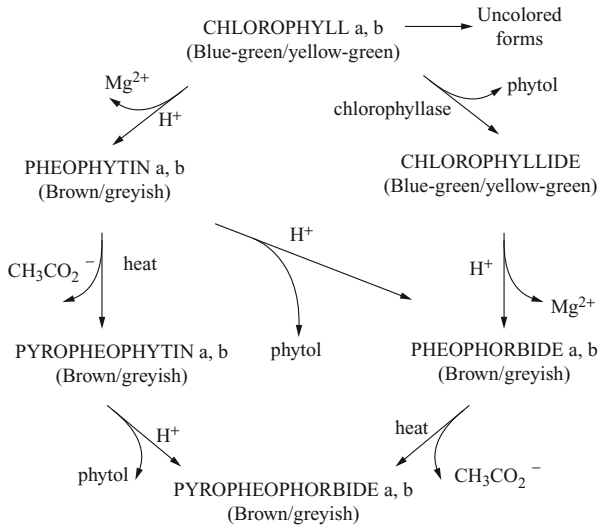

Figure 7.5. Pathways of chlorophyll degradation.

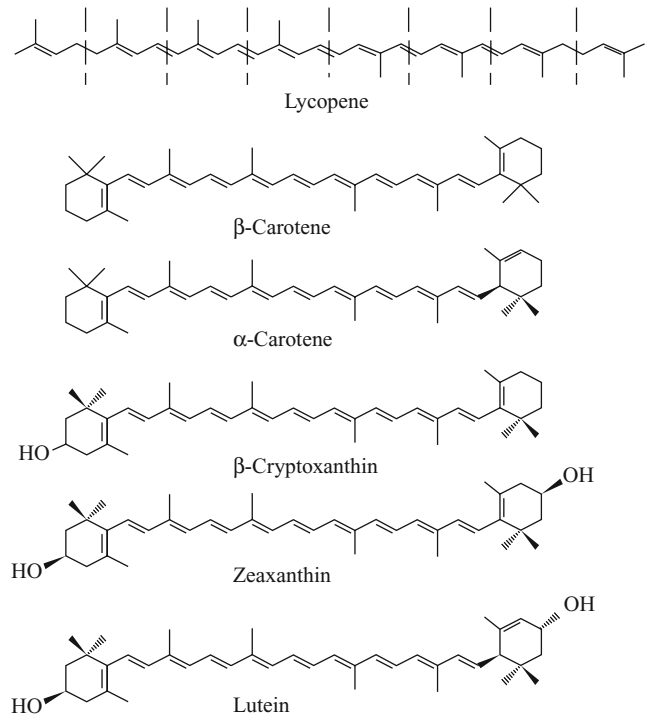

Figure 7.6. Structure of more frequent carotenoids present in fruits.

Loss of the carbomethoxy group may also occur and pyropheophytin and pyropheophorbide can be formed (Fig. 7.5; Heaton et al. 1996).

Acids, temperature, light, oxygen, and enzymes easily destroy the chlorophylls. Thus, blanching (temperature/time), storage (temperature/time), and acidity are the important factors to be controlled during processing in order to preserve chlorophylls. Other chlorophyll degradation mechanism can cause degradation by the action of peroxides, formed in the fruit tissue due to the oxidation reaction of polyunsaturated fatty acids catalyzed by the enzyme LOX. An important quality parameter employed to determine the shelf life of frozen green fruits is the formation of pheophytins from chlorophylls. As different types of enzymes can be involved in chlorophyll degradation (LOX, POD, and chlorophyllase), blanching and addition of inorganic salts such as sodium or potassium chloride and sodium or potassium sulfate are efficient treatments to preserve green color (IIR 1996, Cano and Marín 1992, Cano et al. 1993a, 1993b).

Carotenoids: Carotenoids are among the most abundant pigments in plant products and are responsible for the yellow, orange, and red color of most of the fruits. All of them are tetraterpenes and contain 40 carbon atoms in eight isoprenes residues. β-carotene and lutein are the carotenoids present in most of the fruits. Important sources of these pigments are as follows (Fig. 7.6):

- β-Cryptoxanthin: oranges
- Lycopene: tomatoes, watermelon, papaya, and persimmon
- α-Carotene: banana and avocado
- Zeaxanthin: orange and peach

Carotenoids are affected by pH, enzymatic activity, light, and oxidation associated with the conjugated double bond system. The chemical changes occurring in carotenoids during processing have been reviewed by several authors (Simpson 1986, Rodriguez-Amaya 1997). The main degradation reaction that damages carotenoid compounds is isomerization. Most plants appear to produce mainly *trans* forms of carotenoids but with increased temperature, the presence of light, and catalysts such as acids, isomerization to the *cis* forms increases, and the biological activity is dramatically reduced. However, heat treatments of products rich in carotenoids reduce the degradation of carotenoids because of the inactivation of enzymes LOX and POD. Blanching fruits before freezing could be efficient in the preservation of carotenoids due to enzyme inactivation. Although most carotenoids are heat resistant, some carotenoids, such as epoxycarotenoids, could be affected. Carotenoids are fat-soluble pigments and breakdown of chromoplasts, by heat treatment or mechanical damage, improves their extraction with organic solvents and bioavailability but not their loss by lixiviation (Hof et al. 2000). Freezing without protector pretreatment slightly decreases the total carotenoid concentration (20%) of some fruits rich in carotenoids, such as mango and papaya. But after 12 months of frozen storage at –18°C, an important decrease of total carotenoid concentration

(between 40% and 65%) occurred, although the carotenoid profile was unchanged (Cano and De Ancos 1994, Cano et al. 1996b). Similar results have been found with frozen tomato cubes. A pronounced stability of total carotenoids, β-carotene, and lycopene was recorded up to three months of storage. But after 12 months of storage at –20°C, the losses of carotenoids reached 36%, of β-carotene 51%, and of lycopene 48% (Lisiewska and Kmiecik 2000). Freezing and frozen storage could affect the carotenoid structure and concentration depending on the type of fruit and cultivar (pH, fats, antioxidants, etc.) and the processing conditions (temperature, time, light, oxygen, etc.; Simpson 1986, Rodriguez-Amaya 1997).

Anthocyanins: Anthocyanins are one class of flavonoid compounds, which are widely distributed plant polyphenols, and are responsible for the pink, red, purple, or blue hue of a great number of fruits (grape, plum, strawberry, raspberry, blackberry, cherry, and other types of berries). They are water-soluble flavonoid derivatives, which can be glycosylated and acylated. The effect of freezing, frozen storage, and thawing in different fruits rich in anthocyanins pigments have been reviewed by Skrede (1996). Anthocyanins in cherry fruit underwent pronounced degradation during storage at –23°C (87% after 6 months), but they are relatively stable at –70°C storage (Chaovanalikt and Wrolstad 2004). In raspberries, the stability of anthocyanins to freezing and frozen storage depends on the period of harvest. Spring cultivars were practically unaffected by freezing and frozen storage for 1 year at –20°C, but autumn cultivars showed a decreasing trend in total anthocyanin content (4–17%) (De Ancos et al. 2000b). In general, the freezing process does not affect the level of anthocyanins in raspberry fruit (De Ancos 2000b, Mullen et al. 2002). Anthocyanins are water-soluble pigments located in the vacuoles of cell and are easily lost by lixiviation when the cell membranes break down. Also, oxidation can play an important role in anthocyanin degradation catalyzed by light. PPO and POD enzymatic activities have been related to anthocyanin degradation. Thus, frozen–thawed cherry discoloration disappeared when the fruits were blanched before freezing. The changes in pH during processing can affect anthocyanin stability. Maintenance of red fruit requires an acid pH (pH < 3.5). The flavylium cation structure of anthocyanins transfers a red color to the fruit. But an increase in pH value produces a change from red to blue until the product is colorless, a consequence of transforming flavylium cation into a neutral structure (Fig. 7.7).

The loss of characteristic red color can also be produced by formation of the anthocyanin complex with different products present in the fruit matrix: ascorbic acid, acetaldehyde, proteins, leucoanthocyanins, phenols, quinones, metals (Fe^{3+} and Al^{3+}), hydrogen peroxide, etc. (Escribano-Bailón et al. 1996).

Enzymatic Browning: Browning usually occurs in certain fruits during handling, processing, and storage. Browning in fruit is caused by enzymatic oxidation of phenolic compounds by PPO (EC 1.10. 3.1; Martiner and Whitaker 1995). PPO catalyzes either one or two reactions involving molecular oxygen. The first type of reaction is hydroxylation of monophenols, leading to the formation of *o*-hydroxy compounds. The second type of reaction is oxidation of *o*-hydroxy compounds to quinones that are transformed into polymeric brown pigment (Fig. 7.3). Freezing, frozen storage, and thawing of fruits, like mangoes, peaches, bananas, apples, apricots, etc., quickly develop color changes that result in nonreversible browning or darkening of the tissues. Freezing does not inactivate enzymes; however, some enzyme activity is slowed during frozen storage (Cano et al. 1998). Browning by PPO can be prevented by the addition of sulfites, ascorbic acid, citric acid, cysteine, and others. The addition of antibrowning agents has been discussed in the pretreatments section. Selection of varieties with low PPO activity could help to control browning in frozen–thawed fruits (Cano et al. 1996b, 1998).

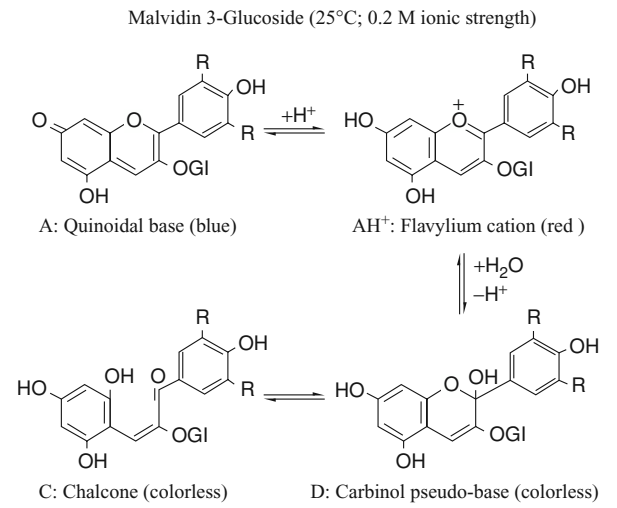

Figure 7.7. Effect of pH on anthocyanins.

Flavor and Aroma Changes Volatile compounds forming the fruit flavor (alcohols, esters, aldehydes, ketones, acids, furans, terpenes, etc.) are produced through metabolic pathways during harvest, postharvest, and storage and depend on many factors related to species, variety, and type of processing. Although freezing is the best way to preserve fruit aroma (Skrede 1996), frozen storage and thawing can modify the natural fresh aroma of some fruits such as strawberries (Larsen and Poll 1995), but other fruits like kiwi (Talens et al. 2003) or raspberry fruits (De Ancos 2000b) do not significantly modify the aroma profile. Freezing, frozen storage, and thawing affect fruits volatile profile in different ways depending on the type of fruit and variety.

Instead of being destroyed during freezing, some enzymes are released. This can cause cell disruption and is one factor in the development of off-flavors and off-odors in plant products during frozen storage. Blanching is the main tool used to inactivate enzymes before freezing, but most fruits suffer important textural changes when blanched. POD enzyme activity has been related to the presence of different volatile compounds such as hexanal, which is produced during lipid oxidation and confers an unpleasant odor to the frozen–thawed product. Cell structure disruption during freezing and frozen storage favors an increase in or preserved important enzymatic POD activity levels in different thawed fruits [mango (Marín et al. 1992) and papaya (Cano et al. 1998)]. It is important to select the suitable fruit varieties for freezing, based on high volatile compounds concentration and low enzymatic activity, to obtain high-quality frozen fruit.

Textural Changes Texture of frozen fruits is dependent on chemical and biochemical modifications of the cell wall and middle lamella components (pectins, hemicelluloses, and celluloses). Freezing causes severe texture loss due to the cryoconcentration phenomena, which can induce cell wall degradation and a decrease in liquid retention. The size and location of ice crystals cause cell membrane rupture that promotes enzyme and/or chemical activity and contributes to mechanical damage in cell wall material. The influence of freezing rate on tissue integrity, texture, and drip loss has been reviewed by different authors (Cano 1996, Reid 1996, Skrede 1996). Ice recrystallization also leads to greater damage during frozen storage (Reid 1996). Pectin is an important component of fruit cell wall. In fact, a decrease of the pectin fraction during freezing and frozen storage has been related to a reduction of firmness in different fruits (Lisiewska and Kmiecik 2000).

Nutritional and Antioxidant Status Changes Consumption of fruits is related to a good nutritional status and contributes to the prevention of degenerative processes, particularly lowering the incidence and mortality rate of cancer and cardiovascular disease (Steinmetz and Potter 1996, Tibble et al. 1998, Willcox et al. 2003). Nutritional compounds found in fruits are vitamins, sugars, minerals, proteins, and fats. Fruits are the main dietary source of vitamins C, A, and E, which are indispensable for human life. The protective effect of a rich fruit diet has been attributed to certain bioactive compounds with antioxidant and antimutagenic properties. Vitamins A and C, carotenoids, and phenolics are the main bioactive compounds that contribute to the antioxidant characteristics of fruits (Rice-Evans et al. 1996, Miller and Rice-Evans 1997, Boileau et al. 1999, Gardner et al. 2000). Retention of the nutritional and antioxidant value of fruit is the main goal of all the processing methods, and freezing and frozen storage can be one of the less destructive methods in terms of long-storage periods.

1. *Vitamin C*. Freezing processes have only a slight effect on the initial vitamin C content of fruit (Cano and Marín 1992, Marín et al. 1992, De Ancos 2000a). The destruction of vitamin C (ascorbic acid) occurs during freezing and frozen storage, and this parameter has been employed to limit the frozen storage period of frozen fruit. The main cause of loss of vitamin C is the action of the enzyme ascorbate oxidase. If pretreatments or freezing processes do not destroy this enzyme, it is continuously active during the frozen storage. Vitamin C degradation depends on different factors, such as time–temperature conditions, type of fruit, variety, pretreatments, type of package, freezing process, etc. (Skrede 1996). Thus, as the frozen storage temperature decreases, higher vitamin C retention is achieved for different fruits like berries, citrus, tomato, etc. (Skrede 1996, Lisiewska and Kmiecik 2000). Also, significantly different vitamin C retention values have been achieved between varieties of fruits such as raspberry (De Ancos 2000a), mango (Marín et al. 1992), and kiwi (Cano and Marín 1992), which were frozen and stored under the same conditions. Vitamin C stability in freezing and frozen storage of strawberries seems to be more dependent on storage temperature than on the type of freezing process. Nonstatistical differences were observed between strawberries processed by fast rate freezing (at –20°C) and quick rate freezing (at –50°C to –100°C), but great loss was shown between strawberries stored at –18°C and –24°C (Sahari et al. 2004).
2. *Provitamin A and Antioxidant Carotenoids*. Some carotenoids, like β-carotene, α-carotene, and β-cryptoxanthin, are recognized as precursors of vitamin A. These provitamin A carotenoids, in addition to lycopene and lutein, constitute the group of antioxidant carotenoids. The prevailing opinion is that freezing and frozen storage do not prevent degradation of carotenoids. The content of β-carotene, and consequently the provitamin A value, was decreased during frozen storage of mango (Marín et al. 1992), kiwi (Cano and Marín 1992), papaya (Cano 1996), and tomato (Lisiewska and Kmiecik 2000). The losses were mainly due to the activity of enzymes (POD, LOX, and CAT), particularly during frozen storage in an oxygen environment. Lycopene, a characteristic carotenoid in tomato fruit, has been recognized as a powerful antioxidant (Rao and Agarwal 1999, Lavelli et al. 2000). After 3 months of frozen storage (–20°C and –30°C), great stability of lycopene was recorded. After this period, slow losses occurred, the rate being faster at the higher storage temperature. After 12 months at –20°C and –30°C, the lycopene content was 48% and 26%, respectively, lower than that in the raw material (Lisiewska and Kmiecik 2000). Other authors have reported an increase in the extraction of lycopene after 1 month

of frozen storage, although after 3 and 6 months, the loss of lycopene concentration was significantly higher than 40% (Urbanyi and Horti 1989). Papaya fruit could be an important source of lycopene, but freezing and frozen storage at –20°C during 12 months produced a significant loss of lycopene concentration (34%) in frozen papaya slices (Cano 1996). Further discussion on the effect of freezing, frozen storage, and thawing on carotenoid stability are included in the section of color changes.

3. *Phenolic Compounds*. The freezing process does not modify either total phenolic content or ellagic acid concentration in raspberry fruit. There is an increasing interest in ellagic acid, a dimeric derivative of gallic acid, due to its anticarcinogenic and antioxidant effects. Although frozen storage produces a slight decrease in ellagic acid content because of PPO enzyme activity, frozen storage is a good methodology to preserve phenolic compounds during long-term periods (De Ancos 2000a).
4. *Antioxidant Capacity.* Radical scavenging capacity, a measure of the antioxidant capacity of fruit extracts, was not affected by freezing and long-term frozen storage (De Ancos 2000a).
5. *Dietary Fiber.* Comparative studies on dietary fiber content between fresh fruit pulp and the corresponding frozen fruit pulp have shown that frozen fruit pulp has lower fiber content than fresh fruit pulp. Freezing and frozen storage induced significant dietary fiber losses ranging from 18% for mango to 50% for other fruits like guava (Salgado et al. 1999).

Stability of Frozen Fruit

Physical, physicochemical, chemical, and biochemical changes that occur in frozen fruit during the storage period lead to a gradual, cumulative, and irreversible loss of quality that limits the storage life of frozen fruit. Temperature and length of storage time are the principal factors that limit the frozen storage period of fruit and are known as TTT factors. In general, lower storage temperatures lead to longer storage life. TTT data for each fruit was determined by different quality analysis of samples of the same product, identically processed, and stored at different temperatures in the range of –10°C to –40°C. At certain intervals of frozen storage, sample quality was analyzed. Sensory analysis, loss of vitamin C, and changes of chlorophylls to pheophytin, or other types of pigment degradation, are the quality analyses used to determine the storage life of the frozen fruit. On the basis of TTT data, different terms have been established to determine the suitable frozen storage life. "High-quality life" has been defined as the storage period quality of a frozen product compared to a similar quality of a product just frozen. After this time, frozen fruits are still suitable for consumption, and a second term has been defined as "practical storage life" or the storage time period that provides frozen foods suitable for human consumption. Table 7.2 shows the practical storage life for different frozen fruits stored at –12°C, –18°C, and –24°C. Fruit frozen with sugar or syrup added is more sensitive to an increase in frozen storage temperature because they freeze at lower temperature than fruit frozen without sugar. Thus, strawberries without sugar stored at –12°C have longer practical storage life (5 months) than fruit with sugar (3 months). These times for suitable storage were obtained on the basis of high-quality raw products, processing in suitable conditions, and without temperature fluctuations during frozen storage. Increasing and fluctuating temperature may occur during transport and retail display. Temperature fluctuations shorten the storage life of frozen foods because of accelerated degradation reactions and increased quality loss (IIR 1996, Cano 1996).

Table 7.2. "Practical Storage Life" at Different Frozen Storage Temperatures (in Months)

Fruit	–12°C	–18°C	–24°C
Strawberry/raspberry/peach	5	24	>24
(Strawberry/raspberry/peach) + sugar	3	24	>24
Apricot/cherry	4	18	>24
(Apricot/cherry) + sugar	3	18	>24
Fruit juice (concentrated)	–	24	>24

Source: Institute of International Refrigeration (IIR 1996).

Thawing

The quality of the original fruit, preserved by freezing, is retained by quick thawing at low temperature in controlled conditions. During incorrect thawing, chemical and physical damage and microorganism contamination can also occur. Fruit products exhibit large losses of ascorbic acid (up to 40%) and color changes when thawed for an unusually long period, for example, 24 hours at room temperature. Good results in terms of vitamin C and anthocyanins retention (90%) were achieved by thawing small frozen fruits such as bilberry, raspberry, black currant, red currant, and strawberry at room temperature (18–20°C/6–7 hours), in a refrigerator (2–4°C/18 hours) or in a microwave oven. Color and ascorbic acid retention of fruit was equally affected by thawing temperature and time. Thorough thawing must be determined by taking into account the size of the fruit and/or the type of packaging (Kmiecik et al. 1995).

Microbiological Quality and Safety of Frozen Fruits

Fruit microflora are dominated by spoilage yeast, molds, and bacteria, but occasionally the presence of pathogenic bacteria, parasites, and viruses capable of causing human

infections has also been documented. Fruits can become contaminated with pathogenic microorganisms while growing in fields, orchards, vineyards, or greenhouses, or during harvesting, postharvest handling, processing, distribution, and food preparation (Beuchat 2002). Freezing halts the activities of spoilage microorganisms in foods but can also preserve some microorganisms for long periods of time. During the freezing process, microbial growth can occur when freezing does not take place rapidly due to increasing temperature or fluctuations during frozen storage, transport or retail display (greater than –18°C), and during slow thawing. Frozen foods have an excellent overall safety record. However, the few outbreaks of food-borne illness associated with frozen foods indicate that some, but not all, human pathogenic microorganisms are killed by freezing processes. Outbreaks associated with frozen foods have been reviewed by Lund (2000). Freezing does not destroy *Clostridium botulinum*, the spoilage organism that causes the greatest problems in plant food processing. However, *C. botulinum* will not grow and produce botulin toxin (a poison) at frozen storage temperature below –18°C or in the low pH of fruits. Acidic pH of fruit is a protective factor against microorganism growth. The effect of freezing and frozen storage on the microbiology of some frozen fruit products has been reviewed (Skrede 1996). Although spoilage microorganisms are not a great problem in frozen fruit and fruit juices, some outbreaks and illnesses associated with frozen food consumption have been due to fruit products. Cases of hepatitis A that were produced by frozen raspberries in the United Kingdom (Reid and Robinson 1987) and frozen strawberries in the United States (DHHS 1997) have been referenced. When thawing frozen food, it is important to remember that if the raw product is contaminated and freezing does not totally destroy spoilage and pathogenic microorganisms, as the temperature of food rises, there may be microorganism growths, mainly on the surface of the product. To preserve safety in frozen fruits, recommended temperature requirements exist for each stage of the cold chain. It is recommended that frozen fruits be maintained at –18°C or colder, although exceptions are allowed during brief periods as during transportation or local distribution (–15°C). Retail display cabinets should be at –18°C and never warmer than –12°C (IIR 1996).

Freezing effects on different types of microorganisms have been studied (Archer 2004). Yeast, molds, viruses, bacteria, and protozoa are affected in different ways by freezing, frozen storage, and thawing cycles. Although gram-negative bacteria (*Salmonella* spp., *Escherichia coli*, etc.) are more susceptible to freezing than gram-positive ones (*Listeria monocytogenes, Staphylococcus aureus*, etc.), the nature of the food can change the survival of some former organisms. Freezing kills microorganisms by physical and chemical mechanisms, and factors related to freezing parameters (ice formation, rate of cooling, temperature/time of storage, etc.), or food matrix composition and nutritional status, or phase of growth determine the survival of the microorganism (Lund 2000). Several mechanisms have been proposed to explain the damage caused to microorganisms by freezing. Cellular damage caused by internal or external large ice crystals and increase of external or internal solute concentration are some of the mechanisms proposed. Better understanding of the interactions between physical and chemical changes in the microorganism cell and food matrix during freezing, frozen storage, and thawing processes could lead to the designing of safe freezing processes where the microorganisms, if they are present, would not survive. For spoilage and pathogenic microorganisms, the freezing process becomes an important hurdle to overcome (Archer 2004).

LEGISLATION

Special rules for frozen food safety regulations have not been adopted by either the United States or the "European Communities (EC)" authorities. Frozen food is regulated by the general rules for food processing safety. Codex Alimentarius Commission adopted special rules for frozen foods—Recommended International Code of Practice for Processing and Handling of Quick Frozen Food. The Commission recognized not only temperature as the main consideration to maintain frozen food quality (Codex Alimentarius 1976) but also other factors. The production of safe frozen food requires maximum attention to GMP and HACCP principles in all the production chain, from raw material (farm) to consumer table (freezer), and to all the steps in between. In the United States, the minimum sanitary and processing requirements for producing safe and wholesome food are an important part of regulatory control over the safety of the nation's food supply and are ruled by GMP (FDA 2004). HACCP and Application Guidelines were first adopted by The National Advisory Committee on Microbiological Criteria for Foods (NACMCF) for astronauts (1970), seafood (1995), low-acid canned food, and juice industry (2002–2004). Other food companies, including frozen foods, already use the HACCP system in their manufacturing processes (NACMCF 1997). The Codex Alimentarius also recommended a HACCP-based approach to enhance food safety (Codex Alimentarius 1999).

The central goal of the European Commission on food safety policy is to ensure a high level of protection for human health and consumer interests in relation to food. The Commission's guiding principle, primarily set out in its White Paper on Food Safety, is to apply an integrated approach from farm to table, covering all sectors of the food chain, feed production, primary production, food processing, storage, transport, and retail sale. The establishment of the European Food Safety Authority (EFSA) was one of the key measures contained in the Commission's White Paper on Food Safety. EFSA is the keystone of European Communities (EC 2002) risk assessment regarding food.

FREEZING METHODS

The rate of freezing and the formation of small ice crystals in freezing are critical to reducing tissue damage and drip loss in fruit thawing. Different types of freezing systems are designed for foods. The selection of suitable freezing systems is dependent on the type of product, the quality of frozen product, desire, and economical reasons. Freezing systems are divided according to the material of the heat-transmission medium (Rahman 1999):

1. Freezing by contact with cooled solid or plate freezing: The product is placed between metal plates and then adjusted by pressure. This method is used for block or regular form products.
2. Freezing by contact with cooled liquid or immersion freezing: The fluids usually used are sodium chloride solutions, glycol and glycerol solutions, and alcohol solutions.
3. Freezing with a cooled gas in cabinet or air-blast freezing: Air-blast freezing allows quick freezing by flowing cold air (–40°C) at relatively high speed between 2.5 and 5 m/s.
4. Cryogenic freezing: Food is frozen by direct contact with liquefied gases, nitrogen and carbon dioxide. Nitrogen boils at –195.8°C and the surrounding food temperature reaches temperatures below –60°C. This is a very fast method of freezing and the rapid formation of ice crystals reduces the damage caused by cell rupture, preserving sensorial and nutritional characteristics. Cryogenic freezing is recommended for cubes, slices, medium, or small whole fruits but is not appropriate for whole medium and large fruits such as prunes, peaches, etc., due to the risk of crushing.

FUTURE PERSPECTIVES

Irradiation

Ionizing radiation has been used as a safe and effective method for eliminating bacterial pathogens from different foods and disinfecting fruit, vegetables, and juices. The application of low-dose (<3 kGy) irradiation to a variety of frozen plant foods to eliminate human pathogens has been studied. The amount of ionizing radiation necessary to reduce the bacterial population increases with decreasing temperature. Significant softening was achieved at –20°C, but textural changes were not shown when lower ionization doses were employed at higher temperatures (–5°C; Sommers et al. 2004).

High Pressure

The quality of frozen/thawed product is closely related to freezing and thawing processes (Cano 1996). The rate of freezing and the formation of small ice crystals in freezing are critical to minimizing tissue damage and drip loss during thawing. Several reports have studied the use of high pressure at subzero temperature (Bing and Da-Wen 2002, LeBail et al. 2002). The physical state of food can be changed by the external manipulation of pressure and temperature according to the water phase diagram. The main advantage of high-pressure freezing is that when pressure is released, a high supercooling can be obtained, and as a result, the ice-nucleation rate is greatly increased and the initial formation of ice is instantaneous and homogeneous throughout the whole volume. The use of high pressure facilitates supercooling, promotes uniform and rapid ice nucleation and growth, and produces small size crystals, resulting in a significant improvement of product quality (Bing and Da-Wen 2002, LeBail et al. 2002).

From a structural point of view, damage to cells during processing is diminished due to the small size of ice crystals, resulting in a significant improvement of product quality. These advantages have been tested with different fruit tissues. Fruit tissues were frozen under pressure. Peach and mango were also cooled under pressure (200 MPa) to –20°C without ice formation, and then the pressure was released to 0.1 MPa. By scanning electron microscope, it was observed that the cells of fruits frozen under pressure were less damaged compared to those frozen using traditional freezing process, including cryogenic freezing (Otero et al. 2000).

High-pressure Thawing

Thawing occurs more slowly than freezing. During thawing, chemical and physical damage can occur, as well as microorganism contamination that can reduce the quality of the frozen/thawed product. From a textural point of view, an incorrect thawing can produce an excessive softening of the plant tissue. A quick thawing at low temperature to avoid rising temperature could help in assuring the food quality. High-pressure thawing would be a new application of high-pressure freezing. Recent studies showed that high-pressure thawing can preserve food quality and reduce the necessary thawing time. High-pressure thawing was more effective in texture improvement than was atmospheric pressure thawing (Bing and Da-Wen 2002).

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8
Conventional Thermal Processing and Preservation

Szu-Chuan Shen, Ming-Chang Wu, and James S. B. Wu

Abstract The conventional thermal processing has long been applied to preserve various food materials in the food industry. Thermal processing applies heat for reducing the population of microorganisms in the product and extends its shelf life as a consequence. In this chapter, the target microorganisms in high-acid/acid and medium-acid or low-acid foods, basic theory of thermal death time calculation, the concept of commercial sterilization, the conventional canning operation for fruit products, and the possible deterioration in the storage of canned fruit products will be described.

INTRODUCTION

In the food industry, thermal processing has long been applied to preserve various food materials, including fruits. The activity of microorganisms is a major cause for the deterioration of fruit products. The main function of thermal processing is to apply heat for reducing the population of microorganisms in the product. As a consequence, the product is preserved with an extended shelf life.

The conventional thermal processing refers to conventional canning and its related processes, including blanching and pasteurization. The other type of thermal processing is aseptic processing, which will be described in Chapter 11.

The conventional thermal processing in a narrower sense is synonymous with conventional canning. The food is filled into a container, which can be made of metal, glass, plastic,

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or laminated material. The filled container is hermetically sealed, heat sterilized, cooled, and then kept at room temperature. The expected shelf life will be at least 2 years.

Establishing conditions for sterilization (operating time–temperature for thermal processing) requires an understanding of the heat-resistant target microorganisms that are likely to be present in the food.

TARGET MICROORGANISMS

The microflora in a food material varies mainly with the water activity, oxygen tension, temperature, and pH value. The processed food of thermal processing is usually at a water activity no lower than 0.85, in a low-oxygen environment, and under ambient temperature storage. Therefore, the most important factor in the selection of target microorganism in the food for thermal processing is the pH value. From thermal processing point of view, foods may be categorized into three groups based on the pH value: (1) high-acid foods (pH $<$ 3.7), (2) acid or medium-acid foods (3.7 $<$ pH $<$ 4.5), and (3) low-acid foods (pH $>$ 4.5) (Desrosier and Desrosier 1977, Ramaswamy 2005). Low-acid foods are usually sterilized under the most severe condition, followed by acid foods, and high-acid foods are usually least severely treated.

Most commercially canned fruits and their products are acid or high-acid foods with a pH value below 4.5. However, there are also low-acid ones. Selected common fresh fruits and their pH values are listed in Table 8.1.

Table 8.1. The pH Values of Various Fruits

Fruit	pH Value	Acidity Class
Avocado puree[a]	6.0–6.5	Low-acid
Watermelon[b]	5.8–6.0	Low-acid
Papaya[b]	4.5–6.0	Low-acid
Banana[b]	4.5–5.2	Low-acid
Lychee juice[c]	4.1–4.7	Low-acid
Pear[b]	3.4–4.7	High-acid, acid, low-acid
Cherry[b]	3.2–4.7	High-acid, acid, low-acid
Plum[b]	2.7–4.6	High-acid, acid, low-acid
Grape[b]	3.0–4.5	High-acid, acid
Peach[b]	3.1–4.2	High-acid, acid
Blackberry[b,d]	2.8–4.2	High-acid, acid
Apple[b,d]	2.8–4.1	High-acid, acid
Pineapple[b]	3.2–4.0	High-acid, acid
Orange[b]	3.0–4.0	High-acid, acid
Mango[b]	3.3–3.7	High-acid
Strawberry[d]	3.2–3.8	High-acid, acid
Greengage[d]	3.1–3.4	High-acid
Grapefruit[b]	2.9–3.4	High-acid
Damson[d]	2.9–3.4	High-acid
Gooseberry[d]	2.7–3.3	High-acid
Passion fruit[b]	2.6–3.3	High-acid
Guava[b]	3.0–3.2	High acid
Loganberry[d]	2.7–3.1	High-acid
Cranberry[b]	2.5–2.7	High-acid
Lemon[b]	2.2–2.4	High-acid

[a] Adapted from Soliva-Fortuny et al. (2004).
[b] Adapted from Worobo and Splittstoesser (2005).
[c] Adapted from Underhill and Critchley (1994).
[d] Adapted from Burrows (1996).

Low-acid Foods

Clostridium botulinum was the original target microorganism in the thermal processing of low-acid foods in early years. *C. botulinum* is a heat-resistant, spore-forming, highly toxic, anaerobic bacterium. It is generally recognized not to grow and produce toxin at a pH value below 4.6 (Ramaswamy 2005). A related bacterium, putrefactive anaerobe 3679 (PA 3679), which is a strain of *Clostridium sporogenes* with much higher heat resistance and gas-forming capability but much lower toxicity than *C. botulinum*, is nowadays commonly used as the target and indicator microorganism in the sterilization trials of low-acid foods. The high heat resistance makes PA 3679 an ideal target organism. Formation of gas inside that swells a container quickly enables the recognition of its survival. The low toxicity renders it safe for handling.

Acid Foods

Bacillus coagulans, one of the flat-sour bacteria, is among common target microorganisms in acid fruit products. Flat-sour bacteria are highly heat resistant. The contaminated cans usually remain flat in appearance while the pH value is reduced because the food has become sour by the production of acid from *B. coagulans* and related bacteria.

High-acid Foods

A microorganism may exist in the form of spore or vegetative cell with a much higher heat resistance in the former than in the latter. It may be converted from one form to the other in the life cycle to respond to the environmental condition. However, in high-acid environments, bacterial spores cannot germinate to become vegetative cells and grow. It usually takes only a relatively mild heat treatment to kill vegetative cells. Therefore, the identification of the target bacterium in high-acid foods is of less necessity in establishing a thermal process than that in low-acid and acid foods. However, the spores of molds, which are aerobic in nature, may germinate and grow in a high-acid canned food, providing there is enough residual air in the container. The required degree of vacuum in the container for high-acid foods is usually lower than that for the other food types because of the lower sterilization temperature for the former, allowing more residual air in the container. The heat-resistant mold spores in low-vacuum, high-acid canned fruits can be a problem. If the product is underprocessed, these spores may germinate and grow under the limited oxygen supply to cause noticeable

deterioration. On the other hand, the sterilization conditions targeted to kill these mold spores usually hurt the quality of high-acid fruit products badly. A better measure to overcome the spoilage problem is to prevent the contamination of these spores in the product by good quality control in receiving the fruit for processing.

THERMAL DEATH CURVES

Each microbial species, or even down to the level of strain, is characterized with a specific heat resistance. Generally, the thermal death of microorganisms follows first-order kinetics. That is, the logarithmic reduction of microorganisms at a specific temperature is proportional to the holding time at this temperature.

The heat resistance of a microorganism at a specific temperature can be described by the D value (decimal reduction time). The effect of temperature change on the heat resistance of a microorganism can be described by the z value.

D Value

Figure 8.1 is a typical thermal death rate curve. It shows the death rate of a specific microorganism in a specific food at a specific temperature. D value is the time at the specified temperature required to destroy 90% in the population of the target microorganism, or to travel down one log cycle on the thermal death rate curve of this microorganism. For example, a D value of 1.0 minute at 250°F (121°C), depicted as $D_{250} =$ 1.0 minute, means that for each 1.0 minute of holding at 250°F (121°C), the population of the target microorganism will be reduced by 90%, or one log cycle. If the holding time at 250°F (121°C) is 2.0 minutes, or 2 D_{250}, the destruction will be 99%, or by 2 log cycles.

D_{250} is usually abbreviated as D_0. D_0 of the target microorganism has much practical significance to the industry, because low-acid foods are usually sterilized at a temperature around 250°F (121°C).

The D_0 values of *C. botulinum* and PA 3679 spores are approximately 0.2 min and 1.0 min, respectively.

z Value

It is defined as the range of temperature change required to results in a tenfold change in the D value (i.e., to travel one log cycle). By plotting D values, which have been determined at various temperatures, in logarithmic scale versus temperature in linear scale, a semi-logarithmic thermal death time curve with negative slope can be constructed. From this plot, the z value can be graphically shown as the number of degrees in temperature required for traveling one log cycle of the D value (see Fig. 8.2).

The z value can be used in the conversion of D values from one temperature to another,

$$z = (T_1 - T_2)/(\log D_2 - \log D_1)$$

where D_1 and D_2 are the D values at temperatures T_1 and T_2, respectively.

Both the z values for *C. botulinum* and PA 3679 spores are approximately 18°F (10°C).

Time–Temperature History

In the sterilization operation of conventional thermal processing, the food in a container is usually heated up gradually, held close to the achieved highest temperature for certain

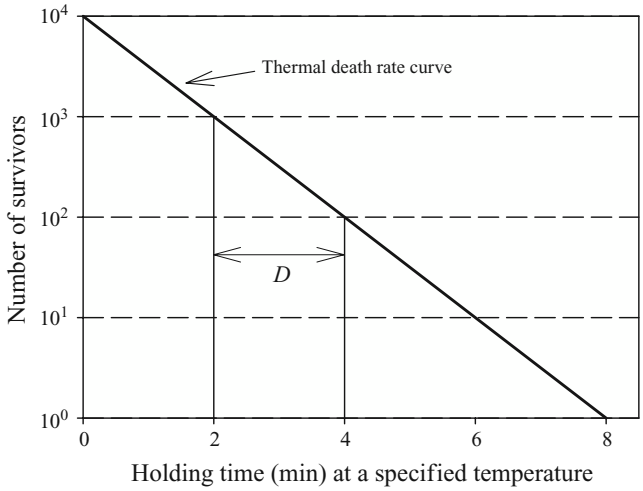

Figure 8.1. A typical microbial thermal death rate curve.

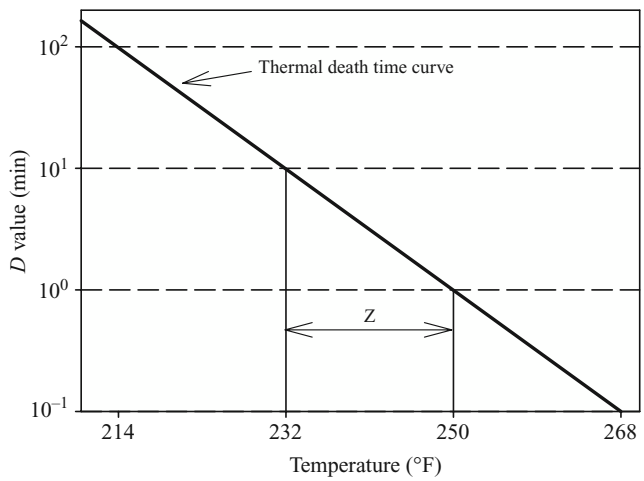

Figure 8.2. A typical thermal death time curve for microbial spores.

duration, and then cooled down gradually. In other words, the temperature of food changes with time. The target microorganisms in the food are experiencing a time–temperature history instead of exposing to a fixed single temperature. The sterilizing effect is cumulated throughout the entire process. F value (also known as lethality, sterilizing value, or sterilization value) specified with a reference temperature and a z value has been introduced to describe the sterilizing effect of a thermal process on the target microorganism characterized with the specified z value. Various combinations of temperature and time in the operation of a sterilizer are available for achieving an expected sterilizing effect, or F value, in the product. Since 250°F (121°C) is a typical sterilization temperature for low-acid foods and the target microorganisms *C. botulinum* and PA 3679 have a z value at approximately 18°F (10°C), the F value with 250°F (121°C) as the reference temperature and $z = 18$°F (10°C), depicted as F_0, is commonly evaluated for comparing the sterilizing effects among different thermal processes in the canning industry.

$F_0 = n$ minutes means the required or achieved sterilizing effect of a thermal process targeted at a microorganism with $z = 18$°F (10°C) is equivalent to a theoretical process that heats up the sample to 250°F (121°C) instantly, holds it exactly at this temperature for n minutes, and then cools it down to room temperature instantly. By dividing the F_0 value by the D_0 value, the number of decimal reduction of the target microorganism is known. The mathematical relation can be shown in the following equation with a and b depicting the initial and final numbers of the microorganism in the sample, respectively,

$$F_0/D_0 = \log a - \log b$$

A sample calculation: The D_0 value of PA 3679 spores is 1 minute. If a batch of low-acid food cans loaded with $1000(10^3)$ colony-forming units of PA 3679 spores per can is processed to achieve $F_0 = 6$ minutes, then in average, 10^{-3} colony-forming units of the spores will be survived in each can, or 1 out of 1000 processed cans may be expected to spoil by the germination of residual PA 3679 spores.

COMMERCIAL STERILIZATION

In thermal processing, the food is often subjected to "commercial sterilization." Commercial sterilization is different from absolute sterilization. The former destroys all pathogenic and toxin-forming organisms, as well as all other types of organisms, which if present could grow in the packed food product and produce spoilage under normal handling and ambient storage conditions; while the latter exterminates all the vegetative cells and spores of microorganisms in the product.

Absolute sterilization is usually achieved by moist heating at 250°F (121°C) for more than 15 minutes or its equivalent. Such a severe treatment tends to be very harmful to the sensory quality of the food product. Fortunately, most foods do not need absolute sterilization to become safe and shelf stable, and the much milder "commercial sterilization" is practiced instead. Commercially sterilized food products may contain a small number of heat-resistant bacterial spores, but normally they will not germinate in the supply chain. Canned products are supposed to be commercially sterile with a minimum shelf life of two years at room temperature.

The food safety authorities require the commercial sterilization of low-acid foods (pH $>$ 4.5) to reduce the population of *C. botulinum* by at least 12 log cycles, or 12 D reduction. Since D_0 of *C. botulinum* spores is approximately 0.2 minutes, the required F_0 value would be 0.2 minutes $\times$ 12 = 2.4 minutes. In actual practice, thermal processes for canned low-acid foods are regulated to have an F_0 value no less than 3.0 minutes for providing additional margin of safety (Downing 1996a). An F_0 value considerably higher than 3.0 minutes, for example $F_0 = 8$ minutes, is not uncommon for achieving a high degree of assurance for certain canned products to prevent the spoilage caused by some microorganisms, for example *C. sporogenes*, which are much more heat resistant than *C. botulinum*.

Generally, the bacteria in an acidic environment with pH under 4.5 are significantly less heat resistant. Therefore, heating at approximately 100°C or slightly higher could obtain a sufficient sterilization effect for acid foods (pH between 3.7 and 4.5). Spore-bearing bacteria will not grow in high-acid foods that are characterized by a pH value lower than 3.7. The thermal processing of high-acid fruit products is usually practiced in a temperature below 100°C.

CANNING OPERATIONS FOR FRUIT PRODUCTS

The manufacture of canned fruit products involves filling, exhaustion, sealing, sterilization, and cooling operations (Fig. 8.3). Prepared fruit materials are filled into containers, may be metal cans, glass jars, or retort pouches. The void space, called "headspace," inside the filled container is usually limited to less than 10% of the volume. The process of "exhaustion" removes air from the filled container before sealing to prevent the damage or distortion of container by the thermal expansion of entrapped air and to minimize the oxidation of food and the inner surface of container. The hermetical seal on the container prevents the outside microorganisms from recontamination to the sterilized food. The "sterilization" process is performed to inactivate the natural enzymes in the fruit, if a "blanching" process has not been practiced in advance, and, more importantly, to kill microorganisms inside the container. The microbial, chemical, and biochemical spoilages of products ought to be all prevented.

There are variations in the canning operations for different fruit products. The following description is common among the majority of these products.

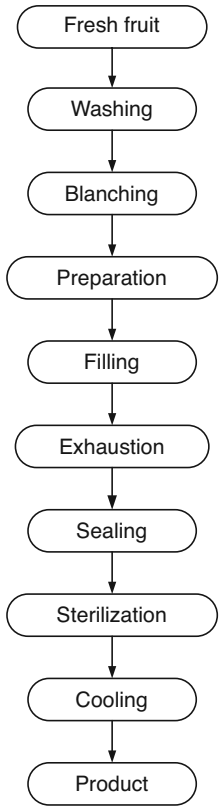

Figure 8.3. Flow chart for the typical canning operation of fruit.

Selection of Fruit Materials

The canning season for a specific fruit is usually not year round. Good raw materials at the right ripeness are needed in the processing for high-quality products. Stored products may be used only if they meet the quality standard.

Many fruits in the "mellow-ripe" stage are pretreated or processed into the form of whole fruits, fruit halves, slices, dices, juices, purees, marmalades, or sauces for canning. Bananas, pears, and some apples when harvested at the "green-mature" stage commonly produce a higher-quality product in canning. Plums, grapes, olives, gooseberries, and maraschino cherries are usually harvested and canned in the "firm-ripe" stage instead (Prussia and Woodroof 1986).

Washing

Right after arriving at the cannery, the qualified fresh fruits are carefully washed to remove dust, dirt, and mold spores. This process should be carried out so thoroughly as to ensure the removal of heat-resistant molds, such as *Neosartorya fischeri*, which have been linked to mold growth in canned fruits (Jesenka et al. 1991). It is recommended that fruit materials be washed in clean chlorinated water. A common method of chlorination is to add small quantities of household bleach to water (usually 50–100 ppm chlorine concentration). The fruits should be completely rinsed with clean water after the treatment. Washing may also be done by equipment in which fruits are subjected to high pressure water sprays or strong water streams while passing along a moving belt or while being tumbled on an agitating or revolving screen. However, caution should be paid to avoid injuring the fruits. Fruits to be peeled may not need washing beforehand.

Blanching

The blanching, or a "partial cook," of fruits is an important operation in the canning process. Fresh fruits are immersed in water at 190–210°F (88–99°C) or exposed to live steam for a short period of time in order to inactivate oxidative enzymes, such as catalase, peroxidase, polyphenol oxidase, ascorbic acid oxidase, and lipoxygenase, that have the potential to cause flavor and textural changes of the product (Ramaswamy 2005). Adequacy of blanching is commonly confirmed based on the negative response of the heat-resistant enzyme peroxidase or polyphenol oxidase. In addition to the inactivation of enzymes, there are other benefits of blanching, such as expelling respiratory gases for increasing vacuum and preventing the oxidative deterioration of product and the internal corrosion of can; facilitating preparative operations, such as peeling, dicing, and cutting; removing undesirable flavors; setting the natural color of certain products; helping cleaning; and decreasing the microbial load (Downing 1996b). A disadvantage of blanching for example is the loss of water-soluble nutrients such as ascorbic acid. Therefore, blanching time should be kept as short as possible. The blanching of fruits is usually accomplished in equipment especially designed for individual applications. There are basically two types of blanchers, using hot water and steam, respectively. Continuous hot-water immersion blanchers with conveyors are very common. Continuous steam blanchers that use a chain or belt conveyor to move fruits through a tunnel of live steam are also frequently used.

Preparation

Many fruits require some other pretreatments or preparative operations before filling into a container. Peeling, coring, slicing, and dicing are examples of these operations. Peeling is the most common one. Many methods are available for the peeling of fruits. Mechanical peeling and lye peeling are among the major ones.

Mechanical Peeling

Some fruits, for example, pears, apples and pineapples, may be knife-peeled by machines. The fruit is impaled and rotated against a stationary knife or vice versa that follows the contour of the fruit. The core may be removed at the same time.

Equipment is specially designed for each application. Abrasion peeling is another type of mechanical peeling in which an agitating/tumbling action is utilized so that all surfaces of the fruit undergoing peeling are exposed to a rubbing action against an abrasive surface, thus loosening the peel, which is then removed by water sprays (Downing 1996b). Some machines fitted with cylinder brushes may be used to help detaching the loosened peel.

Lye Peeling

Apparatus for continuous lye peeling are very popular with fruits, such as peaches, nectarines, apricots, and pears. The lye peeling operation requires a generous water supply, lye (caustic soda or sodium hydroxide), and a source of heat. The fruits are passed through a heated tank containing hot lye solution at a predetermined rate. The caustic lye solution dissolves the fruit skin. The degree of peeling can be adjusted by varying the concentration and temperature of lye solution, residence time, and agitation strength of the fruit in the solution. In practice, the temperature is maintained somewhere from 60°C to close to the boiling point of solution. The residence time is usually 1–2 minutes in 2–10% caustic soda solution (Burrows 1996). After the treatment, fruits must be water washed with pressure sprays to remove the lye-disintegrated peel. Sometimes, an acid dip, most commonly citric acid, is used after washing to neutralize any remaining traces of caustic soda in peeled fruits.

After peeling and perhaps coring as well, fruits may be sliced or diced. In case there is delay between these treatments, fruits may be held in 2–3% salt solution to prevent browning.

Filling

Mechanical fillers are usually used for the filling of fruit products into cans. An accurate and consistent fill of the fruit and syrup/juice at a proper temperature is necessary to maintain a uniform headspace. The volume of headspace in a can is very critical. Insufficient headspace may slow down heat penetration into the can and result in under-sterilization of the product. It also allows less space for hydrogen gas to accumulate in the progress of internal can corrosion and renders a can more liable to "dome." Excessive headspace may result in the underweight of can and hinder the successful operation of exhaustion as well.

Exhaustion

The exhaustion of a container is to remove air and entrapped gases from the container prior to sealing. The advantages of exhaustion include the alleviation of the internal pressure buildup in the container during sterilization, the prevention of the oxidative deterioration of the canned product, the reduction in the growth and propagation of residual aerobic microorganisms, and the mitigation of rusting on the inner surface of the can during storage. A sufficient degree of vacuum in the sealed container also helps heat transfer in the sterilization process.

Common fruits, being of a highly corrosive nature because of their acidity, require a vacuum of 250 mm Hg or above. The major exhausting methods in the canning of fruits are described below.

High-speed Mechanical Vacuum Sealing

A vacuum double-seaming machine is used. In the machine, cans filled with fruit and syrup in relatively cool condition are passed into a clincher that clinches the cans without forming an air-tight seal. The cans are then subjected to a vacuum for a short period of time for exhaustion right before the hermetic sealing in the same machine (Ramaswamy 2005). This method is not good enough for cans requiring a very high vacuum or containing highly viscous products. There is another problem in applying high-speed mechanical vacuum sealing for fruits packed in syrup. The sudden suction of air may spill some syrup out of can and result in contaminating the equipment, soiling of the sealing surface, and insufficient filling in the can.

Hot-filling Exhaustion

The liquid food is preheated, hot-filled into a container, and then sealed as soon as possible. A spurt of steam into the headspace may be applied right before container sealing to purge away the residual air. The vapor pressure in headspace is approximately at atmospheric level upon the sealing of container. The condensation of vapor when the sealed container cools down generates a vacuum. The vacuum in hot-filled containers is usually weaker than that in cans exhausted by other methods.

Thermal Exhaustion

In thermal exhaustion, the fruit product is usually heated before and after filling. A filled open container is run through an exhaustion box that provides live steam to heat the product and to replace the air in the headspace. The container is sealed immediately after exhaustion. The disadvantages of thermal exhausting include being energy intensive due to high-steam consumption and the increased chance of contamination due to the dripping of condensate.

Sealing

After exhaustion, the containers should be sealed as soon as possible. A good sealing operation is necessary to render the success in canning. Faulty sealing usually results in leaking and recontamination of the canned product during and after sterilization.

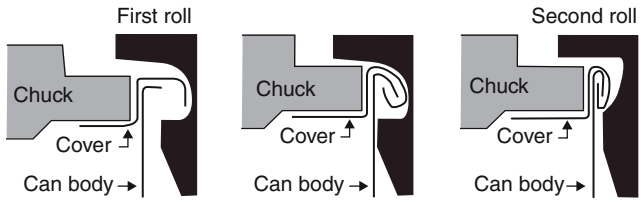

Figure 8.4. The formation of double seam.

The method of sealing varies with the type of container. A metal lid is placed on a filled metal can, and then fixed onto the can body by combined actions involving chuck, lifter, the 1st roll, and the 2nd roll in a typical double-seaming machine to form a double seam (Figs. 8.4 and 8.5). Double-seaming machines may operate at speeds as high as 600 cans per minute for particulate foods (Downing 1996b). Fluid products can be sealed at a speed up to 1600 cans per minute (Lopez 1987).

It is somewhat slower for sealing glass containers than metal cans because of the fragility of glass. Small glass containers may be filled and sealed at a speed up to 1300 containers per minute (Downing 1996b).

Flexible retort pouches may also be used in the packing of fruit products. The packaging material is basically composed of an aluminum foil between plastic layers in a laminated structure that is able to withstand common sterilization temperatures and to serve as the hermetic barrier for the product. Pouches as containers are formed from roll stocks by folding a single roll along its center or by bringing two separate rolls together heat-sealed side to side. The filling of product into a pouch has to be gentle enough as not to soil the top part of the inner surface where the seal will be formed. The filled retort pouches are usually heat-sealed using impulse bars that melt the plastic material on the top inner surface of the two opposite laminas to be fused together upon cooling. It is advantageous to perform an effective exhaustion operation that generates a high vacuum prior to sealing to prevent ballooning of the pouch during the subsequent heat sterilization. The operation usually involves mechanical squeezing of the pouch, vacuuming by suction with a snorkel, or steam flushing. A pouch filler/sealer is commonly used for on-line high-speed filling, vacuuming, and sealing.

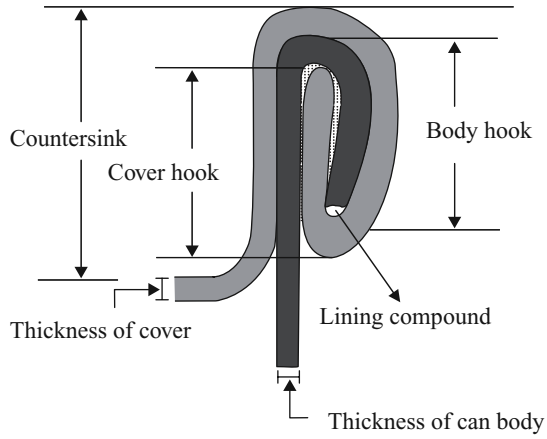

Figure 8.5. Cross-section of a double seam.

Sterilization

The sealed containers are heated in a sterilizer by contacting with steam, hot water, or atomized steam–air mixture. Sterilizers can be grouped into either batch type or continuous type. The conventional retorts are batch-type sterilizers. The continuous sterilizers being used in the industry include water bath sterilizer, cooker-cooler, hydrostatic cooker, flame sterilizer, etc.

In the sterilization operation of canned food, a faster rate of heat penetration, namely the transfer of heat from outside to the slowest heating point in the center part of a container, usually corresponds to a shorter processing time and a better quality product. The heat penetration rate in a specified container under a specific heating condition varies with the type of food, the volume of headspace, and the degree of vacuum in the container. There are mainly two mechanisms of heat transfer in a container, namely, convection and conduction. Heat penetration is comparatively faster in low-viscosity liquids such as fruit juice because convection prevails. For products composed of a high-viscosity liquid or a large portion of solids, such as juice concentrate and fruit cocktail, the heat penetration is primarily via conduction and is much slower. Agitation during the sterilization process may generate forced convection and improve heat penetration in a conduction-heating container. A continuous sterilizer more or less provides agitation to the containers while they are being processed.

Conventional Retort

A conventional retort can be vertical or horizontal in layout. It is subjected to batch-type operation. The retort is basically a steel tank capable of withstanding the high pressure of saturated steam at a temperature well above the boiling point of water, and equipped with steam, water and compressed air ducts, valves, vents, bleeders, drain, overflow, pressure gauge, water-level indicator, thermometer and temperature recorder-controller, etc. The low-acid fruit products in sealed containers are loaded in baskets or trays and placed inside the retort. The retort may or may not be filled with water before or after the loading of containers. In-water processing is preferred for high-vacuum large cans, glass containers, and retort pouches that are not tolerant to sudden temperature

and pressure changes. The lid or door of retort is closed, and then the inlet of steam, steam-heated water, or atomized steam–air mixture is opened to start the heating phase, or come-up, of the sterilization process. The heating phase ends when the retort reaches the preset processing temperature, usually no lower than 116°C (240°F), and then the holding phase follows. Cooling water is introduced into the retort to start the cooling phase when the expected holding time is up. Partially cooled containers may be taken out of the retort and immersed in a trough of water for further cooling.

Most of the conventional retorts belong to the stationary type. However, some conventional retorts have a way of rotating or agitating the containers in the heating medium. Agitation improves the heat penetration in liquid or semi-liquid food cans, reduces the processing time, and achieves better quality retention.

Continuous Water-bath Sterilizer

A sterilization temperature below the boiling point of water may be enough for the production of acid and high-acid canned fruits. In such a circumstance, a water-bath sterilizer may be used to substitute for a retort. A modern continuous water-bath sterilizer is composed of an elongated tank through which containers travel on a belt. The containers may alternatively pass through a tunnel on a conveyer belt subjected to continuous hot-water spray. Such a method is especially suitable for the sterilization of fruit products in glass jars that are sensitive to thermal shocks (Lund 1975).

Cooker-cooler

Cooker-cooler is a continuous agitating retort consisting of a cooking shell and a cooling shell in the basic structure. Cans are moved by a spiral and reel mechanism, and rolled by rubbing against the wall inside the shells. The agitating effect of this type of retort is excellent. It is equipped with specially designed ports or valves. Filled cans enter the cooker-cooler through a rotary transfer valve, which is designed to prevent the escape of steam from the cooking shell. Inside the cooking shell, cans are sterilized by steam supplied from the bottom of the shell. Uniform distribution of steam is ensured by a manifold steam supply system along the entire length of the shell. The "cooked" cans are then transferred through another rotary transfer valve into the next shell for cooling. The cooling shell is approximately two-thirds full of water to provide flood cooling of cans as they proceed through the shell. Water enters at the discharge end and exits at the feed end of the cooling shell for a counter-flow cooling effect. The reel in the cooling shell has a series of baffles. The combination of reel baffles and counter-flow movement of water ensures efficient usage of cooling water and controlled, uniform cooling of cans (Downing 1996c).

Hydrostatic Cooker

The principle of hydrostatic cookers is to balance or to "maintain" the steam pressure by hydrostatic pressure. A hydrostatic cooker is made up of four chambers: a hydrostatic "come-up" or "in-feed" leg, a sterilizing steam chamber, a hydrostatic "come-down" or "discharge" leg, and an after-cooling system. Containers are conveyed through the machine. They enter and move down the in-feed leg while being heated with the surrounding progressively hotter water in progressively higher pressure. The containers continue to travel first horizontally in water and then upward through the water seal to the steam chamber. In the steam chamber, the containers are exposed to a temperature ranged from 240°F to 265°F (116–129°C) for sterilization. Upon leaving the steam chamber in the completion of holding phase, the containers pass another water seal where the cooling phase commences. The containers are conveyed through progressively cooler water to the top of the discharge water leg for cooling and pressure releasing (Downing 1996c). An after-cooling system is equipped downstream for further cooling of the containers to the desired final temperature.

Direct Flame Sterilization

The sterilization process that heats up containers to an internal temperature above 100°C is often performed in a special kind of equipment, commonly called "retort" as above-described, which maintains an environment at elevated pressure. The cost of the retort is bound to increase with the demand for a higher sterilizing temperature as its structure has to withstand a higher pressure. The direct flame sterilization machine was developed in France to be a substitute for high pressure retorts. In the machine, cans are heated directly by rotating over gas flames. The agitation effect is strong. The sterilization can be accomplished in a short period of time. The operation cost is very low. However, this method only works for cans with very strong structure to resist the high internal pressure built up in heating. The viscosity of the product is limited within a proper range as agitation will fail, and burn-on on the inner wall of the can will occur in the processing of highly viscous products.

Hot-fill (Hot-pack)

Another common sterilization method for high-acid fruit products, juice for example, is "hot-fill" or "hot-pack." There is similarity between hot-fill and the previously described hot-filling exhaustion. A liquid or semi-liquid fruit product is heated, held for few min at a temperature sufficiently high although lower than the boiling point, and then filled into containers while it is still hot (usually 85°C and above). The filled container is sealed immediately after, allowed to stand for a while, and then turned upside to complete the sterilization on all sides in the container by the residual heat of the product.

Hot-water sprays onto the outer surface of the container may be applied to help maintaining the temperature.

Cooling

The sterilized product is preferably cooled as soon as possible to an average temperature in the container around 35–40°C (95–105°C) to stop the accelerated deterioration in quality caused by elevated temperature (Jackson 1979). It is also helpful in inhibiting the growth and propagation of the survived thermophilic bacteria in the food. The cooling water should be noncorrosive and low in microbial content. It is usually chlorinated to no lower than 2 ppm of available chlorine to preclude the infection of canned products by spoilage microorganisms suspended in the cooling water (Ramaswamy 2005).

The canned products sterilized in a conventional retort can be cooled either at or above atmospheric pressure, or precooled above atmospheric pressure and then after-cooled at atmospheric pressure. Atmospheric cooling can be done either in the retort or in a trough. The required cooling time varies mainly with the temperature of cooling water, the dimensions of the container, and the characteristics of food in the container. The precooling of retort pouches and large containers has to be done with a constantly monitored overpressure for preventing container deformation due to rapid pressure drops in the retort. Proper overpressure in the early stage of cooling is also helpful to metal cans and glass jars in the prevention of leaking from the container and the subsequent recontamination through the leak. The overpressure in pressure cooling or pressure precooling may be established by injecting steam or compressed air to superimpose over cooling water and submerged containers in the retort.

A glass jar is a fragile container and a bad conductor of heat. The problems of thermal-shock break, stroked fractures, and internal pressure fractures occur easily in glass jars in heating and cooling. Handling with special caution is required. For example, the temperature difference between inner and outer surfaces of the glass jar is better kept within 30°C.

If the cans cooled down far below 35°C, their outer surface may remain wet for a long time, which promotes rusting. The concurrent blow with high speed air to remove the water film on can surface is an efficient preventive measure against storage rusting.

STORAGE DETERIORATION OF CANNED FRUIT PRODUCTS

Deterioration of the canned fruit product in storage downgrades its quality. The deteriorated product may also become a threat to human health. There are three major types of storage deterioration, namely, microbial, chemical, and physical deteriorations.

Microbial Deterioration

The microbial spoilage of canned fruit products may be caused by microorganisms that have survived an insufficient thermal process, by insufficient cooling of the sterilized product, or by the recontamination of microorganisms after sterilization. Unless the process is very seriously under-practiced, insufficient thermal processes usually leave only the most heat-resistant microbial species. Microscopic examination on the incubated sample often finds a single form of microorganism, and in low-acid food, it is usually a rod. Insufficient cooling usually also leaves a simple flora of rods belonging to the genus *Clostridium* or *Bacillus*. Recontamination leads to the growth of a mixed flora as recognized by a microscope, because many microorganisms in the environment may enter a container and grow together.

Underprocessing

Fresh fruits that have been spoiled by the growth of microorganisms or damaged by birds or insects may be loaded with very high microorganism populations (Worobo and Splittstoesser 2005). In some cases, the soil in an orchard may bear microorganisms with extremely high heat resistance in their spore form, for example, the molds *Byssochlamys fulva* and *Neosartorya fischeri*, and contaminate the fruit. The sterilization conditions set previously for normal fruits become insufficient as a consequence. To increase the severity of thermal processing will not be a good remedial measure since the sensory quality of the finished product may become unacceptable. A strict control over microbial load of the incoming raw material is always absolutely important to the factory.

Bad hygiene condition on the machinery along the production line may also contribute to the occurrence of underprocessing. Microorganisms may multiply in the wet and dirty spots on conveyor belts, peelers, and the ports of filling machines, and then contaminate the raw material or semiproduct. All the machinery should be kept dry whenever possible. The equipment used in a canning factory is preferably easy to be dismantled and cleaned. For the equipment unable or difficult to be dismantled, cleaning-in-place should be practiced during a stoppage or after work.

Underprocessing may also result from the failure of sterilization equipment, such as the breakdown of recorder-controller on the retort. Another possible cause is the mishandling in the sterilization process, examples include the improper arrangement of containers in a stationary retort and the overfilling in individual containers for an agitating retort that lead to the inefficiency of heat penetration into the container.

Insufficient Cooling

Insufficient cooling is another possible cause of microbial deterioration for canned foods. Sterilized products may be

cooled with water in a trough. Inadequate water circulation may lead to inefficient cooling and prolonged holding of the canned product above room temperature. The growth of thermophilic microorganisms that have survived the commercial sterilization process may be initiated. In addition, poor ventilation and high temperature in the warehouse may further promote the microbial deterioration of insufficiently cooled containers.

Microbial Recontamination

Leaking in the seal resulting from faulty sealing or improper control over the pressure difference between inside and outside of the container during heating and cooling often results in recontamination of the sterilized food. Vapor in the headspace condenses and restores the vacuum in the container in the cooling phase. Any leak on the container may allow cooling water to be sucked in. The sterilized product may then be contaminated with suspended microorganisms in the cooling water. It is also possible for airborne microorganisms to pass through the leak and contaminate the product after water cooling.

Chemical Deterioration

A variety of chemical reactions may occur between the fruit product and the inner surface of a can, resulting in the deterioration of product. The situation is worsened in insufficiently cooled cans since a high temperature accelerates all kinds of chemical reactions. If the temperature is high enough, the food in the container may even be "cooked" by its own residual heat, causing a phenomenon of fast quality deterioration called "stack-burn." Chemical deteriorations of canned fruits may appear in the form of discoloration, turbidness, off-flavor, off-odor, or hydrogen swelling. Examples are described in the following.

Discoloration

Discoloration of fruit products in canning may be enzymatic or nonenzymatic. The major substrates include phenolic compounds, anthocyanins, ascorbic acid, etc.

Enzymatic Browning

Some fruits, such as apple, pear and banana, may turn brown on the surface when they are peeled and exposed to air, causing the deterioration of color quality even prior to processing. The browning is attributed to the enzymatic reaction catalyzed by polyphenol oxidase in the presence of oxygen. A short-time dip of the peeled fruit in salt solution is helpful in reducing the extent of browning.

Discoloration of Anthocyanin-containing Fruits

Tin on the inner wall of a can may easily oxidize in the presence of oxygen or oxidants, dissolve into the liquid part of food product, and then react with anthocyanins to cause color loss. In canned apricot, tin may react with chrysanthemin, which is an anthocyanin, to form a metal complex that contributes purple color. Some berries, such as strawberries and some varieties of raspberry, gain brown hue during thermal processing because of the degradation of anthocyanins.

Anthocyanins may also react with ascorbic acid and result in the degradation of both compounds. The presence of amino acids, phenolic compounds, and sugar derivatives may also accelerate the discoloration of anthocyanins.

Pink Discoloration in Pear and Lychee

Some varieties of pear acquire pink color after heating, particularly if they are not cooled quickly. The mechanism is not yet fully understood, but it is believed to involve the complex formation between natural pigments in the fruit and metal ions (Burrows 1996).

In mature lychee fruit, flavonone is converted into an eriodictyol-containing compound, hydrolyzed by flavonone-3-hydroxylase to a dihydroquercetin-containing compound, and then degraded to a leucocyanidin-containing compound by dihydroquercetin-4-reductase. When lychee is heated, the leucocyanidin-containing compound is converted to a pink-colored cyaniding-containing compound. A lower storage temperature decreases the extent of pink discoloration in canned lychee, whereas the addition of heavy syrup and the reduction of pH may enhance the discoloration.

Nonenzymatic Browning

In fruit products, the possible nonenzymatic browning mechanisms include caramelization, Maillard reaction, ascorbic acid oxidation, and the oxidative condensation of tannic compounds. Among them, caramelization usually occurs in high sugar products only. The progress of Maillard reaction to a noticeable extent often requires the presence of high concentrations of sugar and amino acids at elevated storage temperature. Many fruits contain considerable amounts of ascorbic acid and tannic compounds, which are a group of phenolic compounds. Ascorbic acid oxidation and the oxidative condensation of tannic compounds occur more commonly in fruit products, for example fruit juice, in comparison with the other browning mechanisms.

Formation of Turbidness

In the canning of unripe, badly peeled, or inadequately washed tangerine fruit, white turbidness may appear in the liquid part due to the excessive leaching of hesperidin from the fruit.

Off-flavor and Off-odor

In the canning of some fruits such as peach and tangerine, the artificial sweetener "cyclamate" may interact with nitrite ions, which exist naturally in the fruit, to form cyclohexene with a foul petroleum smell.

Hydrogen Swelling

It usually occurs in fruits packed in nonlacquered or inadequately lacquered cans. Serious de-tinning on the inner surface of a can exposes the iron metal underneath. The reaction between organic acids in the fruit product and iron metal generates hydrogen and swells the can.

PASTEURIZATION

Pasteurization is another type of thermal processing. The temperature of pasteurization is usually lower than the boiling point of water. Pasteurization extends the shelf life of fruit product by reducing the number of microorganisms and the activity of natural enzymes. Pasteurized fruit products still contain many living microorganisms capable of growing, commonly thousands per milliliter or per gram, which make the stored product life much shorter as compared to commercially sterilized fruit products. A remedial measure to extend the shelf life of pasteurized products is to keep them refrigerated. However, the shelf life will still be shorter than the sterilized products. The short shelf life of pasteurized fruit products is compensated by the high quality when they are freshly made as a result of the low severity of heat treatment.

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9
Dehydration Preservation of Fruits

József Barta, Csaba Balla, and Gyula Vatai

Abstract: This chapter introduces fruit juice concentration methods by principles of evaporation; and discusses the consequent loss of volatile substances and decomposition of valuable components. The chapter also explores the method of increasing concentration with integrated membrane operations based on the principle of reversed osmosis that helps decrease waste of valuable nutritional components.

Fruit drying methods are based on water removal from solid material and for controlling knowledge of moisture transport and principles of water removal are essential. Besides traditional drying technologies, vacuum drying, freeze drying, and osmotic drying are also used for fruit drying as these technologies help to keep main nutritional components of raw material.

FRUIT JUICE CONCENTRATION

The basic aim of juice concentration is to remove water and increase the soluble solids (Brix) content. Increasing concentration of juice offers advantages in preservation of its quality, longer shelf life, storage and shipping. Juice concentration can be achieved by various means:

1. Evaporation: water removal by boiling,
2. Cryoconcentration: freezing of water and mechanical separation of crystals from the unfrozen solution,
3. Reverse osmosis (RO): if the solution separated by a semi-permeable film from the water is affected by higher pressure than its osmotic pressure, water can be removed from the solution through the film.

In fruit juice processing, evaporation is the most frequently applied procedure for juice concentration. Evaporation can have several aims:

1. Decreasing water activity (a_w) to a level where the concentrated product becomes stable. To reach this objective, a_w is lowered to 0.7 or below. Typical examples are the production of apple juice concentrates and dry must (Fathi-Achachlouei 2007).

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

2. Lowering a_w by adding sugar to reach an activity value appropriate for a given product. Examples are the production of jams and jellies (Stevens 2009).
3. Decreasing the water content to such degree that the product would be suitable for spray drying or vacuum drying, for example, production of fruit juice powders.
4. Lowering of the water content to a degree where some scarcely soluble components can be crystallized from the solution. Examples are the production of lactose, sucrose, and crystalline glucose.
5. Concentration of the product to such degree that less energy and smaller number of vessels would be necessary for further preservation of the concentrated material with smaller weight and volume (Győri 2001).

Evaporation of Fruit Juice

Amount of Evaporated Water

Quantity of water removed during evaporation can be calculated by a simple material balance.

During evaporation, the extract content present in the juice is not changed; it remains totally in the concentrated material. In batch running, if the mass of the juice is B (kg) and its dry material content C_B (mass %, e.g., Brix), then the mass of the dry material is

$$B \cdot \frac{C_B}{100}(\text{kg})$$

Let the mass of the concentrated matter be K (kg), its dry material content C_K (%), then the mass of the dry substance in the juice is

$$K \cdot \frac{C_K}{100}(\text{kg})$$

In the above examples, the mass is given in kilogram (kg); however, it can be also be in tons or other units. It follows that

$$B \cdot \frac{C_B}{100} = K \cdot \frac{C_K}{100} \text{ or } BC_B = KC_K,$$

the mass of the concentrated matter

$$K = B \cdot \frac{C_B}{C_K}$$

The mass of the evaporated water W (kg) is

$$W = B - K = B - B \cdot \frac{C_B}{C_K} \text{ or } W = B \cdot \left(1 - \frac{C_B}{C_K}\right)$$

Boiling Point of Juice Concentrates

Boiling point of water, which depends on the pressure at which it is boiled, is the temperature where surface tension of the water vapor is equal to the outside pressure. The lower this pressure, the smaller is the temperature of boiling. At 1 bar absolute pressure, the boiling point of the water is $373.2K = 100^{\circ}$C; at lower pressure (in vacuum) it is smaller, while at higher pressure (during pressure) it is larger.

In an evaporator, the temperature of the boiling water on the water surface is equal to the boiling point corresponding to the pressure measured by a device placed in the vapor space. Pressure in the liquid increases with the hydrostatic pressure; therefore, the boiling point is somewhat higher.

The most important components of the fruit juices are water-soluble substances. The partial pressure of water containing soluble matter is always lower than that of the clean water. This means that at the same pressure, the boiling point of a juice is always higher than that of the clean water. This increase of the boiling point is directly proportional to the number of the dissolved molecules. As juices contain various molecules in different amounts, estimation of the molecule numbers necessary to calculate the precise boiling point increase is not possible in the practice (Szenes and Oláh 1991, Belibagli 2007). For fruit juices, boiling point increase of the sucrose liquors is frequently applied. The main component is saccharose.

Volatile Substances

If the volatile substances are perfectly dissolved in the juice, their partial pressures are directly proportional to the molar ratio (Raoult-law). The partial pressures of some hardly dissolvable substances are higher than the ones expected from the above law. Such hadly dissolvable substances are highly evaporative during boiling of the aqueous solutions. The aromatic substances evaporate from solution in various degrees and have effect on flavor and the taste of the concentrate.

The aromatic content of fruit juices is rather low: 5–250 mg/kg. The human sense of smell is suitable to detect even such low concentrations of the aromatic substances. The main components of the volatile aromatic substances are free alcohols, esters, free acids, carbonyl compounds, and rarely some other compounds too (Győri 2001).

Sugar Decomposition and Nonenzymatic Browning

At the high evaporation temperatures, sucrose, glucose, fructose, and sometimes maltose, undergo changes. For example, in highly acidic medium (pH $<$ 3), transformation of fructose to hydroxymethyl furfural can occur (Fig. 9.1). Hydroxymethyl furfural polymerizes or polycondenses with other compounds, forming dark-colored substances. This type of browning reaction is important mainly in fruit juices (Kus et al. 2005). In less acidic medium (pH $>$ 3.5), glucose and fructose can form brown-colored substances by reacting with free amino acids present in the juices through nonenzymatic browning or Maillard-reaction.

Apple juice has lower pH, but it has lower amino acid content; therefore, it is reported to have little nonenzymatic

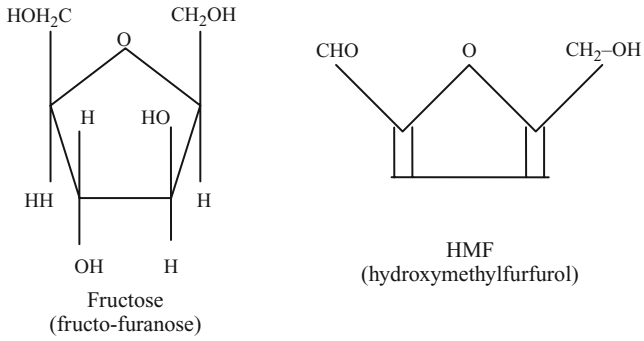

Figure 9.1. Transformation of fructose to hydroxymethylfurfurol.

type of browning even when concentrated to 70% (Thielen et al. 2006).

Caramel is a substance with dark color formed by nonenzymatic browning. It is formed only by heating sugars in dry condition. During evaporation, caramelization can happen if the heating surface is not wetted by the juice and the splashed juice is burnt.

The degree of nonenzymatic browning is proportional to heating time, and it can be reduced by shortening the evaporation time.

Decomposition of the Coloring Components of Juices

It is important to control the loss of water-soluble color pigments such as anthocyanins during concentration as they are sensitive to the temperature (Cortell 2007, Kirca 2007). Lowering the evaporation temperature from 85°C to 75°C decreased the quantity of decomposed anthocyanins to 42%. Further lowering of the temperature by 10°C decreased the decomposed quantity to 17.4%. Similar degree of lowering is achieved by decreasing the time, for example, from 20 minutes to 4 minutes (Will and Dietrich 2006).

Among the fat-soluble coloring substances, carotene is the most important one. Its decomposition due to heating is very low. The green chlorophyll is rather sensitive to heat; however, it is not significant in concentrated juices.

Decomposition of Vitamins during Evaporation

Among water-soluble vitamins, thiamine and ascorbic acid are of importance during evaporation. Vitamin C is not somewhat less sensitive to increase of temperature than the presence of oxygen. Thiamine is more sensitive to changes of the temperature. Among fat-soluble vitamins, carotene is the most important one in juices being evaporated; its heat sensitivity is rather low. Therefore, evaporation must be performed in as short time as possible and at the lowest temperature in order to save heat-sensitive substances (Watzl 2003).

Energy Needed for Evaporation

Energy needed for evaporation consists of three types of energy:

1. To heat the liquid to the boiling point,
2. Energy needed to evaporate the water,
3. Energy loss.

Energy needed to heat the liquid to the boiling point is the difference between the enthalpy of the incoming liquid with lower temperature and that of the liquid heated up to the boiling point. Enthalpy is calculated by multiplying the mass of the liquid with the specific enthalpy. In practice, the specific enthalpy of dilute juices is equal to that of the water.

Energy needed for evaporation of the water, the specific evaporation heat, depends on the boiling temperature (i.e., on the pressure at which the water or the liquor is boiling). The specific evaporation heat of the water decreases with the increase of the temperature. It is significant because evaporators are heated generally by steam.

The heating steam condenses on the heating surface of the evaporator and transmits its specific evaporation heat to boil the liquid on the other side of the heating surface. The heating steam is warmer than the evaporated liquid; therefore, its specific evaporation heat is lower: if 1 kg water is evaporated at 60°C, 2358 kJ is needed. If the temperature of the heating steam is 100°C, its specific evaporation heat is 2257 kJ/kg. In case of heat transport without losses, 2358/2257 = 1.045 kg heating steam would be necessary.

Heat losses are always present during evaporation, for example, from the heat conduction of the walls of the equipment or heat irradiating to the neighborhood. These losses are about 5%. Thus, steam necessary to evaporate 1 kg water would be 5% higher than 1.045 kg, that is, 1.097 or 1.1 kg.

The evaporation heat of the evaporated water can be used to heat up an evaporator running at lower temperature; therefore, the energy needed to evaporate 1 kg water can significantly be decreased by utilizing the energy of the vapor (Szenes 1991).

Evaporation Methods

Liquids may become steam at atmospheric pressure or under vacuum.

1. At temperature of about 100°C, evaporation can take a long time; therefore, browning and degradation in taste and food value may occur. This method is used when caramel-like taste is required for the products (e.g., plum jam).
2. Vacuum evaporation reduces the detrimental changes in quality. By decreasing the pressure on the surface of the liquid in the evaporator, its boiling point is lowered. At the same time, the evaporation temperature is also decreased (e.g., at 600 Hg mm vacuum, the boiling point of the water is 61.6°C). This law operates during vacuum evaporation.

From closed space, the air and vapors (evaporating at a temperature corresponding to the vacuum) are continuously exhausted by a vacuum pump. Vacuum evaporation—since it happens in a medium depleted of oxygen and at lower temperature—preserves color, flavor, and vitamins.

Vacuum evaporation makes it possible to establish multistage evaporators. For economic evaporation, it is necessary that the temperature difference (ΔT) between the boiling point of the liquid and that of the heating steam be quite high (for evaporators used in food industry, it is higher than 15°C). The temperature of steam cannot be elevated above 105°C without the burning effect; therefore, evaporation can be performed only under vacuum.

Evaporation with multistage devices means significant savings in steam usage. While for one-stage unit, 1.1 kg steam is necessary for evaporating 1 kg water, for two-stage unit, 0.5–0.6 kg steam is enough.

The essence of multistage evaporators is that several evaporator units are coupled in line. Direct heating is given only to the first unit. The second unit is heated by the vapor formed in the first unit, while the third one is heated by the vapor formed in the second unit. To perform this in practice, the boiling point of the substance must be decreased stage by stage, that is, gradual increase of air dilution is necessary (Barta 2006).

Requirements for Evaporators

On the basis of the above, general requirements for evaporators are

1. Evaporation must be rapid, that is, the required amount of water should be evaporated as soon as possible.
2. Evaporation must be performed at the lowest possible temperature.
3. Evaporator should be suitable to evaporate the product being concentrated.
4. Time and temperature of the evaporator must be controlled.
5. The specific energy consumption of an evaporator should be low.
6. The specific investment and maintenance costs of the evaporators should be low.

Specific requirements for evaporator should match with the quantity and quality of product being concentrated.

Control of Evaporation

As stated before, the aim of the evaporation is to produce concentrate with a given soluble solids (Brix) content. The basis of evaporation control is the measurement of the Brix of the concentrate during the process.

The main controlling parameter is the pressure of steam, and the other is the air dilution (with valves set on the steam conduction tubes and on the vacuum tubes). Mass flow of the incoming juice is controlled as well. Measuring devices are used to detect deviations from the standard settings. There are manometers and vacuum meters on steam conduction tubes and vapor tubes. Thermometers are provided in the juice space of the evaporators and on the condensers. On the steam side, heat transfer deteriorates if the noncondensable gases are not conducted away. The conductor tubes should be just hot and the ventilation valves must be opened appropriately. Heat transfer is highly deteriorating if the waste water does not flow away. If the pressure is not low enough in the last evaporation stage (vacuum becomes worse), then the cooling water is not enough or it is not appropriately cool. If this is not the case, then the insulation of the vacuum tubes may not be sufficient or the air (vacuum) pump may not be functioning properly.

During evaporation, as the juice flow decreases, the steam pressure is decreased to prevent burning of concentrates. In case of fast evaporators, as a first step, the (missing) juice is followed by water.

Concentration with Integrate Membrane Operations

During fruit processing, there are two important points to consider: (1) the valuable quality components (color, flavor, vitamins, antioxidants, etc.) of the raw materials should not be adversely affected during the processing and (2) the processing should produce the least possible waste.

In order to improve the quality of the product and preserve the intrinsic values, milder procedures for producing fruit juice concentrates can be followed. The membrane technique may be an important and effective means to produce quality fruit juices.

Several industrial applications of the membrane technique are practiced in the food industry. Examples are the preconcentration of milk to produce cheese, preconcentration of egg fluid by ultrafiltration (UF), clarification of fruit juices by microfiltration (MF), clarification and sterilization of wine before bottling by MF, etc.

The membrane technique is a collective designation of several effective separation methods, which are suitable mostly for treatment of juices. The various types of filtration (MF, UF, nanofiltration (NF), and RO) are well-known membrane techniques. These membrane technologies can be looked as pre-evaporation processes (Bánvölgyi et al. 2006, Vatai 2007, Vincze et al. 2007, Kozák et al. 2008, 2009).

Reverse Osmosis

In RO, the pore size of the membrane is between 1 and 0.1 nm. By using this type of membranes, common salt and molecules/ions with similar size can be separated from liquid or juice with great efficiency. In RO, due to the very small pore size and to overcome the rising osmotic pressure, pressure in the range of 10–60 bar is applied.

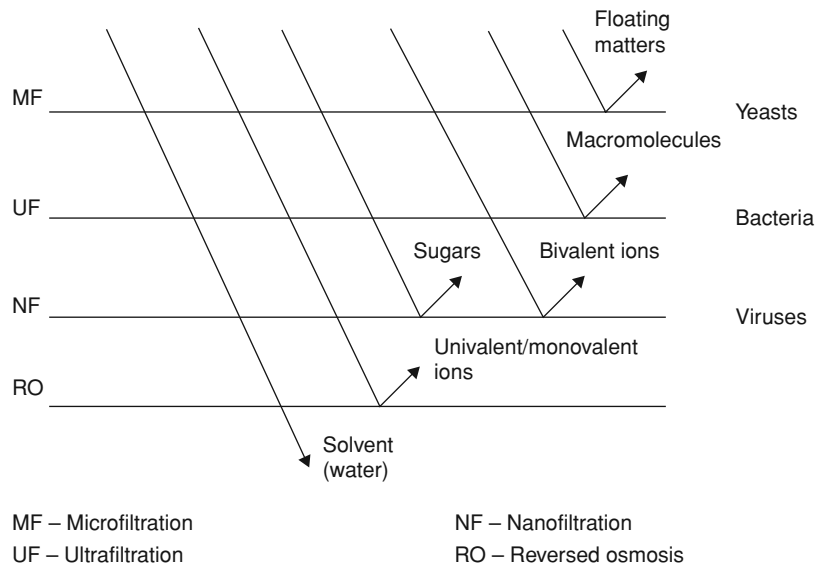

Figure 9.2. Retention of different filter membranes.

Among the membrane filtration techniques, the finest separation can be reached by using the RO technique. The RO membranes practically allow only the solvent molecules. The separation mechanism has not been fully resolved; however, there are various theories of separation, such as sieve effect, wetted surface, sorption–capillary effect, and solution–diffusion model (Porter 1990, Rautenbach 1997).

The RO and the NF are applied to separate solutions containing dissolved material with low molecular weight, further with high priority for separation of inorganic salts and small organic molecules, such as glucose and saccharose from the solvent (water). The membrane filtration operations are based on the same principle. The difference among the membrane filtration domains lies in the size of the particle or molecule being filtered out. The retention of the membranes belonging to the different filtering domains is illustrated in the Figure 9.2 (Vatai 2007). Specific references relating to fruit juice concentrating are Vincze et al. (2006), Rektor et al. (2006), Rektor et al. (2007), and Pap et al. (2007).

FRUIT DRYING

Fruit drying involves removing water in different forms (both free and bound) and different amounts. The amount and manner of water removal change the structure of fruit depending on the type of bonding and also determine the character of the reconstituted dried material. Among the various bonding forms of water, the strongest is the chemical, physicochemical bonding, followed by adsorption, osmotic, micro-, and macrocapillary, and, finally, rehydration (Imre 1974). During drying, the weakest bound water is removed first; removing moisture by breaking stronger bonds requires energy. Removal of free water does not change the character of the material in either the dried or rehydrated states. Significantly higher energy and special procedures are required to remove bound water, that is, to decompose the higher bonding energies (Ginzburg 1968, 1976).

Equilibrium States

By putting wet material into a closed space, water molecules change to the gaseous state, forming a mixture of air and water vapor. At the same time, the molecules of the water vapor adsorb on the surface of the material by moistening it. After a given time, the number of molecules adsorbed on the surface of the material and the number of molecules that change to the gaseous state become equal. At this time, there is a state of equilibrium between the gaseous atmosphere in the space and the solid material. The state of the gaseous atmosphere can be characterized by its water activity, which is the ratio of the partial pressure of water vapor to the saturated partial pressure. The equilibrium relative humidity (ERH) of the material can be determined from the water activity:

$$a_w = \frac{p_1}{p_2}, \tag{9.1}$$

where a_w is the water activity, p_1 is the partial pressure of water in the food, and p_2 is the saturated vapor pressure of water at the same temperature.

The moisture content characterizes the state of the material, that is, its water content expressed in kilogram related to 1 kg of dried material. The equilibrium between the atmosphere and the wet material is highly affected by temperature.

Knowledge of the correlation between the various factors influencing equilibrium has primary importance for drying technology, since the air moistening state determines the final moisture content being reached at the drying temperature. The relationship among the three features of the state makes it possible to have three types of planar representations.

1. The sorption isotherm represents the function of the moisture content of the material with the water activity at constant temperature.
2. The sorption isobar is the function of the temperature and the moisture content of the material at the ERH.
3. The sorption isosthetrms represents the water activity as a function of the temperature at constant moisture content of the material.

Drying technology uses the sorption isotherms most frequently. Determination of the sorption isotherms is done by actual or theoretical measurements. For representation of isotherms, several empirical correlations were proposed (Halsey 1948, Henderson 1952, Chung and Pfost 1967). Several authors dealt with correlations of sorption data for fruits. Requirements necessary for a good correlation can be found in numerous reports (Guggenheim 1966, Thompson 1972, Iglesias and Chirife 1976, Pfost et al. 1976, Crapiste and Rotstein 1986, Ratti et al. 1989). Several methods exist for the determination of the sorption isotherms of fruits. One method consists of the measurement of the relative moisture content and temperature at equilibrium by placing the material with a known moisture content into a closed air space. The measured relative moisture content is equal to the equilibrium relative vapor content. Air moisture values measured at the same temperature but different levels of moisture give sorption isotherms for a specific fruit. Other methods of measuring sorption isotherms make use of air space with a constant relative vapor content established either by cooling and heating of the saturated air or by salt crystal solutions in a desiccator. The moisture content of the material put into the air space becomes constant, reaching a state of equilibrium. The relative vapor content and the moisture content of the material measured at the temperature of the air space will be one point on the sorption isotherm (Jowitt et al. 1983, Mazza 1984, Wolf and Jung 1985). Figure 9.3 shows sorption isotherms of some fruit.

Knowledge of the sorption isotherms of a material is of primary importance from a practical view point (Wolf et al. 1985). To ensure a product with the required moisture content, sorption isotherms are used to determine the state of the air (temperature, relative vapor content; Shatadal and Jayas 1992). The temperature and relative vapor content predict the remoistening and deterioration of a dried product with a given moisture content during storage. Further, it has great importance in selecting the drying procedure and predicting dryability, the binding strength of the moisture, and the shelf life of the fruit (Maroulis et al. 1988). If on the sorption isotherm, low moisture content relates to high a_w value, the material is highly hygroscopic, and drying can be done only with care in a climate-controlled space or in vacuum. Drying procedures with dry air can also be used for fruits having higher moisture content, for example, fruit at a low a_w value. The design of any process in which the transfer of heat is involved requires knowledge of density as well as the thermal properties of fruits being processed. Properties of fruits are discussed by Lozano et al. (1979), Lewis (1987), and Constenla et al. (1989). Empirical equations are proposed for modeling using density and thermal properties of the fruits being processed (Heldman 1975, Choi and Okos 1986, Singh and Mannapperuma 1990, Singh 1992).

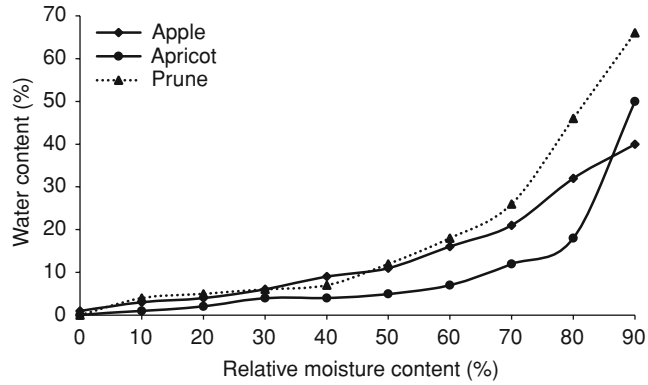

Figure 9.3. Sorption isotherms of selected fruits.

Principles of Water Removal

Drying a moist material and decreasing the water activity mean evaporation of bound water from inside the solid material into the atmosphere. Breaking water bonds, releasing, and transferring heat connected to phase change require energy. Drying can be done with different types of drying energy: convective (warm air), contact (heated surface), radiative (infrared rays), and excitation (microwave) energies. With convective drying, the heated air low in moisture content meets the wet material and as a result, the moisture moves onto the surface of the material and then into the drying air. Tasks of the warm air are to transfer heat to the material being dried to establish the drying potential and to transfer moisture into the air. For contact drying, the heat expanded by conduction from the cooled surface of the material evaporates the moisture. With infrared drying, the heat spreads from a radiating body—which can be a spot lamp, a piece of heated metal, or ceramic—directly to the material being dried. This method can be well applied using vacuum drying for very small or chopped material (Szabó 1987). For heat exchange by excitation, materials consisting of highly polarized molecules absorb the energy of excitation, resulting in heat necessary for drying the material. Using this method, liquids, pastes, and

highly milled materials can be handled quickly and without deterioration of the product. Vacuum drying can be used for heat-sensitive materials with low moisture content. In a vacuum with no transferring medium, convective heat exchange cannot be applied.

Moisture Transport in Solid Material

The phenomenon of drying is similar regardless of the drying method. This section deals with convective drying, the most widely used method in the fruit-processing industry. The wet material (fruit) is placed in an air space with relative moisture content lower than the ERH of the material; moisture is transferred from the solid material (fruit) into the drying medium (air space).

Mass flow of the moisture (q_m in kg/s) is $q_m = \beta_y(Y_s - Y_g)A$, where β_y is the material exchange factor at the gaseous side (kg/m^{2}s), Y_s and Y_g are the absolute vapor content of the air at the surface of the material and in the air (kg/kg), respectively, and A is the surface area (m^2).

Simultaneously, the moisture content of the material is decreased. The water moves from the solid (fruit) and changes to vapor either inside or on the surface of the solid material. This vapor moves to the surface and goes into the air. In certain materials, such as gels, moisture transport is caused by diffusion flow of the water in the given material. This diffusion flow is initiated by the difference in moisture density of the material (Barta et al. 2007). Most foods are capillary-colloidal porous materials in which simultaneous liquid–vapor transport can occur. The character and direction of this transport depend on the texture, shape, and relationship of capillaries and pores. The vapor produced by water evaporation in the capillary-porous structure flows by diffusion to the surface. The so-called Knudsen flow in the microcapillaries can be several orders of magnitude larger than Poiseuille flow in macrocapillaries. In foods, the conduction form of energy mentioned above occurs together with diffusion and moisture transport, which is a function of the type of material and circumstances. For industrial calculations, the various forms of water transport can be handled together by means of an effective apparent diffusion parameter. Using the average apparent diffusion parameter (D_e, m^2/s), the mass flow (q_m, kg/s) of the moisture is in a stationary state:

$$q_m = c_s D_e \frac{dX}{dz} A, \tag{9.2}$$

where A is the surface area perpendicular to the direction of the moisture transport (m^2), c_s is the concentration of the solid material (kg/m^3), z is the length in direction of the moisture transport (m), and X is the moisture content of the material, that is, the amount of water related to 1 kg dry material.

The above relationship can be derived from Fick's law. In a nonstationary state, the material equation written for water results in a second-order, nonlinear, parabolic differential equation, which can be given together with the initial and boundary conditions (e.g., material exchange on the surface). The moisture distribution along the length can be determined at an arbitrary drying period (Mohr 1984, Körmendy 1985, Gion 1986, Gion 1988).

Drying Procedure

At steady-state conditions (constant temperature, air flow rate, and air moisture content), the experimental results of drying are plotted by time. Generally, the moisture content (X) related to dry material is shown as a function of time (t). This is presented in Figure 9.4.

This plot shows a typical case where the moisture from the solid material evaporates first from the moisture layer on the surface and decreases continuously until water evaporates from the inside of the solid material. It can be seen in the figure that variations in the drying rate depend on time and moisture content of the fruit product. This change can be seen better if the drying curve is differentiated and a drying flow rate curve is derived. Drying rate can be presented as a function of the drying period (Fig. 9.5).

Curves for the drying rate and drying flow rate can be divided into several parts. These parts are the result of the inner mechanism of drying and of changes occurring during drying. In the first step of drying, temperature equalization and moisture transport occur. In the next step, which is the constant rate period, there is a constant moisture flow to the surface; therefore, the surface is always wet. The average moisture measured at drying of the surface is the so-called critical moisture content. The drying rate decreases after reaching the critical moisture content. Drying stops and the drying rate becomes equal to zero when the average moisture content reaches the equilibrium moisture content related to the relative vapor content of the air. Dimensions of the material being dried are of primary importance in drying technology (Fig. 9.6).

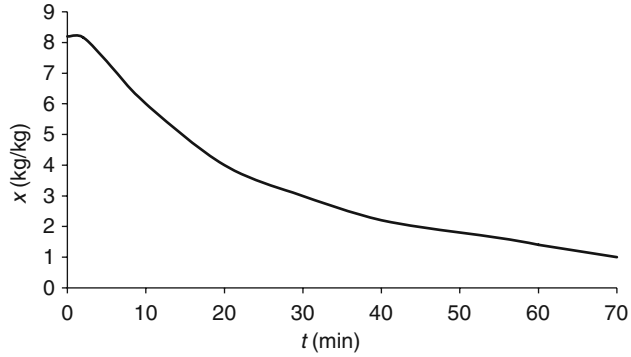

Figure 9.4. Drying curve of a wet material.

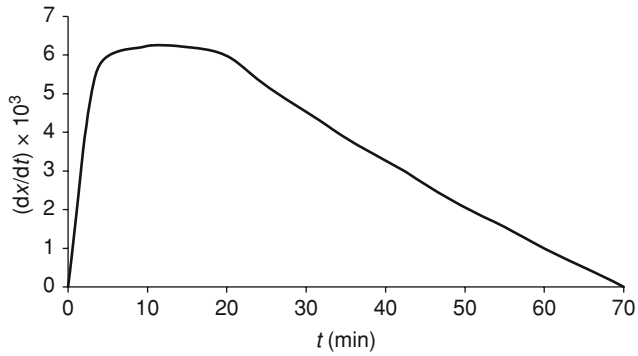

Figure 9.5. Drying rate curve as a function of time.

Linear variation of the size of the material changes the drying period to the second power. Increasing the drying temperature, and therefore the drying rate, the drying time is shortened and the capacity of the equipment is raised. This method is useful only in the constant rate period because the higher temperature of drying air does not result in significant increases in the temperature of the material. The increase in the drying rate is hindered by some stresses in the material, by precipitation of the solute salts on the surface and crust formation. The intensive air ventilation enhances the moisture transport to the surface; however, it can result in crust formation (Barta et al. 2007). Managing the drying process takes into account the following aspects:

1. High temperature and intensive air ventilation at the initial period,
2. Mechanical removal of the surface moisture layer,
3. Temperatures ensuring a low drying rate for a long period at the end of drying, "quiet" ventilation.

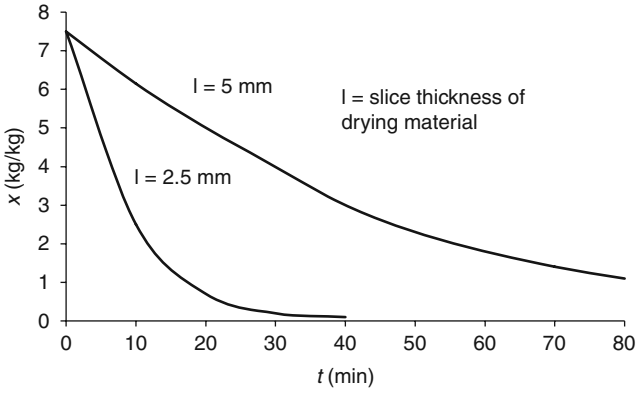

Figure 9.6. Effect of the size of material on the drying process.

Effect of the Drying Air Characteristics on the Drying Process

It is necessary to know the factors determining the quality of the finished product, which can help to establish the parameters of the drying procedure. The concept of optimum drying must include the concept of economy, or the optimal application of heat used for drying. The external factors influencing drying are the following: temperature, moisture content, flow rate, direction of the drying air flow, and drying period. These factors must fit the properties of the material being dried (variety, water content, dimensions) and the methods of preparation (Kilpatrick et al. 1955, Lazar and Farkas 1971, Van Arsdel 1973, Lozano et al. 1983, Ratti 1991).

Principles of the Technical Calculations

The basis of the technological calculations is the law of mass preservation—the sum of masses of materials coming into the dryer is equal to the masses leaving the dryer. For a continuous process, calculations must be done with mass flows of the materials (expressed in kg/s). Drying does not change the mass of the dry material. The incoming and outgoing masses or mass flows are equal. Therefore, the air leaving the dryer takes with it an amount of water equal to the water evaporated from the material being dried. If we study the mass flow and the moisture content of the drying air, we need to add the evaporated water mass flow to that of the air entering the dryer. The drier the air coming into the equipment, the more the moisture it can absorb; therefore, lower specific air consumption is necessary (the amount of the air needed to evaporate 1 kg water). The mass flow of air is also influenced by the size of the conducting flue and the velocity of the air. On an average, the temperature of the used air decreases by about 20°C during drying and about six times more air is required for the evaporation of water than for its transfer. Drying temperature determines the amount of heat given to the material; therefore, the degree of evaporation affects the structure and quality of the material (e.g., deterioration caused by heat). Theoretically, the heat flow is enough to evaporate the water in food; however, this is not the case in practice. During drying, not only water, but also food and the component parts of the drying equipment must be heated to the drying temperature. Extra heat is necessary to compensate the heat losses. Examples are the heat contributed by the equipment together with the warm air and food product. Heat losses can be decreased by insulating the equipment and by using the outgoing air. Drying efficiency is the ratio of the theoretical heat flow to the one used in practice and depends mainly on the type of dryer and quality of the material being dried. However, the temperature, moisture content, and velocity of the drying air also influence the drying period. Calculation of the efficiency is given by the

following mathematical formulas. The heat flow needed to warm the material (Φ_m) is

$$\Phi_m = cq_w\Delta T(\text{kJ/s}),$$

where c is the average specific heat of the material (kJ/kg K), q_w is the average mass flow of the material (kg/s), and ΔT is the temperature difference in the material (K).

The heat flow taken for evaporation (Φ_e) is

$$\Phi_e = q_w\Delta H(\text{kJ/s}) \quad \Delta H > r$$

$$\Delta H = r + H'$$

where r is the heat needed to evaporate 1 kg water at the average temperature of the material (kJ/kg), ΔH is the specific enthalpy change (kJ/kg), H' is the specific binding energy of the water (kJ/kg), and q_w is the mass flow of the water being evaporated (kg/s).

The useful heat consumption (Φ_n) is given by

$$\Phi_u = \Phi_m + \Phi_e$$

and the total heat consumption (Φ_t) by

$$\Phi_t = \Phi_u + \Phi_l$$

where Φ_l is the heat loss parameter.

The total efficiency of drying (η) is

$$\eta = \eta_d\eta_{eq}$$

where η_d is the efficiency of drying

$$\eta_d = \frac{\Phi_u}{\Phi_t} = \frac{\Phi_m + \Phi_e}{\Phi_t} \tag{9.3}$$

and η_{eq} is the efficiency of the drier

$$\eta_d = \frac{\Phi_l}{\Phi_t} \tag{9.4}$$

Dryers

The following references can be used for designing a dryer: Crank (1967), Lazar and Farkas (1971), van Arsdel et al. (1973), Suzuki et al. (1976), Lozano et al. (1983), Ratti (1991), Gion and Barta (1998), Mujumdar (2000, 2004), Kudra (2001), and Oetjen (2004). For dielectric drying, the following references are recommended: Ginzburg (1969), Nelson (1983), Mohsenin (1984), Sandu (1986), Schiffman (1987), and Ratti and Mujumdar (1995). To evaluate drying efficiency, it is necessary to know the capacity of the dryer and the production ratio of the food being dried (the ratio of the dried finished product to the raw material). The aim of dehydration is the best usage of the properties of the raw material and capacity of the dryer to produce the specified quality dried product. The ideal is when the relationship among changes in heat, moisture content of the air, and volume are matched to changes in water leaving the material. These conditions can be accomplished (including the efficiency) by special equipment suitable for large-scale manufacturing. Assumptions are difficult to make due to variability of the equipment and materials and the milling sizes. Therefore, there is no universal equipment. Each type has an optimum working range determining the type of product that can be processed efficiently. Dehydration can be done under various conditions in different forms; therefore, dryers with various configurations are made (Kudra 2001). Their classification can be done from several points of view.

1. According to the working mode of the equipment:
   - Batch,
   - Continuous,
   - According to the pressure in the dryers,
   - Atmospheric dryers,
   - Vacuum dryers (their spread is apparent now).
2. According to the heat exchange:
   - Convection heat,
   - Radiation heat,
   - Conduction (contact) heat,
   - Combined,
   - Dielectric.
3. According to the relationship between the motion of the drying medium and the material:
   - Direct flow,
   - Counter flow,
   - Cross-flow,
   - Combined flow.

Menon and Mujumdar (1987) gave a detailed scheme for the classification from another point of view. For drying coarse products such as fruits, convection dryers are mainly used. The heat exchange medium is the warm air, and the material being dried is placed evenly on thin-layered perforated sheets, screens, or a grid. Pieces of the material change positioning during the movement of the trays. Because of the low air velocity, the material dries as a stationary layer. Generally, at an air velocity of 1–3 m/s, air does not carry particles. Production of coarse dried products is done in tray, tunnel, or bend dryers, and often vacuum dryers are used. Drying for shorter time at lower temperature preserves the product. It is a reversible method. Spray drying technology is widely used for drying liquids and food pulp. Drying as a technological process can be controlled at several steps. The controlling possibilities of dryers are summarized in Table 9.1.

The main requirement for rehydrating a dried product is that, upon placing the dried product in water, the amount of water absorbed is the same as the water content in the original, nondried food. The rehydrated product must also have, as much as possible, the shape, consistency, color, taste, and odor of the original food. Therefore, the dried product must be well dehydrated. A study of rehydration can be done by putting the dried fruit in distilled water for a given period (1–2 hour) or by cooking in salty water for 10–20 minutes. The water absorptivity factor or rehydration index (W_r) is the

Table 9.1. Controlling Possibilities of Dryers

	Control Features						
Sensory Features	Heat Introduction	Air Supply	Moving Rate of the Conveyor or the Tray	Air Recirculation	Solid Supply Rate	Mass of the Outgoing Air	Product Recirculation
Temperature of the incoming air	*	*	–	*	–	–	–
Temperature of the outgoing air	*	*	–	–	*	*	*
Mass flow rate of the air	*	*	–	*	*	*	–
Temperature of the product	*	*	*	*	*	–	*
Moisture content of the product	*	*	*	*	*	–	*
Heat decay of the product	*	*	*	*	*	–	*
Thickness of the solid medium	–	–	*	–	*	–	–
Holding period	–	–	*	–	*	–	*
Air velocity	–	*	–	*	–	*	–
Evaporation rate	*	*	–	–	*	–	–

Source: Barta et al. (2007).
Note: Asterisks (*) present in the meeting points of some columns and rows means that the measurement in the given row can be applied for characterizing of the feature in the column.

ratio of the mass of the dehydrated product (m_r) to the one of the dry product (m_o) (Barta et al. 2007).

$$W_r = \frac{m_r}{m_o} = \frac{U_r + 1}{U_o + 1}, \tag{9.5}$$

where U_r is the water content of the rehydrated product and U_o is the water content of the dried product being studied (both in mass ratio).

In addition to the remoistening index, the dehydrated product is evaluated by sensory and objective methods (its consistency, flavor, smell, and color). Important requirements are the storability, cleanliness and, if required, the size (uniformity).

Vacuum Drying

To meet the demand for coarse dry matters, which is required by instant foods, inspired developments in other forms of drying beside the traditional drying methods have to be evolved. The vacuum drying, which is more and more widespread nowadays, is a combined procedure. The coarse or pulpy material being dried is warmed by contact method under vacuum. Using high enough vacuum, the moisture of the material can be evaporated even at low temperature. Depending on the grade of the vacuum, the drying can be rather quick. Therefore, in the material being dried, small channels have been formed from the evaporated water, preserving their forms and shapes. The foods dried in this way have "instant" character. This means that if they get to wet medium, they practically sponge up the liquid through the channels inside the foods, and within a few minutes, they become similar to their former condition before drying. During drying, the material warms up just a little, so the heat-sensitive components are not damaged considerably. The great advantage of this procedure is the feasibility for drying practically all kinds and types of foods.

Production of the instant fruit powder can be carried out by combination of the foam-drying and the vacuum drying, as well as by their further modification. Using this technique, instant fruit powder can be produced directly from liquid foods, fruit and vegetable juices, and purees. By using this method similarly to foam-drying, fruit foam should also be formed from the material being dried during the drying process. It means that the foam-forming material is distributed evenly in the substance being dried. Then, after beginning of drying, the value of the vacuum is selected to make sure that the formation of foam will take place and it will be stabilized.

The essence of the procedure is that small bubbles are formed in the liquid under the effect of vacuum. The liquid expands and as a result, the speed of water loss (WL) is increased. By the help of the bubbles and the supporting material, medium compact foam with 5–10 cm height is formed from the 3–4 mm thick layer of liquid material in the vacuum chamber. The operation takes place at low temperature, so the drying material is affected by a very low heat effect. The special advantage is that due to the vacuum, the material is practically in an air-free environment, so the oxidation processes causing deterioration in quality in case of other drying methods will not occur here. During the well-controlled drying procedure, a dry foam with light, loose structure is originated, which can be pulverized very easily. The powder has an instant character; it can be dissolved within seconds and its solution is stabile.

The vacuum drying of liquids can conveniently be carried out in vacuum chambers supplied with heating plates. There are trays that fit in the heating plates; the material being dried

will get to these trays. Because of the relatively small size of the vacuum chambers, the investment costs are average.

The instant products prepared either by pulverization or vacuum drying is highly hygroscopic, and in order to preserve their quality, the manner of their packing and storage is an especially important task.

Freeze-drying

Principle of Process

By using quick freezing preservation of foodstuffs, the constituents of the tissues, solids, and fluid are immobilized and thereafter the water can be removed by sublimation at subfreezing temperatures so that practically no concentrations of salts occur and little denaturation of proteins or gelling of starches or twisting of fibers occur. As a result, the final product is as little changed as it can be, and when water is added, it instantly perfuses the microscopic honeycomb of sponge-like tissue, swelling it out, and reconstituting the food in substantially its original condition within a few minutes. The lyophilization or freeze-drying of biological materials generally calls for true, rapid, and deep freezing, followed by sublimation of the ice without thawing. The objective is to establish the whole frozen mass without the growth of large ice crystals to disrupt cells and membranes, to change the ionic concentrations to avoid supercooling with violent heat movements and volume and concentration changes, and then to be able to hold the mess without low-temperature enzymes or chemical activity. Thereafter, only the frozen water is to be evaporated, without melting and without undue heating of the resulting dried tissue.

At the ice surface in the frozen food, there is a vapor pressure of molecules escaping. This is directly proportional to the temperature of the ice, since it is a measure of the activity surface. The escape of the faster-moving water molecules from the ice surface causes a loss of energy from the ice, so temperature would then fall if it were not replaced (evaporative cooling), with consequent lowering of vapor pressure and slowing of the process. For continuous ice sublimation, a continuous heat supply is needed as fast as possible. Because of the continuous sublimation of the food surface, a dryer layer appears and the surface become dehydrated until the last of ice is sublimated. The properties of the dry layer, which is a porous mass, depend on the commodity, the rate of freezing, the direction of fibers in the drying foods, the direction of cutting, etc. But during the drying process, the increasing drying layer isolates the ice layer from applied heat. In the balance between heat input and vapor outflow, the limiting factor can swing from the one factor to the other during the dryer cycle. If the resistance to heat transfer is the limiting factor, the applied heat must be reduced; if the vapor diffusion is limiting, the applied heat must be reduced to avoid melting the ice face. During the process, the optimum is when the two factors are in balance.

So, the freeze-drying process is a preservation process to preserve high water content materials, mostly of a labile biological nature, by freezing and sublimation and later to rehydrate them. The process requires several successive steps:

1. Prefreezing: the materials are prepared and frozen at a low temperature.
2. Primary drying: the ice crystals formed on freezing are sublimed by gentle heating under vacuum.
3. Secondary drying: with the disappearance of the ice, the residual moisture is desorbed at around ambient temperature under high vacuum.
4. Conditioning and rehydration: at a sufficiently low moisture content, the vacuum is broken with a dry inert gas, and the product is then packed and stored.

The dried product can be shelf-stored until it is required for rehydration. The operating conditions, temperature, pressure, and time for each steps, are critical and must be carefully controlled.

The freeze-dried product is dry, light, and porous with almost its original shape and texture and so disposed to have an evenly distributed residual moisture content. In the dry state, it can be stored almost indefinitely, provided there is no contact with moisture and oxygen from the air. Because of its "lyophile" nature, ability to absorb moisture, it quickly recovers most of its original physical, organoleptic, and physiological properties.

Physical Requirements in Freeze-drying

Since the method involves the sublimation of ice, it is evident that natural liquid component of the foodstuff must be converted to ice before freeze-drying could commence. In this case, it is preferable to prefreeze material before loading into the cabinet. There is possibility to use an evaporating freezing system before drying, which means to cool the raw material sufficiently simply by loading it into the drying cabinet and evacuating the system to a low absolute pressure. In this case, water evaporated from the cut surfaces, the latent heat absorbed from the foodstuff by this evaporation, progressively lowers the temperature of the remaining water until freezing takes place. During this process, the materials has been losing its water content (drying), but the process is not really freeze-drying, because the water content of raw material is evaporating and no sublimation occurs because of the absence of ice. Using freezing by evaporation can be faster as conventional freezing, but some undesirable changes could occur, like shrinkage and salts or sugar transport to the surface, which can affect the rehydration process.

Ice Formation

When a foodstuff is frozen, the water in it forms crystals of ice, smaller or larger according to the rate of freezing. If the ice could be sublimed, the food should not change in

volume, but retain its original shape. The true freezing point of a foodstuff is rather difficult to establish. As the temperature is lowered, ice crystals begin to separate out, thereby concentrating the salt and sugar solutions, and a eutectic point or glass transition point is reached when the mass of the remaining solution freezes. In high biopolymer-containing materials like fruits or fruits juices, usually the glassy stage formation takes place at low temperature without eutectic formation. The process of vitrification is well known.

No two foodstuffs have exactly the same freezing characteristics, and it is essential to know the true freezing point before effective freeze-drying can be undertaken. The rate of freezing has a marked effect on the size of the ice crystals formed, their location in the foodstuff, and the drying and reconstitutions characteristics. As the speed of freezing is reduced, the size of ice crystal increases, becoming more and more extracellular in location, and severe mechanical damage can occur to the cell structure. As this ice is sublimed away, pores of large diameter remain in the dry tissue, offering a reduced resistance to the escape of vapor from the ice surface as compared with material that has been frozen rapidly. In general, the faster the freezing rate, the longer it takes to freeze-dry and the better the quality of the final product. The structural changes accompanying slow freezing adversely affect the appearance and texture of the product. It is therefore desirable with some foods to use an intermediate rate of freezing.

The Drying

During dying, the frozen material is placed in a closed chamber from which the air is evacuated by a vacuum pump, and as a result, the ice sublimes slowly if the condition parameters require the sublimation (Fig. 9.7), and energy for latent heat is supplied to it. The vapor given off move to the surface of ice condenser and freeze again. The driving force for sublimation depends essentially on the difference in vapor pressure between the ice interface and the condenser. The vacuum ensures that the interface temperature is always very low.

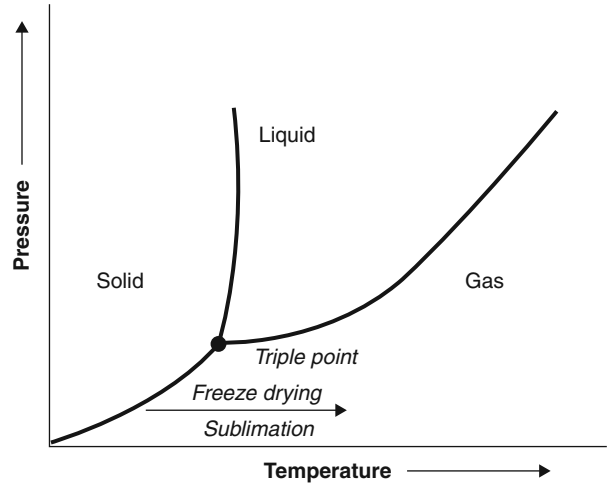

Figure 9.7. Phase diagram of water.

The rate of drying depends on two factors: the resistance of the heat transfer to the surface of ice crystals and the resistance of vapor flows from the sublimation zone to the ice condenser surface. During freeze-drying, there are no possibilities to transport heat to the ice surface because there is no gas molecules present as a result of the high vacuum, so only the contact or the dielectric heating can be used for transferring the heat to the sublimation zone. Using contact heating from one side of the product, the heat transfer happens through the frozen layer. In this way, the drying process can be controlled by the thickness of the product. During drying, the thickness of the ice is reduced and the rate of heat transfer is increased. The temperature of the heating surface is controlled to avoid ice melting. The rate of the heat transfer to the sublimation front depends on the thickness of the food, the thermal conductivities of the dried layer, and the temperature difference between the surface and the ice front. During the freeze-drying, the temperature of the heater is usually limited to 40–60°C.

When heat reaches the sublimation front, it raises the temperature and the water vapor pressure of ice. Vapor then moves through the dried food to a region of low vapor in the pressure in the drying chamber. The factors that control the vapor pressure gradient are

1. The pressure in the drying chamber and the temperature of the vapor condenser, both of which should be as low as economically possible;
2. The temperature of ice at the sublimation front, which should be as high as possible, without melting.

In practice, the lowest economical chamber pressure is around 13 Pa, and the lowest condenser temperature is about −35°C. Theoretically, the temperature of the ice could be raised to just below the freezing point. However, above certain critical "collapse temperature," the concentrated solutes in the food are sufficiently mobile to flow under the forces operating within the food structure. When this occurs, they flow into spaces left by the sublimated ice and there is an irreversible collapse of the food structure. This restricts the vapor transfer and effectively ends the drying operation. Therefore, the food should stay below the collapse temperature during the sublimation stage of drying and below the glass transition temperature during desorption.

During the primary drying, the ice in the food materials disappears, and the moisture is desorbed from the drying material, which was the site of the ice crystal. At the same time, it is necessary to decrease the heating rate so as to retain the temperature below the limiting value. In this period, the proposed temperature for biological material is about 30°C and 50–60°C for foods.

Quality of Freeze-dried Food

We can analyze the quality of freeze-dried food by comparing it with traditionally (wet) dried foods. The most obvious difference between freeze-drying and wet drying is the absence or presence of a mobile liquid phase during the drying process. The result of this is illustrated by in Figures 9.8 and 9.9, showing how the evaporation of wet liquid transports dissolved matters to the product surface during conventional drying, giving rise to permanent local concentration displacements in the product, often in the form of hard, insoluble crusts. In freeze-drying, this liquid transport does not take place, and the result is normally a homogeneous and porous product (Lorentzen 1979).

In freezing an aqueous solution, the major part of the water will normally crystallize into ice crystals, leaving a concentrated liquid between the crystals. Subsequently, the concentrated solution will freeze as a matrix in the form of the ice crystals interspaces. In fact, a very fine separation of water molecules and solute molecules takes place during the freezing operation. In the subsequent sublimation process, the crystallized water is evaporated and escapes directly to the surroundings, leaving a network of pores inside the product. The smaller fraction of the water contained in the matrix between the pores subsequently will diffuse to the nearest pore and then escape.

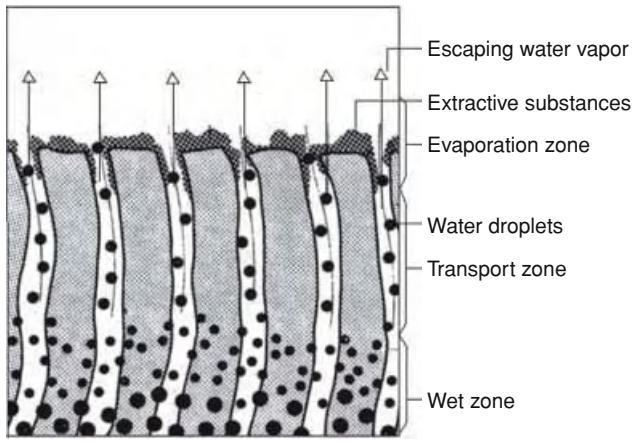

Figure 9.8. Principle of a conventional drying process (Lorentzen 1979).

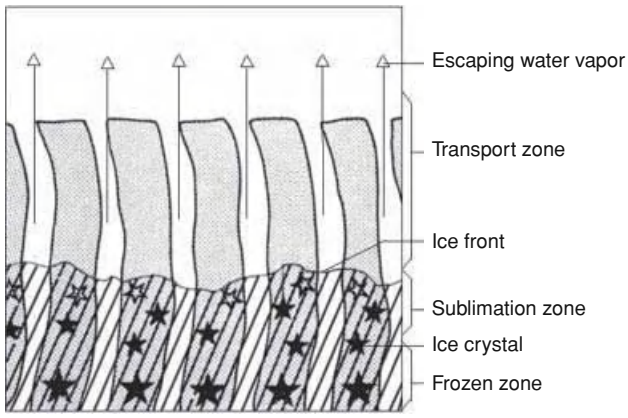

Figure 9.9. Principle of a freeze-drying process (Lorentzen 1979).

During drying, the loss of quality is a major problem that limits the market demand for dry food products. One of the main reasons for that loss in quality is the structural changes caused by the product shrinkage during drying (Achanta and Okos 2000). Freeze-drying provides the dried products of porous structure with advantageous quality properties, which are weighted against its high treatment cost (Krokida and Maroulis 2000). The solid state of water during freeze-drying protects the primary structure and minimizes changes in the shape of the product, with minimal shrinkage. The low temperatures applied in the process contribute to preserve constituents like minerals and vitamins, as well as to retain original flavor and aroma (Marques et al. 2006).

Rehydration capacity (RC) and rate are one of the quality attributes in relation to drying (Meda and Ratti 2005). Rehydration behavior has been considered as a measure of the induced damage in the material during drying (Lewick 1998), such as integrity loss and reduction of hydrophilic properties, which decrease the rehydration ability (RA; Krokida and Maroulis 2000). In order to know how much water was absorbed and what were the losses of soluble solids, and to fully characterize the rehydration of the freeze-dried fruits, the water absorption capacity, dry matter holding capacity, and RA can be used (Lewick 1998). Marques et al. (2009) investigated the rehydration characteristics of five freeze-dried tropical fruits. In their studies, mango, papaya and pineapple presented the higher rehydration rates as compared to acerola and guava, which had higher rehydration ratio at the saturation using freeze-drying process. Regarding their analysis, it was presumed that structural changes induced by rehydration itself have a great influence on the capacity of materials to immobilize water and fully rehydrate. The decreased porosity of acerola due to structural collapse during rehydration was a reasonable explanation for the lower RC and rate presented by the most porous freeze-dried fruit.

The freeze-drying technology offers advantages in aroma retention as well. Krokida and Philippopoulos (2006) investigated the volatility of apples during air and freeze-drying. They confirmed that factors affecting drying kinetics to be air temperature for convective drying and sample temperature for freeze-drying. The retention of flavor in freeze-dried materials was higher than in the convective drying experiments. It is obvious that the higher retention of aroma in freeze-drying is caused mainly by a lower product temperature.

Equipments

The freeze-dryers consist of a strongly constructed vacuum chamber, which contains trays to hold the food for drying, heated shelves to supply latent heat of sublimation, vacuum pumps, and a refrigeration unit. Refrigeration coils inside the chamber are used to condense the vapors directly to ice.

Freeze-dryers can be batch, semi-continuous, or continuous in operation. Batch or semi-continuous dryers are usually cylindrical tunnels that have air locks door for trolleys containing trays of food to enter. In batch dryers, the food enters and leaves the same door, but in semi-continuous dryers both ends have airlocks.

The high-capacity dryer usually has automatic loading and unloading system. For the drying process, after loading product is sealed into the drying chamber, the heater temperature is maintained at 80–120°C for initial drying and then gradually reduced over a drying period of 4–12 hours (Fellows 2009). The precise conditions in the drying cycle are determined for individual foods, but the surface temperature of the food does not exceed 60°C.

Regarding heating system, different types of dryers are characterized by the method to supply heat to the surface of the food. Conduction and radiation types are used commercially in most cases, and there are several developments to use microwave heating. Using contact freeze-dryers, the food is placed on trays to the heated shelves. This type of equipment dries more slowly than other designs because heat is transferred by conduction to only one side of the food. There is uneven contact between the frozen food and the heated surface, which also reduces the rate of heat transfer. In the accelerated freeze-dryers, food is placed into a special tray when additional heating surface serves heat from two directions. In this way, the heat transfers more rapidly into food, and vapor escapes more easily from the surface.

Infusion or Osmotic Drying

Osmotic dehydration is an operation used for the partial removal of water from plant tissues by immersion in a hypertonic osmotic solution. Water removal is based on the natural and nondestructive phenomenon of osmosis across cell membranes (Rastogi et al. 2005). The driving force for water removal is the different water activity, i.e., osmotic pressure in the plant and the hypertonic solution, which means that the water activity in the hypertonic solution must be lower than in the plant tissues. In this operation, the diffusion of the water from the fruit or vegetable cells is accompanied by a simultaneous countercurrent diffusion of solutes from the osmotic solution into the tissue. Since the cell membrane is not selective for compounds present in the fruits and vegetables (organic acids, reducing sugars, minerals, flavors, and pigment compounds, etc.), these can leach into osmotic solution. This phenomenon, diffusion from the hypertonic solution to fruit for sugars and for some other important components, resulted in the other name of this unit operation, known as infusion-drying. For example, osmotic treatment (OT) was applied to infuse grape phenolic compounds into plant tissue (Rózek et al. 2010). The stability of the grape phenolics after a posttreatment, such as convective air-drying, was evaluated. A model food made of agar gel and three plant commodities (two fruits, apple and banana, and one vegetable, potato) were osmo-treated and subsequently air-dried. During OT, total phenolic content and antiradical scavenging capacity of plant foods significantly increased.

An inclusion of 0.5–2.0% of salt in the sugar solution can increase the rate of osmosis; some other low molecular weight compounds such as malic acid and lactic acid have been shown to have similar effect (Brennan 2006). Commonly, sugar solutions with initial concentration of 40–70% are used. In general, the higher the solute concentration, the greater the rate of the osmotic drying. The initial WL is high at the beginning of the process, but after 1–2 hours, it reduces significantly, and it can take days for reaching the equilibrium concentration. Typical processing time for 50% water reduction is 4–6 hours.

In case of vegetables, sodium chloride solution in the range of 5–20% is generally used. Glycerol and starch syrup have been used experimentally for vegetables and some fruits also (Misljenovic et al. 2009a).

In general, the higher the temperature of the hypertonic solution the higher the rate of water removal; temperatures in the range between 20°C and 70°C have been used. As the temperature is higher, there is a danger for cell wall damage (Brennan 2006).

Determination of Process Parameters

During the process of osmotic dehydration (OD), two parameters of the process are important and can be calculated: the WL of the dried product and the solid or sugar gain (SG) in the dried product.

WL (g/g fresh product in dry basis) and SG (g/g fresh product in dry basis) were calculated based on the following equations (Mandala et al. 2005):

$$\mathrm{WL} = \frac{(ww_0) - (w_t - ws_t)}{(ws_0 + ww_0)} \times 100$$

$$\mathrm{SG} = \frac{(ws_t - ws_0)}{(ws_0 + ww_0)} \times 100$$

where ww_0 is the weight of water and ws_0 is the weight of solids initially present in the fruit, since w_t and ws_t are the weight of the fruit and the weight of the solids at the end of the treatment, respectively.

Other important process parameters, the effective diffusion coefficients of water, and sucrose (D), can be determined according to Fick's second law applied to a plane sheet, when the shape of the piece is similar to it. Garcia et al. (2007) reported that the effective diffusion coefficients of sucrose were lower than water in all treatments. Both water and sucrose

diffusivities were independent of osmotic concentration at 50% and 60% sucrose solutions; this was probably due to a conjunction of opposite factors.

Application of Osmotic Dehydration in Foods

There are several examples of the application of OD in food technologies, mainly in the drying processes of valuable fruits and vegetables. In most cases, the OD is often applied as pretreatment of air-drying, but there are several cases when it has been used as pretreatment of freezing and frying. For the improvement of mass transfer rate during the OD process, several pretreatment methods are investigated, such as high hydrostatic pressure, high electric field pulse, ultrasound, gamma-irradiation, vacuum, centrifugal force, microwave, etc. (Rastogi et al. 2005). In the different OD processes, different hypertonic solutions are often used, such as sugar and/or salt solutions, organic acid solutions, and some byproducts of industrial production, such as molasses (Koprivica et al. 2009a, 2009b).

Fernandes et al. (2006b) investigated the combination of OD and air-drying of papaya. They concluded that papayas are a fragile fruit, characteristic that limits large-scale exportation from the producing centers to countries in temperate regions. Loss of fruit ranges from 10% to 40% and has been reduced if papayas were dried. The process of OD followed by air-drying was studied and modeled for papaya preservation. They validated the developed model with experimental data and simulations have shown how the operating conditions affect the process. An optimization was done using the model in order to search for the best operation condition that would reduce the total processing time. The results show the advantage of using high sucrose concentrations for the osmotic solution, and the use of the OT to reduce the total processing time of fruit drying. They achieved similar results in the optimization of combined drying of bananas (Fernandes et al. 2006a).

By the above-mentioned authors, in the same laboratories, the effect of the ultrasound pretreatment of OD of melon (Fernandes et al. 2008) and pineapple has been studied (Fernandes et al. 2009). In case of the melons, the experiments proved that OD alone induced gradual loss of shape of cell wall, disconnection between the cells, and breakdown of the tissue. Ultrasound induced the formation of microscopic channels in the fruit structure but did not induce breakdown of the tissue. The changes observed on the structure of the fruit explain the effects of these two pretreatments on the water diffusivity of the subsequent air-drying step. Osmotic dehydration, when carried out for less than 30 minutes, decreases the water diffusivity due to the incorporation of sugar, but increases water diffusivity when carried out for more than 1 hour due to the breakdown of cells lowering the resistance to water diffusion. Ultrasound treatment increases water diffusivity due to the formation of microscopic channels, which also offers lower resistance to water diffusion.

Dehydration of tomatoes is a process commonly used to preserve the product and extend shelf life. However, the quality of the dehydrated product is often poor. Collapse of the structure, discoloration, and a tough texture are frequent quality problems. No less important, although not visually apparent, is the lack of flavor and nutritional value. The combination of OD and microwave drying is a potential new process that could improve the quality of dried tomatoes. Various osmotic solutions formulated with salt, sugar, and calcium lactate were used in an OT prior to microwave assisted air-drying (Heredia et al. 2007). The influence of microwave energy on the kinetics was analyzed and correlated with the dielectric properties of the samples. They showed that OD combined with microwave-assisted air-drying makes it possible to obtain dried and intermediate moisture tomato products that are shelf stable and have better quality than the traditional product. Heredia et al. (2010) studied cherry tomato dehydration by a combination of different techniques (OD, convective drying, and microwaves assisted air-drying) in order to evaluate the effect of the process variables on degradation and isomerization of lycopene, as well as on the optical properties. Specifically, the effect of prior OT, air-drying temperature (40°C, 55°C, and 80°C) and level of microwave energy (0, 1, and 3 W/g) were studied. Results showed that the osmotic pretreatment limited the isomerization during the later stage of drying, whereas both the loss of total lycopene and the *trans–cis* isomerization, mainly to the 13-*cis* form, were favored by an increase in temperature and the microwave power.

The influence of pretreatment by OD and combination with microwave heating to dry frozen strawberries using microwave-assisted convective or only convective method was investigated by Piotrowski et al. (2004). For processes carried out without microwave aid, use of OD caused decrease of final drying time, while implementation of OD before microwave/air process did not have an influence on final drying time. The introduction of OD when the same microwave doses were applied allowed decreasing drying time only for processes aimed to obtain 50% of water content.

Defrozen raspberries were osmotically dehydrated in sucrose solution initially at low pressure (1.33 kPa for 8 minutes) and then at ambient pressure (4 hours). Moisture decreased from 84% to 49% (wet basis), and almost one-half of water removal occurred at the vacuum period. Losses of vitamin C were high (80%). Osmotically dried raspberries were microwave-vacuum dried under on–off temperature control by varying microwave settings. Dried product (7.8% wet basis) of high quality (color, taste, structure) was obtained by Bórquez et al. (2010).

The effect of blanching and glucose concentration before drying on the rate of moisture movement during the early stages of air dehydration of strawberries at 55°C was studied by Alvarez et al. (1995). They found that the effective diffusion coefficient of water in strawberries was strongly affected by heat pretreatment, but glucose dipping after

blanching caused no additional effect. Taiwo et al. (2002) studied the influence of predrying treatments (high intensity electric field pulses (HELP) and OD on some characteristics of rehydrated apples at different temperatures. They concluded that RC values of HELP treated + OD samples were 10–30% higher than the RC of the untreated + OD samples. Solid retention after rehydration was highest in HELP-treated samples, which also had firmer texture at full rehydration. Sugar gained during OD increased product firmness.

Osmodehydrofreezing is a combined process consisting of OD followed by air dehydration and then freezing. This process has been proposed by Forni et al. (1997) to obtain intermediate moisture (water activity = 0.86) apricot ingredients without sulfur dioxide, having a natural and agreeable color suitable for different applications.

The effect of microwave-assisted air-drying with or without osmotic pretreatment on apple cubes was evaluated by Prothon et al. (2001). Osmotic pretreatment in sucrose solution was followed by microwave-assisted air-dehydration at different temperatures. Results showed that osmotic pretreatment before microwave-assisted air-drying increased the overall quality of the product. Although the drying time to reach 10% moisture content (wet basis) was reduced, the presence of infused sucrose in the osmotically dehydrated tissue decreased the drying rate during the microwave drying. The effective moisture diffusivity was slightly lower for the osmosed samples than for the nontreated ones at all the studied temperatures. Osmotic pretreatment had a beneficial effect on the firmness of the rehydrated samples that had been air-dried.

The ongoing research activities related to osmotic drying are focused partially on modeling (Khin et al. 2007, Sutar and Gupta 2007) and optimization of the process of OD as well as the combined drying processes of osmotic drying followed by air-drying (Singh & Gupta 2007, Souza et al. 2007). The other development in this topic are use of solution of different compounds (Jokic et al. 2007) in some cases to infuse some health beneficial compounds to the fruit or vegetable (Rózek et al. 2010), as well as using "natural" high-concentrated byproducts like molasses (Misljenovic et al. 2009a, 2009b). As indicated by Al-Muhtaseba et al. (2010), commercial processing of tomato utilizes only juice, while the wet pomace is considered merely as a waste product. However, tomato pomace represents a very significant source of lycopene, lipids, ascorbic acid, fibers, and proteins. High protein and lysine content tomato seeds, a major part of the pomace waste, are an unexplored source of nonconventional oil, but tomato pomace is highly perishable in its fresh state because it contains about 95% moisture. Tomato pomace must be dried immediately to reduce moisture before microbial spoilage and mold develop. The aim of work of Al-Muhtaseba et al. (2010) was to investigate the effect of temperature and OD on air-drying kinetics of tomato pomace. Osmotic pretreatment was found to be effective in enhancing drying rate and reducing drying time by approximately 30%.

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10
Developments in Minimal Processing of Fruits

Csaba Balla, József Farkas, and István Dalmadi

Abstract: Several minimal processing methods for keeping main characteristics of fresh fruits are available for food industry. Extending shelf life could be achieved by using novel washing and sanitizing, MAP, edible coating, ultraviolet light, or radiation treatment.

Effective methods for decreasing microbial effects on fruits such as high hydrostatic pressure processing, pulsed electric field treatment, pulsed light technology, and cold plasma treatment are also discussed in the present study.

INTRODUCTION

Consumer demands for convenient but fresh and healthy foods are driving the food industries to apply new, environmentally friendly, and mild preservation techniques. They satisfy the increasing market demands for fewer preservatives, or even nonchemical alternatives that provide higher nutritive value, and fresh sensory attributes. Traditional preservation technologies and techniques may affect the appearance, sensory characteristics, and nutritional value. Minimal processing has emerged to meet this challenge of replacing traditional methods of preservation whilst retaining nutritional and sensory quality (Ohlsson and Bengtsson 2002).

In recent years, fresh produce has been reported to be the source of numerous foodborne disease outbreaks (De Roever 1998, Sivapalasingam et al. 2004). Some less acidic fruit products may even permit the growth of certain acid-tolerant pathogens (Zhuang et al. 2003, Balla and Farkas 2006). The pH of cantaloupe and honeydew melons is between 6.2 and 6.7, and that of watermelons and papaya, 5.8 and 6.0 (Splittstoesser 1996). Thus, there is an increasing need to develop and apply new means, which show promise for powerful microbicidal effects without affecting sensory and nutritional quality.

"Minimal processing" is an ambiguous term. In this chapter, processes that do not fundamentally alter the state of a raw produce or that only separate a whole fruit into component part are considered as minimal processing.

Other chapters of this book deal with the basic concepts of preservation systems and traditional methods of fruit processing. The aim of this chapter is to give a short review

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of recent developments of the following nonthermal minimal processing techniques used for extending the shelf life and microbiological safety of fresh fruits and fruit products:

- Novel washing and sanitizing treatments of fruits
- Modified atmosphere packaging (MAP) of fresh fruits and fruit products
- Edible coating of fruits
- Biocontrol of fruit and fruit products
- Ultraviolet light treatment
- Ionizing radiation treatment
- High hydrostatic pressure (HHP) processing
- Pulsed electric field (PEF) treatment
- Pulsed light technology
- Cold plasma treatment.

The use of nonthermal treatments on minimally processed (MPR) fruits and vegetables is attractive to both industry and consumers (Bliss 2006). However, minimal processing does not inactivate completely all microorganisms present in the raw material. Thus, the microbiological safety during the shelf life of MPR foods depends largely on

1. An appropriate refrigerated storage and distribution, which prevents the growth of microorganisms
2. Label (restriction) indicating "use-by" date.

For optimizing new technologies, an item-by-item approach is required to design processing conditions of the food materials, and it is essential to know the tolerance level of different microorganisms in specific situations. A comprehensive review on the kinetics of microbial inactivation for alternative food processing technologies has been provided by the U.S. FDA's Center for Food Safety and Applied Nutrition on the basis of a task force work of the Institute of Food Technologists (USFDA/CFSAN 2003).

NOVEL WASHING AND SANITIZING OF FRUITS

Contamination of fruits and vegetables with human pathogens or organisms causing spoilage has important economic consequences. Consequently, it is in the interests of the produce industry to develop interventions to reduce the risk of microbial contamination (Sapers 2006). The washing of fresh produce is an important step for removing soil and debris, improving the appearance of the commodity, lowering the produce's temperature, and limiting the development of physiological changes. Washing also reduces the microbial load on the surface of incoming produce, which impacts the product's quality, shelf life, and safety. With increasing concerns about the safety of fresh and fresh-cut produce, the benefit of washing is becoming increasingly more important. In most cases, antimicrobials are added to the washing systems to enhance the control of microorganisms that are found on the surface of incoming fresh produce (Herdt and Feng 2009). Several factors influence the effectiveness of washing: produce surface properties (skin or wound tissue), the microbial attachments (vegetative cells or spores), and the quality of water used for washing (organic loading, pH, the hard water components like magnesium and calcium ions, etc.). The washing techniques are very important especially for MPR fresh-cut produce where the topography of the product surface is an important physical property influencing the microorganism attachments and removal (Han et al. 2000, Liao and Sapers 2000).

The conventional washing technology mainly uses clean or reused water for cleaning superficial surface of fruits, with the regulation that final washing of commodities must use clean water that is acceptable for human consumption. In order to increase the antimicrobial effect of the washing, chemical agents are often used. The most common washing agents are the chlorine and its alternatives: chlorine dioxide (or acidified sodium chlorine), ozone, and peroxyacetic acid; (Nguyen-the and Carlin 1994, Sapers 2006). Chlorine is active against viruses, nonacid-fast vegetative bacteria, acid-fast bacilli, bacterial spores, fungi, algae, and protozoa.

Chlorine wash is the most widely used industrial washing method in the produce industry because of its efficacy, availability, relatively low cost, and ease of operation. Chlorine is normally used for the disinfection of the fruit surface by adding sodium hypochlorite (NaOCl) to the wash water. Dips in water from 50 to 200 ppm of added free chlorine are commonly used for pome fruits, either before processing or during pre- and post-cutting operations (Dong et al. 2000, Bett et al. 2001, Soliva-Fortuny and Martin-Belloso 2003). As the chlorine only delays microbial spoilage and does not exhibit any beneficial effects in biochemical and physiological disorders of fresh produce, when chlorine is used, the fruit surface should subsequently be rinsed to eliminate residual chlorine and keep the sensory properties of the untreated fruit (Ahvenainen 1996).

However, current chlorine-based sanitizers used to wash fresh produce do not provide satisfactory microbial reduction in industrial scale sanitizing treatments. Within the FDA-approved concentration, a chlorine wash can only achieve a 1–2 log CFU/g reduction in microbial populations (Hegenbart 2002). Because the use of chlorine also brings up health and environmental concerns, the fresh produce industry constantly seeks alternative sanitizers which are safe, environmentally friendly, and effective.

Sapers (2006) suggests hydrogen peroxide, trisodium phosphate and other alkaline, and different organic acids like lactic acid and acetic acid as alternative antimicrobial agents. Herdt and Feng (2009) indicated that besides widely used chlorine and chlorine compounds, electrolyzed low NaCl water, chlorine dioxide, and acidified sodium chlorite can be used as an antimicrobial agent. Ozone and hydrogen peroxide are also frequently used for washing and sanitizing fresh fruits or fresh-cut fruits.

Hydrogen peroxide (H_2O_2) is recommended for fresh-cut melon and analogous fruits. Residual H_2O_2 in treated fruits might be eliminated passively by the action of endogenous catalyst, given sufficient time for reaction, or actively by rinsing immediately after treatment to avoid reactions between H_2O_2 and food constituents that might affect product quality or safety. But in apple and pear wedges little or no gas evolution was observed, indicating low catalase activity and the possibility of a H_2O_2 residue problem, which may make the treatment unfit for fresh-cut pome fruits (Soliva-Fortuny and Martin-Belloso 2003).

Narciso and Plotto (2005) investigated the effect of sanitation system on the final result of microbial stability of sliced mango fruits. Their results confirm that sanitation method of whole fruit plays a role in determining the cleanliness of the cut fruit. The sanitizer systems (peroxyacetic acid on whole fruit followed by peroxyacetic acid or acidified $NaClO_2$ on cut slices) effectively reduced microbial growth and kept microbial counts low on cut-fruit surfaces for 21 days when compared to cut fruit slices from NaOCl-treated whole fruit.

The effects of electrolyzed oxidizing water (EO) on biological potential of different microorganisms have been studied by several researchers. Most of them investigated the effect of it on the fresh or fresh-cut vegetables. Udompijitkul et al. (2007) investigated the antimicrobial effect of EO water against *Escherichia coli* O157:H7 and *Listeria monocytogenes* on fresh strawberries (Fragaria × ananassa). Their results showed that more than 2 log(10) CFU/g reductions of aerobic mesophiles were obtained in fruits washed for 10 or 15 minutes in EO water prepared from 0.10% (w/v) NaCl solution. Bactericidal activity of the disinfectants against *L. monocytogenes* and *E. coli* O157:H7 was not affected by posttreatment neutralization, and increasing exposure time did not significantly increase the antibacterial efficacy against both pathogens. The effectiveness of EO water component is very fast. Wang et al. (2006) using dual-phase inactivation of *E. coli* O157:H7 with peroxyacetic acid, acidic EO, and chlorine on cantaloupes and fresh-cut apples found that residual counts of *E. coli* O157:H7 on both fruits exhibited a dual-phasic reduction behavior, with a fast inactivation (D values, 0.8–5.0 minutes) in the first minute of treatments followed by a much slower inactivation (D values, 14.6–59.8 minutes) in the remaining time (phase II). The dual-phase inactivation seems to be related to fruit surface topography that determines the bacterial distribution.

Washing and sanitation are among the most important processing steps affecting the quality, safety, and the shelf life of the MPR fruit products. If chlorine is the most widely used disinfectant, recent outbreaks associated with pathogen contamination in MPR products raise the concerns about the efficacy of chlorine treatment in assuring the safety of the products. Because of the environmental and health risks, there is a trend in eliminating chlorine from the disinfection process. So, more research is needed for fine alternative sanitizers for the disinfection of fresh-cut vegetables, not only for the organic food sector but also for the conventional food processors.

MODIFIED ATMOSPHERE PACKAGING OF FRESH FRUIT AND FRUIT PRODUCTS

To prolong storage life of fresh fruit, controlled atmosphere (CA) storage is frequently used, and the basic CA effect on biochemical reactions can also be used to extend the shelf life of processed and ready-to-use fruit products. The technique that provides CA condition for this ready-to-use fruit dishes is usually MAP.

When the fruit tissues respire, they take up oxygen and release carbon dioxide. The increased carbon dioxide and decreased oxygen cause a reduction of the respiration rate of the fruit tissue. This reduces the energy available for chemical changes that occur in fruits and vegetables, resulting in slower rates of ripening and prolonged preripening storability of produce.

In the MAP technology, the concentrations of both CO_2 and O_2 are important. The reduced O_2 concentration between 20% and 2% level decreases the rate of respiration. The effect is higher at lower oxygen concentration. To prevent anaerobic respiration, some oxygen needs to be present. At the critical O_2 level, the anaerobic respiration starts producing acetaldehyde and alcohol that poison the tissue, causing physiological disorders or death, and lead to quality loss of perishable fruit. The critical O_2 concentration that initiates anaerobic respiration depends on the respiratory activity of fruit tissue. Each produce has its own tolerance of oxygen and response to lowering of O_2 level. The total absence of O_2 results in the development of off-flavors and softening.

The effect of CO_2 on respiration is to decrease the activity of decarboxylation of organic acid on the Krebs cycles. Experiments indicate that CO_2 may indeed diminish the action of ethylene, provided the concentration of the latter is less than 1 mL/L. It is also supposed that CO_2 is responsible for the ACC oxidase action that takes part in the ethylene production. The tolerance against high CO_2 level is different in different fruits. Strawberries can tolerate high CO_2 level up to 20%, peach up to 10–15%, but McIntosh apples are damaged by about 3% CO_2 level.

Detailed antimicrobial mechanisms of CO_2 are not fully understood but theorized as follows (Yuan 2003):

1. Changes in ionic charges of the cell membrane that can interrupt the transport of specific ions needed for maintaining homoeostasis in the cytoplasm.
2. CO_2 permeates the membrane and reacts with water in the cytoplasm.
3. CO_2 plays a role in the synthesis of some cytoplasmic enzymes.

Important parameters influencing the shelf life of freshly prepared produce are the respiration rate, storage

temperature, relative humidity, initial microbial load, packaging film and equipment, filling weight in the package, volume and area, light, etc. The respiration rate is affected by product type and size, degree of preparation, product variety and growing conditions, maturity and tissue type, atmospheric composition, and temperature. For MPR food products, there is a great effect of peeling and slicing on the tissue metabolism. The observed changes include a rise in respiration, and DNA and RNA synthesis, including new enzymes, membrane degradation, and the appearance of novel mRNA.

The packaging materials have additional task in MAP technology. The factors that affect MAP-induced atmosphere within the package are respiration rate, mass of product in the package, the optimal gas concentration of the fruit in the pack, the free gas volume in the pack, etc. (Hong and Gross 2001). The other factors are the packaging film factors, such as permeability of film used for packaging and the surface and mass ratio in the package.

The permeability of film for CO_2 and O_2 are mainly determined by the material and the thickness of the film, the area of the surface, and the gas concentration difference between outside and inside the package. Since respiring MPR products utilize considerable oxygen, suitable plastic film for this type of MPR should have a relatively high oxygen permeability to avoid an oxygen-depleted atmosphere within the package. Plastic films used for MAP of fresh fruits need to have relatively high permeability to O_2 and CO_2. Most films have higher permeability to CO_2 than O_2 because of the solubility of CO_2 in polymer. It is suggested that permeability of film used for MAP of respiring products need $CO_2 > O_2 > N_2$. The suggested O_2 level is below 5–6% O_2 to prolong the shelf life of the product. At 3–2% O_2, there is high risk of anoxia. The maximum tolerable CO_2 concentrations for many fresh products are in the range 2–5%.

Active packaging system uses O_2 and CO_2 absorbers in the sealed pack. Some of the absorbers being used are calcium hydroxide, activated charcoal, and magnesium oxide. Sometimes C_2H_4 absorbers like potassium permanganate are used to prevent the accelerated respiring effect of ethylene.

Minimal Pretreatment Processing

The minimal process operations should be valuable adjuncts to MAP for successful extension of the shelf life of fruit commodities. These operations include

- Washing to remove the nondesirable (soil, insects, pesticides, etc.) materials from the surface and to cool the produce,
- Trimming to remove unsound tissue, separating inedible portions from desirable edible segments,
- Cutting edible tissue into suitable shapes and sizes,
- Draining to remove the water content from the surface,
- Applying food additives for pH adjustment, microbial control, oxidative reaction control, and texture modification,
- Cooling and temperature conditioning.

The success of the MAP technology of MPR fruit depends on the good manufacturing practice (GMP) and good hygienic practices. The initial microbial load of the fresh or fresh-cut produce is an important limitation factor for the shelf life of the products. The bruising of tissue leads to oxidative reactions, such as the enzymatic browning and off-flavor development. The presence of cut surfaces with a consequent release of nutrients, the absence of treatments able to ensure the microbial stability, the active metabolism of fruit tissue, and the confinement of final product enhance the growth of the naturally occurring microbial population in MPR fruits. The low acid fruits such as cut melon and tropical fruits can favor the proliferation of pathogenic *Salmonella* spp. and enteropathogenic *E. coli*.

For fruits with pH values below 4.5, yeast, lactic acid bacteria, and fungi are the major contributors to spoilage. Food additive diffused or infused into fruit tissues are used to reduce the pH, modifying the textural attributes, inhibiting microbial growth, and preventing discoloration. Some fruits may have pH values above pH 4.6, under MAP conditions, spoilage and possibly human pathogen growth may occur. Generally, as the pH of a cut produce decreases, there is less growth of spoilage and human pathogens. Lemon juice, citric acid, or ascorbic acid (AA) can be added to cut-fruits for pH adjustment prior to MAP. Calcium in plant tissues is involved in the delaying of senescence, reducing respiration, decreasing ethylene production, increasing tissue firmness, and preventing enzymatic browning. The increase in tissue firmness with the elevation of tissue calcium is caused by the interaction of the calcium ions with pectin-polysaccharides in both the middle lamellae and parenchyma cell walls.

The final stage of processing is packaging. The pretreated product is placed into the pack and sealed. Sometimes, vacuum is used to reduce the oxygen content of the fruit tissue. A mixed gas with increased CO_2 and reduced O_2 is introduced to the package to provide a good environment to reduce respiration and prolong shelf life. Thus, the packaging room is a critical zone in the processing chain. This room has to be appropriate for the temperature of the product and the hygienic requirement of the processing.

The quality of modified atmosphere packaged and MPR fruits or fruit products in the distribution chain is affected by many factors, and for the extended shelf life of the products, the following procedures are important: minimize handling frequency, provide continued control of temperature, RH, CA conditions during storage and transport, and rotating products on a first-in-first-out basis. The most important factor is the temperature. High temperature or temperature fluctuation increases the human risk of the product and decreases the quality and shelf life. Temperatures to be used during

Table 10.1. Suggested Parameters for MAP of Fruits Regarding Their Temperature Sensitivity (Gorris 2000)

Type of product	Temperature (°C)	RH (%)	O_2 %	CO_2 %
Fruit—cool ripening				
Apple	1–4	90–95	1–3	0–6
Pear	0–1	90–95	2–3	0–2
Fruit—cool ripen				
Apricot	0–1	90	2–5	0–2
Blackberry	0–2	90		
Cherry	0–2	85–90		
Currant red	0–1	90		5–10
Grape	1–2	90		
Kiwi	0–2	85–90		3–5
Peach	0–2	85–90	1–2	5
Plum	0–1	85–90	2	2–5
Raspberry	0–1	85–90		
Strawberry	0–1	90		
Fruit—warm ripening				
Avocado	12–13	90	2–3	4–7
Banana	12–14	85–95	2–3	8
Fruit—warm ripen				
Mango	8–12	90		2–5
Pineapple	11–13	85–90	2–4	5–10
Fruit—cool citrus product				
Grapefruits	10–16	90	5–10	0–1
Lemon	3–5	85–90	5–10	0–1
Mandarin	1–4	85–90	5–10	0–1
Orange	1–6	85–90	5–10	0–1

processing and distribution and their relationship to the sensitivity of products are described in Table 10.1.

SHELF LIFE EXTENSION WITH EDIBLE COATING

From the economic aspect, the success of fresh fruit market and processing depends on how long the shelf life of the fruits are extended, and how successfully the quality loss is reduced. Up to now, many storage techniques have been developed to extend the marketing period for fresh horticultural commodities after harvest. One method of extending postharvest shelf life is the use of edible coating (Baldwin et al. 1996) or edible film.

Edible coatings are continuous biopolymeric matrices formed as films and directly applied on the exterior surface of fresh fruits. Edible coatings are prepared as solutions and emulsions from proteins, lipids, and polysaccharides and are applied on produce surfaces by different mechanical procedures, such as dipping, spraying, and brushing, or by electrostatic deposition (Amefia et al. 2006, Tara et al. 2009). Edible films are thin films that act as a barrier material to control moisture, oxygen, carbon dioxide, flavor, and aroma exchange between food components or with the atmosphere surrounding the food and also to protect the product, extend its shelf life, and improve its quality (Suyatma et al. 2005). Usually, edible film is a thin layer of edible material placed on fruits and can be used as wraps or pouches for fruits.

Fruits are living and intensively respiring materials, which mean that changing the quality characteristics like carbohydrates, organic acids, water content, texture profiles, appearance, etc., and retarding this process may lead to successful shelf life extension and has beneficial aspects in the postharvest sector and market.

Several fruits are coated during postharvest handling. The physiological background of using coating or film is similar to the CA or MA storage, when the environmental O_2 and CO_2 level around fruits are modified using decreased O_2 and increased CO_2 level to moderate the respiration. Similar process occurs using coating or film on the surface. The barrier ability of applied coating and film can reduce the oxygen uptake and lead to increased CO_2 level in fruit tissue and retard the internal oxidation process. So, the coatings can influence the inner atmosphere and extend the shelf life of the commodities.

Coating of fruits and using different types of film for this case have long history. Waxes were used to retard the

desiccation of the citrus fruit in twelfth and thirteenth centuries in China, and several applications of different coatings started in the twentieth century all over the world: hot melt paraffin waxes for citrus fruits and carnauba wax and oil-in-water emulsion for coating fresh fruits and vegetables. Several recent reports discussed different successful applications of coatings and edible waxes made from polysaccharides, proteins, and lipids alone or in mixtures to produce composite film applied for fresh fruits surface. The most successful coatings were lipid film made from acetylated monoglycerides and waxes (beeswax, carnauba, candellia, paraffin, and rice bran), (Baldwin et al. 1996).

The three main categories of macromolecules found in edible films are polysaccharides, proteins, and lipids (McHugh 1996). Hydrocolloids are used to produce thin layers of edible materials on food surfaces or between food components. Such films serve as migration inhibitors to moisture, gases, aromas, and lipids. They can include antioxidants, antimicrobial agents, preservatives, or other additives to improve mechanical integrity or handling characteristics and food quality, and to change surface gloss (Chen and Nussinovitch 2001).

Polysaccharides are usually used because of their ability to form films and their selective permeability to O_2 and CO_2. Polysaccharides commonly used in edible coatings include cellulose derivatives, starches, and chitosan. Recently, several studies reported the use of locust bean gum as polysaccharide that is widely used in the food industry as a stabilizer, viscosity modifier, and as an edible coating in the fruit surface (Aydinli and Tutas 2000, Bozdemir and Tutas 2003, Conforti and Totty 2007).

The natural waxes like beeswax and carnauba wax are very often used for reducing the weight loss of different fruits. Sometimes, shellac is used for citrus fruits but its high gas barrier habit can cause off-flavor and peel pitting. The applicability of coating wax very often is improved by different plasticizers that are usually necessary to improve the film and coating integrity, while avoiding pores. Plasticizers weaken intermolecular forces, increase the mobility of polymer chains and, in general, decrease the barrier properties of the coating. The effectiveness of coating formulations will determine coating thickness around the fruit, which will affect the final barrier properties (Amarante and Banks 2001, Rojas-Argudoa 2008). Waxing enhances shine, reduces water loss, and provides a vehicle for fungicides. Wax application has also been proven to reduce the incidence of chilling injury in citrus (Martínez-Jávega et al. 1989). Waxing restricts gas exchange, modifying the internal atmosphere, and affects the respiration process. The application can help to retard the inner sensory characteristics, but wax application may increase the incidences of anaerobic off-flavor.

The effects of wax and wax-based coatings on ethanol content, internal atmosphere, and weight loss in apples and citrus fruit, and the shelf life of tropical fruits have been reported (Chen and Nussinovitch 2001).

There is a recent interest in developing and applying edible coatings to improve food safety. The replacement of synthetic components used in commercial waxes such as polyethylene by natural substances has advantages with respect to environmental protection and food safety (Rojas-Argudo et al. 2008).

The successful application of coating depends on different factors that can affect the performance of coating-containing systems such as type of fruit, coating surface coverage, coating thickness and permeability, and temperature. Cisneros-Zevallos and Krochta (2005) showed that the relative humidity also plays an important role in permeability of coating that highly affects the gas exchange process across the film when hydrophilic films are used as a coating material. Their model confirms that increasing relative humidity around the coated fruits will result in exponential relationship on O_2 and CO_2 permeability, applying a plasticized whey protein film as a coating, and increasing the thickness of the film would increase CO_2 pressure in the fruit tissue.

The investigation of the efficiency of different edible coating and edible film is of research interest on postharvest handling of fruits and vegetables. There is search for new nature-based materials for producing new edible coating for fruits, and how the barrier properties of the new coating and film would control gas exchange and respiration rate. In the last decade, several studies investigated the application of the chitosan as a coating material (Baker and Hagenmaier 1997, Choi et al. 2002, No et al. 2007). Chitosan is a modified natural biopolymer derived by deacetylation of chitin, a major component of the shells of crustaceans. Recently, chitosan has received increased attention for its commercial applications in the biomedical, food, and chemical industries. Use of chitosan in food industry is readily seen due to its several distinctive biological activities and functional properties. The antimicrobial activity and film-forming property of chitosan make it a potential as a food preservative or coating material of natural origin (No et al. 2007). The application of chitosan was suggested as a coating to extend the shelf life of strawberries and litchi fruits. Fresh-cut apple and papaya cylinders were successfully coated with 2% (w/v) alginate or gellan film-forming solutions containing viable bifidobacteria. Water vapor permeability (WVP) in alginate or gellan probiotic coatings were investigated for papaya and apple by Tapia et al. (2007). In their studies, the gellan coatings and films exhibited better water vapor properties in comparison with the alginate coatings, and values > 106 CFU/g *Bifidobacterium lactis* Bb-12 were maintained for 10 days during refrigerated storage of fresh-cut fruits, demonstrating the feasibility of alginate- and gellan-based edible coatings to carry and support viable probiotics on fresh-cut fruit.

McHugh and Senesi (2000) investigated using coatings made from apple puree with various concentrations of fatty acids, fatty alcohols, beeswax, and vegetable oil. The apple-based wraps significantly reduced moisture loss and

Table 10.2. Application of Edible Films on Fresh Fruits and Vegetables (Tara et al. 2009)

Product	Application	Film Materials	Functions	References
Strawberry	Wrap, pouch	Wheat gluten-based films	Retention of firmness, reduced weight loss, and maintained visual quality during storage	Tanadu-Palmu and Grosso 2005
Apple	Wrap	Apple-based edible films	Reduced moisture loss and browning in fresh-cut apples	McHugh and Senesi 2000
Lettuce	Wrap	Biodegradable protein film	Did not show any beneficial effects on pectic substances and pigments	Schreiner et al. 2003
Green pepper	Wrap	Polylacticacid-based biodegradeblefilm	Can be used to maintain quality and sanitary conditions in modified atmosphere packaging	Koide and Shi 2007

browning in fresh-cut apples, and this novel method extends the shelf life and improves the quality of fresh-cut produce. One of the other major advantages of using edible films and coatings is that several active ingredients can be incorporated into the polymer matrix and consumed with the food, thus enhancing safety or even nutritional and sensory attributes. Rojas-Graü et al. (2009) reviewed the use of edible coatings as carriers of functional ingredients on fresh-cut fruits, including the recent advances in the incorporation of antimicrobials, antibrownings, texture enhancers, and nutraceuticals to improve quality and functionality of fresh-cut fruits. Table 10.2 shows the application of edible film on fresh fruits and vegetables (Tara et al. 2009).

BIOCONTROL OF FRUITS AND FRUIT PRODUCTS

Quality control and the continuous search for new applications have been the keys to the success of fresh fruits and fruit products. Nowadays, the biological control has become a new tool for managing storage diseases, which until recently were controlled by biochemicals (Mercier and Marone 2006). Expansion of postharvest biocontrol is focused on adaptation to small orchard operations and on broadening its use by combining with GRAS substances and other nonfungicidal methods. Potential uses also include application to mechanically harvested fruits and use as a precautionary measure against the growth of foodborne human pathogens on intact and fresh-cut produce (Janisiewicz 2007). Yeasts or bacteria are used and are able to colonize the fruit wounds and can convert as biocontrol agents by transforming with foreign gene(s) responsible for antifungal activity. This system can be used for commercial application to reduce the postharvest decay or used as biofilm to control the population of microorganisms growing on the surface of peeled or fresh-cut fruit products.

Biocontrol is a defensive method when the abilities of one pathogen microorganism to defend are reduced by other antagonist organisms (Cook and Baker 1983, Vajna 1987). For biocontrol, two methods can be used: use of living microorganisms on the surface of the fruit or applying new antagonist microorganisms as an artificial contamination on surface of the fruit. In the first case, the aim is to manage the condition around fruit to support growth of the effective microorganisms that are successful against mold and bacteria.

Several experiments confirm that artificial application of selected strains are effective (Wisniewski and Wilson 1992). Petersson (1998) indicated the effective use of microorganisms for:

1. Antibiotic production. Consider the definition of antibiotic given by Deacon (1997): to be antibiotic the concentration of the produced metabolism is effectively beyond 100 μg/mL,
2. Hypha interference and parasitism: when one of the parasite strains defends the hypha of the other to get nutrient without killing it,
3. Competition for the space and nutrient: experiments show that some yeasts can grow faster than molds and consume all the nutrient materials like sugars and proteins before the mold could grow,
4. The defensive mechanism of the plant organization should increase.

The applied organisms that are successfully used in the biocontrol of the postharvest disease have to meet the following requirements (Wisniewski and Wilson 1992): stability, efficient in low concentration/population, has no special demands regarding nutrients, resistant against pesticides, and be able to grow on the surface of the fruits. Despite several successful experiments using antibiotic-producing bacteria in biocontrol, the methods have not been widely applied because of cost and the risks of negative effect. In the last decade, the researchers have turned to yeasts, applying them in biocontrol systems. The main reasons are they do not produce antibiotics, mycotoxins and allergenic components, and are resistant against extreme environmental conditions like low water activity and low pressure. They have fast metabolic mechanisms in different substrates, and sometimes they can

Table 10.3. Yeast and Yeast-Like Microorganisms Against Plant Pathogen

Control Organisms	Plant Pathogen Organisms	Fruits
Aureobasidium pullulans	*Botrytis cinerea*	Strawberry
	Rhizopus stolonifer	
Acremonium breve	*Botrytis cinerea*	Apple
Candida olephila	*Botrytis cinerea*	Apple, strawberry
	Rhizopus stolonifer	
	Penicillium digitatum	
Candida famata	*Penicillium digitatum*	Orange
Cryptococcus humicola	*Botrytis cinerea*	Apple
Cryptococcus laurentii	*Botrytis cinerea*	Apple
	Mucor sp.	Pear
Cryptococcus albidius	*Botrytis cinerea*	Apple
	Mucor sp.	Pear
Cryptococcus flavus	*Botrytis cinerea*	Apple
	Mucor sp.	Pear
Cryptococcus spp.	*Penicillium expansum*	Apple
Klockera apiculata	*Rhizopus* sp.	Pear
Metschnikowia pulcherrima	*Botrytis* sp.	Apple
Pichia guilliermondii	*Penicillium digitatum*	Citrus fruit
	Penicillium expansum	
	Botrytis cinerea	Grape
Sporobolomyces roseus	*Penicillium expansum*	Apple
	Botrytis cinerea	

Source: Brückner (2001).

produce extracellular polysaccharides that can help the adhesiveness of the cells to the surface of fruits (Petersson 1998). The successfully used microorganisms (as an antimicrobial agent) are given in Table 10.3.

The application of different control microorganisms requires careful consideration because sometimes the effect depends on the fruits. Giobbe et al. (2007) reported biofilm-forming strain of *Pichia fermentans* to be most effective in controlling brown rot on apple fruit when coinoculated into artificial wounds with a phytopathogenic isolate of *Monilinia fructicola*. When inoculated into wounds artificially inflicted to peach fruit or when sprayed onto the surface of peach fruit, the same strain showed an unexpected pathogenic behavior, causing rapid decay of fruit tissues even in the absence of *M. fructicola*.

Janisiewicz and Jeffers (1997) and Usall et al. (2001) conducted scale-up and pilot tests, which resulted in the registration of several biocontrol agents in a relatively short period of time compared to biological control of the field diseases. The first commercial application was that of BiosaveTM, and during the last decade, intensive research has been done to look for effective strains against microorganisms causing postharvest diseases. The successful registration and commercialization of BiosaveTM helped the expansion of the control of diseases to those like blue mold and grey mold on cherries (Janisiewicz 2007). The methods of the application are simple. BioSaveTM is resuspended in water for at least 10 minutes for the frozen pellet formulation or 30 minutes for the dry formulation to allow for cell rehydration. The recommended rate is 250 g of frozen pellets or dry formulation per 150 L, which results in a suspension containing 1.6×108s CFU/mL and can be applied as a drench to bins with apples and pears, as a drip application with rotating brushes to apples, pears, and citrus fruit on packing line or as a dip to apples and pears on packing lines (Janisiewicz 2007). The biocontrol of postharvest disease has been successfully used for mechanically harvested fruits. Mechanical harvesting results in a larger number of wounded fruit than hand harvesting. Biological control of diseases can be very effective on these fruits because most successful biocontrol agents protect fruit wounds from infections. Janisiewicz and Peterson (2004) found that *P. syringae* was very effective in reducing the infection by *P. expansum* on those apples that were picked without stem. To understand the antifungal activity, Arrebola et al. (2010) looked into inhibition of seven postharvest fungal pathogens of citrus fruit by *B. amyloliquefaciens* strain. Assays using *B. amyloliquefaciens* lipopeptide extracts showed a strong inhibitive activity, which resulted in abnormal conidial germination and germ tube development when conidia were treated with different lipopeptide extract concentrations. Further analysis confirmed the presence of fengycin, iturin, and surfactine, of which iturin A showed the strongest and most common inhibitory effect. Fruit trials confirmed disease development inhibition when the antagonist was applied 1 day prior to or 1 day after fungal application.

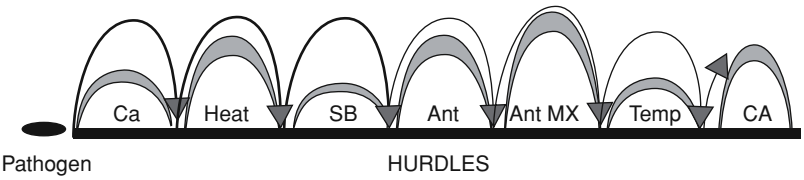

Figure 10.1. Hurdle concept for controlling postharvest diseases on pome fruits. (Adapted from Janisiewicz 2007.) Ca, calcium; Heat, 38°C for 4 days; SB, sodium bicarbonate; Ant, antagonist; AntMX, antagonist mixture; Temp, low storage temperature; CA, controlled atmosphere storage.

The biocontrol agents have been suggested as replacements for fungicide, but in general, biocontrol agents have narrower spectrum of activity than fungicides with respect to commodities and conditions under which they are effective in controlling postharvest diseases (Janisiewicz 2007). However, sometimes, the biocontrol agents can be effective against foodborne human pathogen in the semi-processed fruits when the application of fungicide is not possible (Leverentz et al. 2006). The most investigated area in this field is the biocontrol of *E. coli* O157:H7, *L. monocytogenes*, and *Salmonella enterica* in intact or processed fruits. Leverentz et al. (2003, 2006) found that biocontrol agents could prevent the growth or even reduce the populations of these microorganisms. Taczman-Brückner et al. (2004) found that antagonistic activity of *Kluyveromyces lactis* and *Metschnikowia pulcherrima* were effective biocontrol agents against *Penicillium expansum* in apple medium and apple under *in vivo* conditions, and Leverentz et al. (2006) also found that *Metschnicowia pulcherrima* greatly reduced or sometimes completely eliminated populations of *L. moncytogenes* on fresh-cut apples.

The success of biocontrol against postharvest diseases depends on environmental effects. For the development of food preservation system, the hurdle concept is well known. Bastiaanse et al. (2010) successfully combined antagonistic yeast (*Candida oleophila* strain O at 1.10 (7) CFU/mL) with 2% (w/v) calcium chloride ($CaCl_2$) treatment and MAP of banana fruit in nonperforated polyethylene bags. The study indicated that the integrated strategy had potential for control of crown rot of banana under commercial conditions. Similar positive effect of postharvest behavior of peaches (*Prunus persica*) pretreated with antagonist *Debaryomyces hansenii* and calcium chloride was reported by Singh and Sharma (2009). Janisiewicz (2007) study confirmed that each additional treatment can reduce fruit decay by a certain amount, but applying them together, additional and synergic effects can be achieved (Fig. 10.1).

ULTRAVIOLET LIGHT TREATMENT

Microbicidal effect of short wave ultraviolet light has been known over 100 years. The most effective UV radiation is in the 200–280 nm wavelength range (germicidal radiation, UVC range). Inactivation is caused by cross-linking between neighboring pyrimidine nucleoside bases in the DNA and RNA, which prevents replication and cell reproduction. They cause physiological disruptions that induce cellular death (Blatchley and Peel 2001).

UV radiation is an established disinfection alternative used to produce drinking water (Lopez-Malo and Palou 2005). However, the low penetrability of UV radiation and the difficulty in attaining an even exposure level over all points of the food surface are major technological problems that limit the feasibility of UV radiation in food preservation. To achieve microbial inactivation, the UV exposure must be at least 400 J/m^2 in all parts of the product. Critical factors are the transmissivity of the product, the geometric configuration of the reactor, the power, wavelength and physical arrangement of the UV source(s), the product flow profile, and the radiation path length (Sastry et al. 2000).

Pigmented microorganisms (e.g., conidia of *Aspergillus niger*) have the potential to be more UV resistant, depending on the UV absorption properties of the surface pigmentation (Lagunas-Solar et al. 2006).

Interest in using UVC for reducing microbial counts in fruit and vegetable juices has increased recently (Bintsis et al. 2000). UV light irradiation was shown to destroy pathogens such as *E. coli* O157:H7 or oocysts of *Cryptosporidium parvum* in apple cider (Duffy et al. 2000, Hanes et al. 2002). However, the efficacy of UV light treatment of any liquid is strongly and negatively affected by turbidity and the sizes of any particles present (Keller and Miller 2006). For this reason, the current FDA regulations (FDA 2000b) require turbulent flow to expose all portions of the juice to the light treatment. One type of treatment chamber for UV pasteurization of fruit juices that utilizes turbulent flow to form a "continuously renewed surface" has been described by Geveke (2005). However, one should keep in mind that several factors need to be considered for quantitative risk assessment of a process due to method variability, biological variability, and process variability. Regarding the efficacy of ultraviolet light treatment on *E. coli* in apple cider, the experiments summarized by Duffy et al. (2003) showed widely varying results. They considered that "a highly reliable process that causes

a lower average inactivation of bacteria may assure greater food safety than a widely variable process with a higher main inactivation of bacteria."

IONIZING RADIATION TREATMENT

Treatment of food by specific ionizing radiations (gamma rays, electron beams, and X-rays) to improve microbiological safety and storability was one of the most extensively studied technology in the twentieth century (Farkas and Mohácsi-Farkas 2011). Its potential applications are very diverse, from inhibition of sprouting of tubers and bulbs to production of commercially sterile food products (Farkas 2004). In addition to the microbial decontamination of foods of animal origin and spices and disinfestations of stored products by irradiation, ionizing radiations can be applied for radiation processing of fruits and vegetables, including their MPR forms (Farkas 2001).

Worldwide development of clearances and food irradiation facilities can be noted from the IAEA/nucleus databases (Anon 2010a, 2010b). According to these databases, food irradiation is currently approved for use in over 55 countries, and 68 food irradiation facilities registered worldwide, at least 25 of them being situated in Asia and Australia. However, it is true that opposing attitude of certain activist groups forming "public opinion" induces unfounded fears by misinformation and causes unwillingness of certain legislators and industrial stakeholders to act, which hamper the implementation of the process, particularly in Europe (Kume et al. 2009a, 2009b).

Main objectives of irradiation (Thomas 2001) of fruits and fruit products are

1. Extension of shelf life by delaying maturation and ripening,
2. Control of fungus causing postharvest rot,
3. Inactivation of human pathogens in fresh-cut produces and fresh juices,
4. Quarantine treatment to control insect pests.

One particular benefit of irradiation is that food can be treated in its final packaging, ensuring that it will not become contaminated before it reaches the consumer. Cost analyses of food irradiation are available in the literature (e.g., Kunstadt 2001).

Dose-limiting factors of radiation processing of fruits and fruit products are sensorial factors, particularly softening, or discoloration. However, low-dose treatment (doses not higher than 1–2 kGy) is feasible for specific applications discussed by several reviews (Niemira 2003, Niemira and Fan 2006).

Currently, irradiation is permitted in the USA for use on fresh fruits and vegetables at a maximum dose of 1 kGy. However, FDA is considering a petition that requests use of irradiation on both fresh and fresh-cut fruits, and vegetable at a maximum dose of 4.5 kGy (FDA 2000a). Recently, it became necessary to study the effect of ionizing radiation on furan formation in fresh-cut fruits and vegetables. Furan is regarded as a possible carcinogen that is commonly found in foods that have been treated with traditional heating techniques (FDA 2004a), thus both the FDA and the European Food Safety Authority are requesting information about furan formation and its toxicity (FDA 2004b, EFSA 2006). Fan and Sokorai (2008) conducted studies on 19 fresh-cut fruits and vegetables irradiated by 5 kGy gamma rays at 4°C. The results showed that almost all tested fruits and vegetables, upon irradiation, produced nondetectable levels, or less than 1 ng/g of furan, except grapes and pineapples, which produced furan within a level of 2.0–3.6 ng/g, that is, much lower than those of some thermally processed foods (FDA 2004a). Therefore, it appears that irradiation-induced furan is unlikely to be a concern for fresh-cut produce (Fan and Sokorai 2008).

Recent studies concentrated on use of irradiation to ensure hygienic quality of fresh and precut fruits. Fungi and viruses are typically more resistant to radiation than are bacteria. Irradiation is therefore clearly best suited to control bacterial pathogens (Niemira and Fan 2006).

Palekar et al. (2004) examined cut cantaloupe pieces and determined that chlorine wash combined with e-beam irradiation of 1.4 kGy led a lasting suppression of the bacterial flora during a 21-day storage period. Fan et al. (2005) reported that combination of calcium ascorbate and low-dose irradiation resulted in microbiologically safe and high quality fresh-cut apples, while Shashidhar et al. (2007) based on inoculated pack studies showed that treatment with a 2 kGy dose radiation could eliminate 5 log10 CFU/g of *Salmonella typhimurium* in ready-to-eat pineapple slices. Irradiation D values of *Salmonella* spp. in diced tomatoes dipped in 1 % calcium chloride ranged from 0.26 to 0.39 kGy, indicating that a 5 log10 CFU/g reduction would require a dose of 1.3–1.95 kGy (Prakash et al. 2007). It should be emphasized that irradiation would not replace the current food hygienic measures; it only contributes to their efficiency.

The increasing application of irradiation as a quarantine treatment (phytosanitary application) is reported (Luckman 2002, IPPC 2003, Moy 2005). Large-scale confirmation testing has been performed with numerous insect species to establish efficacy of irradiation as a phytosanitary treatment for fresh horticultural commodities (Follett and Griffin 2006). Similarly, promising results were reported on X-ray quarantine treatment by Spanish authors (Alonso et al. 2007). Tropical fruits from Hawaii that were irradiated as a fruit fly quarantine treatment were test-marketed in the USA mainland and were well received by consumers. The advantage of irradiation as a pest quarantine treatment is that—unlike the (vapor) heat treatment, where, for example, papaya would be picked quarter ripe—irradiation can treat fruits that are fully ripe without compromising the quality and appearance of the fruit. This, in turn, enables farmers to receive a higher price

for their products. In 2000, a commercial X-ray irradiator was installed on the island of Hawaii to treat large quantities of papaya, mango, carambola, rambutan, lichi, longan, etc., enabling export of tropical fruits to distant markets (Moy 2005).

Further developments in design and adaptation of uses of the machine sources (e-beam facilities and X-ray machines) can assist altering the image of the irradiation process into a type of electrical technology (Cleland 2006, Pillai et al. 2006). A Michigan-based company has a patent pending for the use of low-energy (max. 250 kVp) X-rays for the irradiation of foodstuffs. The "low-energy" level means less protective shielding is necessary, so that the equipment is more compact than the facilities working with e-beam or radionuclide sources. It is claimed that this process allows a food processor to install a custom-designed X-ray machine in line with other processes and can use it to treat a variety of foods, including fruits and fruit juices to destroy food-borne pathogens and extend shelf life (Lindsay et al. 2009a, 2009b).

In 2006, the United States signed Framework Equivalency Work Plans with India, Mexico, and Thailand to facilitate the introduction of irradiated produce from these countries into the USA (Eustice 2006). In 2007, The USDA amended the fruits and vegetables regulations to allow importation into the continental U.S. mangoes from India. As conditions of entry, the mangoes must undergo quarantine irradiation treatment (USDA 2007). Several other Asian and Latin American countries are also interested in the subject and are involved in irradiation and trial shipments of irradiated fruits and vegetables (Eustice 2006).

HIGH HYDROSTATIC PRESSURE PROCESSING

General Aspects

Although the first HHP treatment of food material took place more than 100 years ago, the first industrial application of this food-preservation technology is only 20 years old. Hite (1899) was the first researcher who applied HHP on foods. He reported that the shelf life of milk and other food products could be extended by pressure treatment. The developments in the field of ceramics and metallurgical industries enabled treatment of food by this method at industrial level during the 1970s and 1980s. The Meidi-ya company introduced the first high-pressure processed foods to the Japanese market in 1990. They produced jams, jellies, and sauces packaged and processed without application of heat. Later different kinds of fruit products became available like fruit preparations, fruit juices in Japan; apple and orange juice in France and Portugal; and guacamole in the USA (Rastogi et al. 2007). Application of HHP has steadily increased during the past 10 years. In 2009, 135 industrial installations existed in 70 companies, and total annual production volume was more than 170,000 tons. Almost half of the products were vegetable preparations or different kinds of fruit products (Purroy 2010, Volker and Buckow 2010).

During the HHP treatment, foods are subjected to HHP in the pressure range of 100–1000 MPa; 500 MPa is equivalent to the weight of three elephants on a strawberry (Patterson 2005). Temperature of processing can be adjusted from below 0°C to above 100°C with exposure times ranging from a few seconds to over 20 minutes. Pressure primarily reduces the volume of a system. Under equilibrium conditions due to the Le Chatelier principle, the tertiary and quaternary structures of molecules, maintained chiefly by hydrophobic and ionic interactions, are only altered by high pressure >200 MPa at a relatively low temperature (0–40°C). The covalent bonds are unaffected (Yaldagard et al. 2008).

A HHP system is built from a high-pressure vessel with its closure and a pressure generation system. Most systems consist of a temperature control device as well. The main part of the HHP system is the pressure vessel, which determines the maximum working pressure by its wall thickness. Pressure can be increased either by direct or by indirect compression. The direct compression method uses a piston, driven at its larger diameter end by a low pressure pump, so the pressure medium in the vessel is pressurized directly. In case of the indirect compression, a high-pressure intensifier pumps the pressure medium from the reservoir into the closed vessel until the desired pressure is reached. Pressure transmitting fluids ensure the uniform pressure in the vessel. Among others, food-grade glycol–water solutions, silicone oil, sodium benzoate solutions, ethanol solutions, inert gases, and castor oil are used as pressure-transmitting fluids (Yaldagard et al. 2008).

As for packaging material, pumpable products can be treated in continuous or semi-continuous systems, so this type of food is packaged after HHP treatment aseptically. On the other hand, for batch processing, flexible or partially rigid packaging is the best alternative. The packaging material must be able to withstand the compression and have good sealing properties. The package should be flexible enough to transmit the pressure, thus, glass, rigid metal, or plastic containers are not suitable for HHP processing. The pressure medium and the pack contents are compressed to about 80–90% of their original volumes during pressurization in the 400–800 MPa pressure range, but, of course, return to their original volumes when the pressure is released. Good exclusion of head space, while sealing the package, minimizes the time taken to reach the target pressure and ensures efficient utilization of the package as well as space within the pressure vessel (Rastogi et al. 2007). Common packaging materials used in high-pressure processing of foods are ethylene vinyl alcohol copolymer (EVOH) and polyvinyl alcohol (Yaldagard et al. 2008). EVOH-based packaging materials treated by HHP (400 and 800 MPa, 5 and 10 minutes, at 40°C and 75°C) or heat treatment (120°C, 20 minutes) were compared to untreated ones based on their oxygen barrier and

morphological properties. It was noted, that high-pressure treatment slightly affected packaging materials (Rubio et al. 2005).

It was reported that there are several challenges related to the temperature, which have to be considered before optimization and design of industrial processes (Yaldagard et al. 2008). Most of the high-pressure applications in food are not only pressure dependent but also temperature dependent. The evolution of temperature is very important, but it is difficult to monitor or model heat transfer in high-pressure processes because of the lack of data on thermophysical properties under pressure. Owing to the physical compression, the temperature of food material increases during HHP processing. The magnitude of temperature increase depends upon the initial temperature, the target pressure, material compressibility, and specific heat. Immediately after depressurization, the product temperature returns to the nearby initial temperature. Water has the lowest adiabatic heating values (3°C per 100 MPa), while fats and oils have the highest (6–8.7°C per 100 MPa). Since most foods contain large amount of water, rates of the adiabatic temperature changes in them are very similar to that of water. Besides, the pressure-transmitting fluid also influences the temperature of the sample, because its temperature changes during pressurization due to its own thermal properties. This subsequent heat transfer should be taken into account in microbial inactivation by HHP.

Microbiological Aspects

Inactivation Mechanisms of Pressure on Microorganisms

Patterson (2005) noted that despite numerous data found in literature concerning pressure inactivation of microbial cells, the mechanism is not fully understood. The cell membrane is considered to be a primary target of pressure in the microorganisms. Increasing pressure causes decreasing membrane fluidity, and microorganisms with less fluid membranes are more pressure sensitive. If the cell membrane becomes damaged, loss of protein and RNA to the extracellular medium can occur at the same time. Because of more robust cytoplasm membrane of cells in stationary phase, they can better withstand pressure treatment than in exponential phase. Although the cell wall is less affected by high pressure than the membrane, in some cases morphological changes can be observed. For example, Ritz et al. (2001) indicated that after HHP treatment (400 MPa, 10 minutes) bud scars were seen on the cell surface of *L. monocytogenes*. Modifications of biochemical reactions seem to have big potential to inactivate microorganisms during HHP processing. Since high-pressure treatment promotes reactions that lead to a volume decrease, most biochemical reactions are therefore affected by pressure. Studies have shown that the primary sites of pressure are hydrophobic and electrostatic interactions, while hydrogen bonds, stabilizing the α-helical and β-pleated sheet forms of proteins, are not significantly influenced by pressure. Because of the structure of the DNA helix, being largely the result of hydrogen bond formation, nucleic acids are relatively resistant to high pressures. However, the enzyme-mediated steps involved in DNA replication and transcription are disrupted. Enzymes, having complex protein structure, show different sensitivity toward HHP treatment. It is worth noting that the effect of high-pressure treatment on microorganisms is not always lethal, but rather it injures a proportion of the population, and the recovery of the injured cells would depend on the conditions after treatment (Patterson 2005).

Pressure Effect on Fungi

Fungi (yeasts, molds) are generally not associated with foodborne disease, although toxic mold growth may be a safety concern in foods. They are important microorganisms because they are responsible for spoilage of food. Yeast strains do not seem to be pressure resistant, thus shelf life of fruit products can be successfully extended by application of HHP. *Saccharomyces* species can be inactivated at a pressure level lower than 400 MPa for a few minutes, although some strains within species have exhibited a slow inactivation rate at pressures of 500 MPa (Norton and Sun 2008). As for molds, their vegetative forms are relatively pressure sensitive, while ascospores are more resistant. There is little information on the pressure sensitivity of mycotoxin forming molds.

Pressure Effect on Bacteria

Generally, rod-shaped bacteria tend to be more sensitive to pressure than cocci, and gram-negative bacteria more sensitive than gram-positives. Sensitivity of gram-negatives can be explained by their more complex membrane structure, which makes them more susceptible to environmental changes caused by pressure. However, certain strains of *E. coli* O157:H7, belonging to the gram-negatives, can be exceptionally barotolerant. Barosensivity of bacteria depends on environmental factors as well. For example, bacteria are more barotolerant at lower water activity, due to the state of cell cytoplasm, which becomes less compressible when its water activity decreases (Moussa et al. 2006). The pH of foodstuff is another important factor that can modify the efficiency of high-pressure treatment. Pressure and pH can act synergistically, leading to increased microbial inactivation. At lower pH, more efficient pressure inactivation of microorganisms can be observed; sublethally injured cells were inhibited in recovery and died more rapidly during subsequent storage (Patterson 2005). Synergistic effect can also be observed between high pressure and other factors as well. For example, HHP treatment was able to increase the sensitivity of bacteria to subsequent low temperature/low oxygen storage conditions (Upmann et al. 2000) and to subsequent heat treatment (Linton et al. 2000). As for heat sensitivity,

it is worth noting that, generally, there is only a weak, or no, correlation between pressure resistance and resistance to other stresses (Patterson 2005).

Pressure Effect on Bacterial Spores

Although vegetative bacterial cells, yeasts, and molds can be inactivated using relatively low pressures, bacterial endospores can survive extreme high pressure (>800 MPa, around ambient temperature). Despite the fact that there is significant variation between spores of different species and also between strains of the same species, it can be concluded that bacterial endospores are the most pressure-resistant forms of microorganisms. *Clostridium botulinum* spore is one of the most pressure-resistant spores, and *Bacillus cereus* has been widely studied due to its anaerobic nature and very low rate of lethality (Norton and Sun 2008). Alternatively, high-pressure treatment can be combined with other processing methods to inactivate spores effectively by achieving a synergistic or hurdle effect. It is known that relatively low pressure (below 200 MPa) can promote spore germination, which provides the opportunity to kill spores in a two-stage high-pressure process. In the first, lower pressure treatment stage, the dormant spores would be changed into vegetative cells, then the germinated more pressure-sensitive cells would be killed during the second higher pressure treatment. The mechanism of low-pressure germination is still debated. According to Rivalain et al. (2010), high pressure activates nutrient germinant receptors present at the surface of the spore's inner membrane. It could cause some structural changes on the receptors themselves or on the inner membrane in which the receptors reside. After the activation, germination induced by high pressure follows the same pathway as germination by nutrients. However, application of this approach in industrial scale seems to be limited, since a small proportion of each spore population remains resistant to pressure-induced germination, and the kinetic background of germination is not properly known (Ludikhuyze et al. 2002). For inactivation of bacterial spores, combination of high pressure with elevated temperature is much more promising. Application of high-pressure-elevated temperature combination results in direct inactivation of cortexlytic enzymes in spores, thus spores can be eliminated without the germination step. Pressures of about 600 MPa in conjunction with process temperatures in the range of 80–110°C could inactivate *Bacillus cereus* (van Opstal et al. 2004). The phenomenon has been justified for a wide range of spore types, although the effectiveness of the combination varies greatly in magnitude for different spores (Yaldagard et al. 2008).

Matser et al. (2004) reported that there have already been numbers of patents that were designed to achieve the commercial sterilization of foods that have a pH greater than 4.5. In general, high-pressure sterilization (HPS) is possible by starting high-pressure treatment at elevated temperatures, for example, 60–90°C, and using the adiabatic compression for rapid heating to higher temperatures (>100°C). The result of HPS is a shelf-stable product, and in many cases, higher sensory and nutritional quality can be obtained than by conventional methods. Another big advantage of the HPS technology is that the specific energy input required for sterilization of cans can be reduced from 300 to 270 kJ/kg. Compression energy recovery rate of 50% can be estimated in case of two-vessel system or by pressure storage HHP processing. This means that, by using energy recovery, a specific energy input of 242 kJ/kg will be required for sterilization, thus the total energy requirement can be reduced by 20% (Toepfl et al. 2006). Apparently, this innovative technology needs a lot of research work to fulfill all requirements concerning food safety. Nevertheless, some technical issues stand in the way of comparable microbial inactivation studies relating to HPS processing. These are (i) the equipment-centered issues (material of different parts of high-pressure machines cause differences in compression heating), (ii) chemical changes in the sample (e.g., pressure shift pH changing), and (iii) biological issues (e.g., differences in media or enumeration techniques applied by various laboratories; Wilson et al. 2008).

Finally, it must be noted that fruit preparations, fruit juices, and sauces seem to be appropriate raw material for high-pressure processing. Although their high acidity does not support the growth of spore-forming microorganisms, they are susceptible to spoilage by microorganisms such as yeasts, molds, and lactic acid bacteria, which are relatively pressure sensitive (Wilson et al. 2008).

Quality Aspects

Pressure Effect on Some Special Enzymes of Fruits

Biochemical changes play an important role in preservation of quality attributes by HHP processing. Effects of high pressure on quality-affecting enzymes have been widely investigated. These studies suggest that, pressure-induced changes in catalytic activity of enzymes differ depending on the type of enzyme, the nature of substrates, and the conditions of processing (pressure, temperature, and time; Ludikhuyze et al. 2002, Yaldagard et al. 2008). In case of fruits, the most important enzymes are polyphenoloxidase (PPO), peroxidase (POD), pectinmethylesterase (PME), and β-glucosidase.

PPO is responsible for enzymatic browning. Contrary to its relatively low heat-resistance, PPO can be inactivated by pressure between 200 and 1000 MPa, depending on some intrinsic and extrinsic factors. PPO derived from, for example, apple, strawberry, apricot, or grape seems to be sensitive to pressure, while PPO of plum or pear shows higher pressure-resistance. In several cases, faster HHP-induced inactivation of PPO was observed at lower pH. However, contrary to inactivation at higher pressure level, some authors reported a

pressure-induced activation of PPO at low pressure for apple and strawberry. In case of apple, pear, and strawberry, protective effect of low pressure against thermal inactivation of PPO was observed as well (Ludikhuyze 2002, Yaldagard 2008).

POD induces unfavorable flavor during storage. Similar to PPO, POD is also very pressure resistant. In case of strawberry, for instance, POD activity was reduced only by 25% after high-pressure treatment at 230 MPa for 15 minutes. Moreover, another study showed that even at higher pressure level (400 and 600 MPa, 15 minutes), the maximum POD inactivation was only 35% (Yaldagard 2008).

PME is responsible for cloud destabilization and consistency changes. It was found that PME is considerably thermotolerant, and depending on its source and the medium, pressure level between 150 and 1200 MPa is needed for inactivation of PME. Higher acid and less-soluble solids content promote faster inactivation. According to most studies, due to the presence of isozymes with different pressure resistances, only a partial inactivation of PME can be achieved (Ludikhuyze 2002).

Among them, β-glucosidases are involved in the release of flavor volatiles, thus they also have a positive effect on fruit flavor. Zabetakis et al. (2000) reported that 600 and 800 MPa decreased activity of β-glucosidase of crude strawberry extracts, while 200 and 400 MPa increased it.

Pressure Effect on Vitamin Content and Antioxidant Capacity of Fruits

Pressure stability of AA is most widely studied among water-soluble vitamins in fruit. Oey et al. (2008b) indicated that concentration of oxygen is a critical factor in AA degradation at all pressure levels. AA is more stable at lower oxygen concentration. Besides, AA stability varies in different media. Investigators reported a lower AA loss in buffer solutions compared to that in fruit juice because the existing metal ions and enzymes act as endogenous pro-oxidants in fruits. HHP treatment showed higher AA degradation in orange juice than in tomato juice. In general, high residual AA concentration is mostly found after HP treatment, for instance, (i) 91% of the initial AA content in orange juice remained after HP treatment of 400 MPa/40°C/1 min, (ii) 11.32% loss of AA in strawberry coulis and in strawberry nectar after HP at 400 MPa/20°C/30 min, and (iii) a high retention of AA in strawberry nectar after HP treatment at 500 MPa/room temperature/3 min. At higher temperatures, pressure treatment could decrease the stability of AA to a large extent with long treatment time, e.g., pressurization up to 600 MPa at 75°C for 40 minutes, resulting in 70% and 50% losses of AA, respectively, in pineapple and grapefruit juice. Generally, AA is unstable at high-pressure levels combined with high temperatures (above 65°C), and the major degradation is caused by oxidation especially during adiabatic heating. AA content of HHP-treated products decreases during storage, which can be further moderated by lowering storage temperature (Oey et al. 2008b).

Some studies have reported that vitamin B is stable during high-pressure treatment at room temperature. For example, a content of vitamin B1, B2, B6, and niacin in red orange juice was not changed by HHP-treatment (200–500 MPa/30°C/1 min). On the basis of the studies of model solutions, it can be concluded that (i) folate degradation during HP treatment was primarily caused by oxidation, (ii) due to pressure enhanced oxidation reactions, cleavage of covalent bonds could occur during HHP treatments especially at high temperatures, and (iii) at elevated temperatures, chemical (nonoxidative) conversion can happen during HHP processing. Antioxidants such as AA can retard the (oxidative) folate degradation during HP treatment, but they can promote formation of 5,10-methenyltetrahydrofolic acid from 5-formyltetrahydrofolic acid (Oey et al. 2008b).

The effect of pressure on antioxidant capacity depends on the food products. In case of orange juice, HHP treatment (100–800 MPa, 30–65°C up to 90 minutes) decreased the TEAC (Trolox Equivalent Antioxidant capacity) index. It was observed, at all temperatures studied, that higher pressure level resulted in faster decrease in antioxidant capacity attributed to degradation of AA in orange juice. On the contrary, TEAC index of apple juice was only slightly affected by high temperature (600 MPa/60°C/30 min).

The results are contradictory as for the retention of antioxidant capacity of HHP-treated fruit juice during storage compared to their heat-treated counterparts (Oey et al. 2008a).

Pressure Effect on Color of Fruits

Numerous authors reported that HHP-treatment could preserve fresh color in case of many fruit products (e.g., fruit jams, juices, and purees). Compared to the heat-treated variants HHP-treated fruit preparations (produced at low and moderate temperatures) showed better retention of color parameters (brightness, L-color value; and redness/greenness, a-color value) and pigments (e.g., chlorophyll, carotenoids, anthocyanins, etc.) responsible for the color of fruits (Ludikhuyze 2002, Oey et al. 2008a). Anthocyanins are among the most intensively studied water-soluble pigments. They belong to the flavonoid group and are responsible for the red to blue color of fruits. Anthocyanins are stable during HP treatment at moderate temperature, for example, in red raspberry and strawberry during HP treatment at 800 MPa (18–22°C/15 minutes). However, degradation of anthocyanins of pressure-treated fruits can be observed during storage. Oey et al. (2008a) reviewed various hypotheses on the degradation mechanism of anthocyanins in pressurized fruits during storage. According to them, these are (i) incomplete enzyme inactivation (β-glucosidase, POD, and PPO), (ii) specificity of β-glucosidase acting on anthocyanins, and

(iii) effect of AA on the stability of anthocyanins. As it was mentioned before, PPO, POD, and β-glucosidase can be inactivated by high level of pressure, or pressure-elevated temperature combination. After treatment, if they remain active, even at least partially, they can cause discoloration via degradation of anthocyanins. As for AA, although it is an antioxidant, and it retards enzymatic browning, it can also accelerate the degradation of anthocyanins. Chlorophyll and carotinoids are considered to be pressure-stable pigments, especially at moderate temperature.

Pressure Effect on Flavor of Fruits

It is generally considered that high-pressure processing does not alter the fresh flavor of fruits, since high pressure does not affect the structure of small-molecular weight flavor compounds. This has been noticed, by means of both chemical and sensory analyses, in case of strawberry puree, mandarin juice, orange–lemon–carrot juice, white grape juice and guava juice treated in the pressure range of 200–600 MPa combined with ambient temperature. However, HHP processing could indirectly alter the content of some flavor compounds by enhancing and retarding enzymatic and chemical reactions, thus disturbing the balance of flavor composition in fruits (Oey et al. 2008a). Strawberry is one of the most frequently examined fruits regarding the effect of HHP treatment on volatile components due to its intensive flavor. Some volatile components (e.g., hexanal, esters, etc.) have been highlighted as they contribute to the fresh character. Gas chromatographic studies showed contradictory results about the effect on these components by high pressure. For instance, Navarro et al. (2002) indicated that hexanal content was more than double in HHP-treated strawberry purée (400 MPa, ambient temperature, 20 minutes) while according to Lambert et al. (1999), high-pressure processing has less pronounced effects on hexanal content of strawberry purée in the pressure range of 200–500 MPa (ambient temperature/20 minutes); moreover, pressurization at 800 MPa resulted in a slight decrease in the hexanal content.

Since the flavor of fruits is a very complex attribute, it is difficult to estimate overall flavor characteristic, of fruits or fruit products, modified by high pressure. In strawberries, for instance, more than 350 volatile compounds have been identified. This complexity can be partially handled by means of electronic nose analysis. Dalmadi et al. (2007) applied electronic nose detector to compare volatiles of untreated, HHP-treated (600 MPa/ambient temperature/5 minutes) and heat-treated (80°C/5 min) strawberry, raspberry, and black currant purées, respectively. Better flavor retention of HHP-processed purée was shown in contrast to heat-treated one. It is worth noting that HHP-processed samples could be distinguished properly from untreated variants, which indicates that HHP-processing has an effect on volatiles.

Pressure Effect on Texture of Fruits

The effect of pressure on texture changes in fruits can be explained by transformations in cell wall polymers due to enzymatic and nonenzymatic reactions. For example, substrates, ions, and enzymes can be liberated and can interact with each other during HP treatment since they are no longer separated from each other. Besides, HHP treatment can modify the cell permeability of fruits, which enables movement of water and metabolites in the cell (Oey et al. 2008a).

As for the texture of solid fruits, it was observed that HHP processing (100–400 MPa/5–60 minutes/room temperature) caused a rapid firmness loss during compression in fruits such as apple, pear, orange, and pineapple. During the subsequent pressure-holding period (30–60 minutes), the firmness either decreased further or gradually recovered. Phenomenon of recovery was explained by the activity of PME. The liberated enzyme could get in contact with the highly methylated pectin and demethylate it. The de-esterified pectin is capable of forming a gel network with divalent ions, resulting in increased hardness (Oey et al. 2008a).

Rheological properties of fruit purées, pulps, and juices can be modified by HHP treatment. The conditions of the HP process and the type of fruit, influence the effect of pressure treatment. Ahmed et al. (2005) reported, for example, that the pressure effect on viscosity of mango pulp varied based on the pressure level (20°C/15 or 30 minutes). Below 200 MPa, the viscosity of the fruit increased, while above that level decreasing viscosity was observed.

Cloud stability is an important factor for the quality of some fruit juices. Polydera et al. (2005) showed that pressure treatment (600 MPa/40°C/4 minutes) increased the viscosity of navel orange juice, and during storage (0°C, 5°C, 10°C, 15°C, or 30°C for 64 days), only a minimal cloud loss and decrease in the viscosity of HHP-treated juice were observed. The residual PME activity was suspected to be responsible for the quality loss of orange juice during storage.

Regulatory Aspects

There are two diverse regulatory attitudes towards commercialization of food treated by high pressure. In countries outside the EU, currently there are no special legislations regarding high-pressure process. In the USA, for example, the traditional health regulations (U.S. Food and Drug regulations) are applied to products treated by high pressure. Currently, high-pressure pasteurized products are required to be processed under GMP conditions and relevant commodity-specific regulations (e.g., juice HACCP), as well as distributed under refrigerated conditions. The temperature fluctuation during cold chain has to be evaluated and minimized (Rastogi et al. 2007). On the contrary, in EU countries, high-pressure processing and food products treated by high pressure must comply with special regulations. According to "Novel food"

legislation (Regulation 258/97/EC), which came into force in 1997, HHP-processed food products are designated as novel foods based on the facts that their history of human consumption has so far been negligible and a new technology has produced them. In order to simplify the regulation, from July 2001, the national authorities decide on the legal status of high-pressure-treated foodstuffs on the basis of appropriate data provided by the manufacturer. If the competent authority arrives at the decision that the product does not fall within the scope of Regulation (EC) No 258/97, it can be marketed without approval.

Advantages and Limitations of Using Hydrostatic Pressure Method

Advantages of HHP

1. High pressure acts instantaneously and independently of the size/shape of the food product and the time of processing.
2. Covalent bonds remain unaffected; therefore, the HHP processing maintains the natural flavor of the products.
3. It enables food processing at ambient temperature or even lower temperatures, thus reducing the amount of thermal energy needed for food products during conventional processing.
4. It causes microbial inactivation whilst virtually eliminating heat damage and the use of chemical preservatives/additives, thereby leading to improvements in the overall quality of foods.
5. It can be used to create ingredients with novel functional properties.
6. It requires only electric energy and there are no waste products, so the process is environment friendly.

Limitations of HHP

1. Food enzymes and bacterial spores are very resistant to pressure and require very high pressure for their inactivation.
2. The residual enzyme activity and dissolved oxygen results in enzymatic and oxidative degradation of certain food components.
3. Most of the pressure-processed foods need low temperature storage and distribution to retain their sensory and nutritional qualities.
4. Equipment barrier (extreme high investment cost, relatively low productivity due to the batch processing compared to the conventional techniques) (Rastogi et al. 2007, Yaldagard et al. 2008).

PULSED ELECTRIC FIELD TREATMENT

It is well established that high voltage PEF (20–80 kV/cm) is able to inactivate microorganisms. A comprehensive analysis of microbial inactivation by PEF and its application as a novel food-processing technology are reviewed by several authors in their chapters in the books edited by Barbosa-Cánovas et al. (2005) and Lelieveld et al. (2007).

When external electric field charges cells, an electric potential develops over the cell membrane. If the induced electric potential exceeds some critical value, it results in a reversible increase in membrane permeability (electroporation). When the critical electric field is greatly exceeded, the ion channels and pores are irreversibly extended to such a degree that cell contents leak out and the cells die. Gram-positive bacteria are less sensitive to electric pulse treatment than gram-negative bacteria. Yeast cells are more sensitive to PEF processing than bacteria (Cserhalmi et al. 2002). Much greater field strength is required for inactivation of ascospores and bacterial endospores. Rodrigo et al. (2005a) reviewed inactivation kinetics and model developments in PEF field.

The microbial inactivation effects of the PEF are generally inversely proportional to the ionic strength of the suspending material and proportional to the number and duration of pulses. Reduced pH increases the inactivation ratio. Inactivation by PEF is also increased by increasing temperature. The results show that bipolar square-wave pulses are more efficient in terms of microbial inactivation.

High-voltage PEF treatment applied across electrodes, between which liquid foods can be pumped, has been investigated as a potential nonthermal preservation treatment. (The application of many rapid high-power pulses can significantly increase the temperature of the product if the generated heat is not removed by cooling.)

Fruit juices can be pasteurized by PEF treatment without significant loss of flavor, color, and vitamin C (Hodgins et al. 2002, Cserhalmi et al. 2006). A comprehensive review on PEF treatment of orange juice products has been published by Rodrigo et al. (2005b). Sensory evaluations indicated that flavor of PEF-processed juices was preferred to that of thermally processed juices (Min et al. 2003a, 2003b). Using the hurdle approach, antimicrobial compounds (nisin and lysozyme) increased loss of viability of *Salmonella typhimurium* in combination with PEF treatment (Liang et al. 2002).

Enzyme inactivation by PEF is an ongoing research (Barbosa-Cánovas and Sepúlveda 2005). While some authors claim that considerably high inactivation of enzymes accompanies pasteurization of juices using PEF technology (Giner et al. 2002, Min et al. 2003a), others reported much less inactivation efficiency for some other enzymes (Van Loey et al. 2002).

Another type of PEF application in the fruit and vegetable sector is based on the observation that PEFs remarkably enhance the extraction of juices from plant tissue (Vorobiev et al. 2005). Introduction of PEF equipments in a process line is easy and the cost of PEF is not prohibitively high. However, further work is needed to optimize and harmonize processing conditions, and to facilitate regulatory, industry,

and consumer acceptance, convincing stakeholders that the process will provide safety and stability from both a microbiological and chemical points of view (Lelieveld 2005).

PULSED LIGHT TECHNOLOGY

Among nonthermal technologies, high-intensity pulsed light treatment is also currently being studied as a new microbial surface decontamination process (Federighi et al. 2007). The procedure has been developed first under the trade name Pure Bright technology. The broad-spectrum light produced includes wavelengths from ultraviolet to near infrared range. Lethal effects of the very high-intensity pulsed light on microorganisms can be attributed mainly to the UV content and the high peak power (Takeshita et al. 2003). The treatment unit contains one or more inert gas lamps. When a high current pulse is applied to the lamp by discharging a charged capacitor with a high voltage switch, the lamp emits an intense light pulse of several hundred microseconds. The frequency of flashing, number of lamps, and flashing configurations apply according to the requirements of the process.

Lagunas-Solar et al. (2006) reported use of pulsed UV (PUV) light (extremely rapid, high-peak power UV beams) processes for surface disinfection of fresh fruit. Several fungal pathogens inoculated to the surface of various fruits were rapidly and efficiently (>5 log) killed. Only partial disinfection could be obtained if the fungi penetrated into the epidermis or were located in crevices or in surface irregularities, due to UV-shielding (shadowing) effects. However, noncoherent, broadband, and pulsed light beams (high in UV emission) from lamps with dispersing reflectors appeared to provide sources of multidirective PUV light that may be capable of effective disinfection of geometrically round or elliptically shaped fruits.

COLD PLASMA TREATMENT

The "cold plasma" treatment is being increasingly investigated to kill microorganisms in the air or on the surface areas of processing plants, or treating fresh foods to reduce their microbial load without chemical biocides. The potential technology would use nonthermal ionized gases, which are mixtures of electrons, ions, and free radical species inflicting damage to microorganisms. One possible application of cold atmospheric gas plasma is the treatment of the fruit or cut-fruit surfaces (Critzer et al. 2007, Perni et al. 2008a, 2008b, Niemira and Sites 2008).

One particular embodiment of cold atmospheric plasma units is when a mixture of helium and oxygen gases flows through a discharge formed by a ring electrode, which is attached to a gas-confining ceramic tube. The reactive plasma particles form a long plume outside of the nozzle of the ceramic tube (Perni et al. 2008a, 2008b).

The efficacy of the treatment is obviously reduced when microorganisms are internalized in the fruit tissue. Much further work on this novel food treatment is also needed to show that its application does not result in either sensory or nutritional degradation of foods. More information is also needed on the economics of the process using larger scale equipment.

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11
Aseptic Processing and Packaging

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Abstract: Aseptic processing, also called aseptic packaging, is an alternative method to conventional canning for long-term preservation of food products at ambient temperature. The major advantages of aseptic processing over conventional canning include the retention of more color, flavor, and nutrients in the product, the capability of using flexible and semirigid packaging materials, the realization for bulk storage of food products, and the reduction in processing, storage, and transportation costs. These advantages and the entire operations of aseptic processing for fruit products are described in detail.

INTRODUCTION

Aseptic processing, also called aseptic packaging, is an alternative method to conventional canning for long-term preservation of food products at ambient temperature. The fundamental difference between aseptic processing and conventional canning is in the sequence of operations. The filling and container sealing operations come prior to sterilization in conventional canning, while the products and containers are sterilized and cooled down before filling and sealing operations in aseptic processing.

The history of aseptic processing dates back to nearly 100 years ago. In 1917, Dunkley in the USA received a patent for sterilizing cans and lids with saturated steam and the subsequent aseptic filling. In 1961, Tetra Pak introduced its first aseptic carton, the Tetra Classic Aseptic, in Sweden. The classical Tetra Brik Aseptic (TBA) system was launched in 1968. In 1981, the U.S. Food and Drug Administration (FDA) recognized the safety of using hydrogen peroxide (H_2O_2) as a sterilant on aseptic packages. This action gave a great impetus to the application of aseptic processing technology throughout the world.

Application of aseptic processing was limited to homogeneous food fluids, that is, food fluids containing no particles, in the beginning. The commercialization of large particle/liquid mixtures lagged behind due to stringent regulatory demands for clear demonstration of the achieved lethality (also known as *F* value, sterilizing value, or sterilization value; please refer to Chapter 8) for the destruction of microorganisms. In mid-1970s, much development work was performed for processing and filling fruit purees and small particles in drums and later in bag-in-box packs (Buchner 1993). In the 1980s and 1990s, considerable research and capital investment were focused on extending the aseptic concept to products containing large particles. Today, it is still more popular to apply the aseptic processing technology on homogeneous food fluids and food fluids containing small particles than on food fluids containing large particles.

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

Aseptic processing is basically a heat–hold–cool–fill–seal process. Its first advantage is that the food product can be rapidly and evenly heated to a high temperature, for example, 130°C, held at this temperature for a very short period of time, usually only a few seconds, to achieve a satisfactory sterilization effect, and then cooled down rapidly and evenly in the continuous system. The higher-temperature, shorter-time conditions in aseptic processing, as opposed to the conventional lower-temperature, longer-time sterilization processes, retain more color, flavor, and nutrients in the product. Microbial inactivation is more sensitive to temperature increases than are chemical reactions that reduce food quality. Aseptic processing takes the advantage of this difference to produce better quality food as compared to conventional processing.

The second advantage of aseptic processing is its capability of using flexible and semi-rigid packaging materials. The range of packaging materials and container shapes in aseptic processing is very extensive. Metal containers, glass containers, plastic containers, plastic/paper laminated containers, and plastic bag-in-boxes or other types of containers are all usable. The continuous sterilization process in aseptic processing delivers a cool product to be packed. No heating is required after the package is sealed. The packaging materials in aseptic processing do not need to withstand the high temperature and high pressure, which would be encountered in conventional thermal processing.

The third advantage of aseptic processing is its great impact on the bulk handling of food products. The continuous flow sterilization process allows large containers, such as drums and tanks, to be filled and closed under aseptic conditions. Conventional canning could not be used for containers of these sizes because the heat penetration into the large mass of product would be too slow. Even if the required time–temperature history for sterilization was reached, the products would have become inedible due to overcooking. Aseptic processing led to the development of aseptic bulk storage technology for food fluids since the 1970s. The container can be a 55-gal tin-plated steel drum, 300-gal flexible bag-in-box, 1000-gal tote, transportation container with a volume around 20,000 gal, and aseptic plastic-lined steel tank sized over 1 million gallons. Aseptic bulk storage has replaced a big portion of the traditional methods of concentration and freezing for preserving commodity products such as orange juice. The saving in energy and the retention of product quality, as shown by the superiority of the not-from-concentrate juice over the reconstituted juice from concentrate, motivates the replacement. The low cost, as calculated based on unit volume of the product, and high reusability of the container further promotes the application of aseptic bulk storage technique in product transportation. For example, aseptic bags of passion fruit juice are air-freighted from Columbia, South America, to the United States, and orange juice is land- and ocean-freighted from Brazil to Europe in aseptic tanks. Aseptic bulk storage of semi-products may enable food factories to produce products with consistent quality and quantity throughout the year, especially important for seasonal fruit materials.

The last advantage, but not necessarily the least, is in the running cost. Although septic processing systems usually have higher initial capital costs, once in use they may incur significantly lower variable costs than the conventional canning systems.

ASEPTIC PROCESSING

The basic operations in aseptic processing are shown in Figure 11.1.

Presterilization

Presterilization is to ensure the sterility of the food product to be packed. It is an integrated operation involving the heating of food materials to the desired temperature, holding at this temperature for a given period of time in order to achieve the desired F value, and subsequent cooling, usually down to the ambient temperature and sometimes to a somewhat elevated temperature to maintain the suitable viscosity for filling.

Heating and cooling in presterilization should be performed as rapidly as possible for most of the food products in consideration of quality retention. The heating may be done directly by using steam, microwave, or electrical current as in ohmic heating, or indirectly by using a plate, tubular, or scraped-surface heat exchanger. Alternatively, microfiltration using a membrane at pore size no larger than 0.5 μm is feasible for the presterilization of clear food fluids,

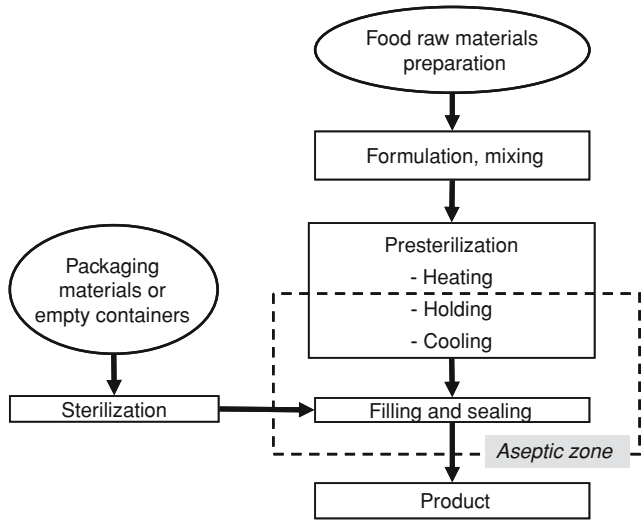

Figure 11.1. Typical flow diagram for aseptic processing.

such as high-quality clear apple juice, which are sensitive to heating. No cooling is required after microfiltration.

The main concern in the presterilization of the food is the destruction of microorganisms. Knowledge on the flow behavior and the kinetics of microbial death in the food is required in the evaluation for the required processing conditions. Considerations have also to be given to the reductions in enzymes and nutrients and the changes in color, texture, taste, and flavor. Through mathematical deduction and pilot production trials, an optimum temperature–time operation condition may expectably be established that effectively prevents the public health hazard of food poisoning while producing a product with the best possible quality.

Heating and Cooling Methods

Heating and cooling in the presterilization of food products is most frequently done either in a direct system consisted of a steam injector or steam infuser followed with a flash cooling chamber or in an indirect system using heat exchangers. There are advantages and disadvantages to use either type of heating/cooling systems as described in the following.

Direct Steam Heating Systems with Flash Cooling

In these systems, steam heats and condensates into the product. The efficiency of heating is very high since the steam passes both its sensible heat and latent heat to the food in direct contact. A flash cooling chamber is installed downstream to the holding section to evaporate the added water and also to perform a rapid cooling of the sterilized product. These systems are not suitable in those applications that resent to the escape of aroma through evaporation or resent to the addition of water into the product, single-strength orange juice, for example, even though a similar quantity of water is removed in the subsequent flash cooling. The direct heating can be done in two ways,

Steam injection: Steam is injected directly into the product. It is a simple and fast method of heating homogeneous food fluids as the system is relatively simple and the steam mixes well with the food.

Steam infusion: The product is sprayed into a large pressurized steam chamber and is being sterilized when falling as a film or droplets in the chamber.

Indirect Heating/Cooling Systems

There are three major indirect heating/cooling systems in aseptic processing: Plate heat exchanger, tubular heat exchanger, and scraped-surface heat exchanger. Each system is composed of heating, holding, and cooling sections in series.

Plate heat exchanger (Fig. 11.2): The heating and cooling sections are sets of thin, corrugated stainless steel plates. The plates are often spaced by rubber sealing gaskets, which are cemented into a section around the edge of the plates. Thin

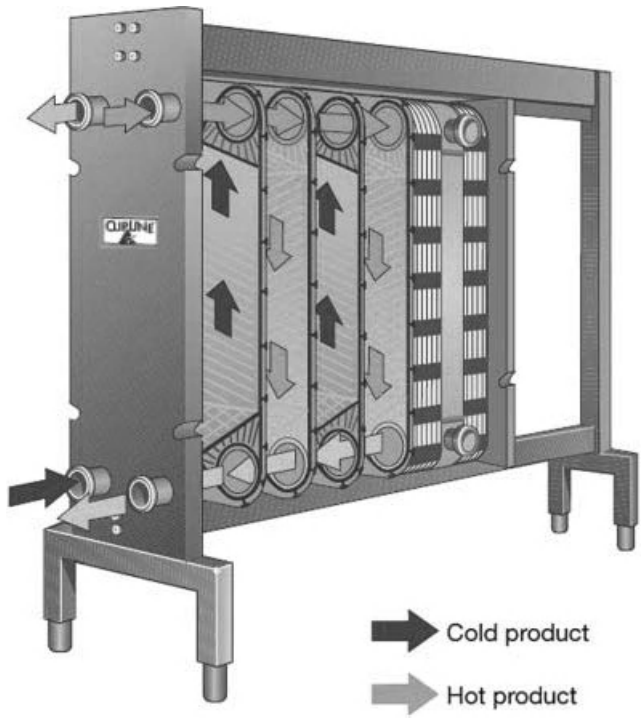

Figure 11.2. A plate heat exchanger (courtesy of Tetra Pak Processing Components).

layers of the food product and the heat exchange medium, most commonly hot water for heating or cold water for cooling, flow in opposite directions on separate sides of a metal plate that renders good heat transfer. The narrow space between adjacent plates restricts the ideal use of the equipment in the processing of low-viscosity homogenous food fluids, for example, apple juice. The holding section of the system is usually a well-insulated stainless steel tube that connects the heating and cooling sections.

Tubular heat exchanger (Fig. 11.3): The tubular heat exchanger is also composed of heating and cooling sections with a holding tube connecting them. Tubular heat exchangers process a variety of products in a wide range of viscosity with and without the presence of particles. Fruit purees are good objects for the system. Tubular heat exchangers are usually in the shape of a tube or a cylinder. The simplest design is the mono-tube, basically a smaller tube held within a larger tube with the food, and the heat exchange medium flow along separate sides of the wall of the inner tube. The more complex designs include the concentric tubular heat exchangers and the shell-and-tube heat exchangers with the product flowing through the gap between two heat exchange medium channels. The tubular heat exchangers are usually easier to be cleaned and sterilized than the plate heat exchangers. The size of the gap for the product to flow through can be tailor-made to match with the application, giving wider gaps for products

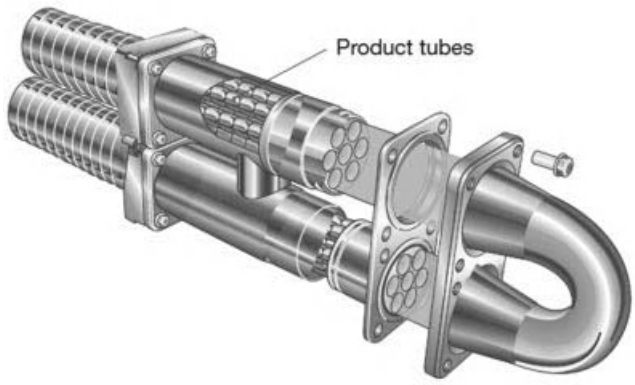

Figure 11.3. A multitube tubular heat exchanger (courtesy of Tetra Pak Processing Components).

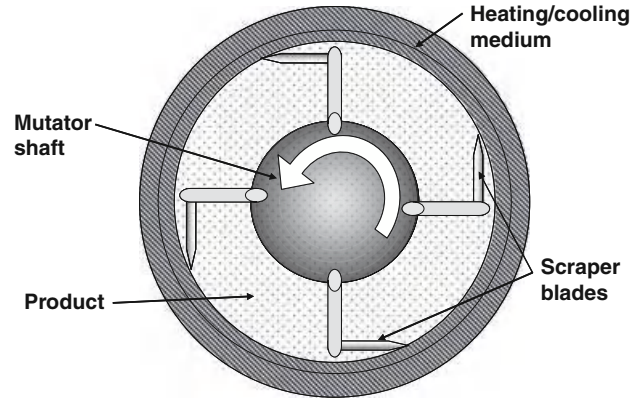

Figure 11.5. Cross-sectional view of a scraped-surface heat exchange cylinder.

containing particles. Generally, tubular heat exchangers are more versatile in application than plate heat exchangers.

Scraped-surface heat exchanger: It is normally composed of two scraped-surface heat exchange cylinders (Fig. 11.4), one for heating and the other for cooling, with a holding tube to connect them. The scraped-surface heat exchanger offers a proper alternative for processing highly viscous products with and without particles that traditionally have been processed by the slower, batch-type conventional canning operations and enables the making of a higher quality product. An example is the assorted fruit particulates in syrup.

Figure 11.4. A scraped-surface heat exchange cylinder.

The scraped-surface heat exchange cylinder can be viewed as a special type of heat exchange tube that has a mutator shaft with scraper blades concentrically located within the large, jacketed, insulated tube with clearances of one-fourth to two inches (Fig. 11.5). The blades rotating at 40–400 rpm continuously remove the product from the wall, increasing the heat transfer and reducing burn-on. The heating or cooling medium flows on the outside of the product tube and in some designs it also flows through the hollow mutator (Morgan et al. 2010). The main disadvantage of the scraped-surface heat exchanger is that it is more expensive to set up and maintain than the other types of heat exchangers (Morgan et al. 2010).

Holding Temperature

High acid foods such as lemon juice can be processed at a temperature lower than 100°C, aimed to destroy the vegetative cells of microorganisms and enzymes. Acid foods usually require a holding temperature above 100°C for the inactivation of spoilage bacterial spores. The temperatures employed for low-acid foods are much higher, normally above 121°C, to achieve the commercial sterility that ensures sufficient destruction of the spores of the pathogenic bacterium *Clostridium botulinum* and other spoilage bacteria with even higher heat resistances.

Desired *F* Value

The design of a thermal process in aseptic processing incorporates the principles of thermobacteriology (Stumbo 1973).

The thermal process must be designed so that every volume element of the food fluid, with or without suspending particles, will receive a sterilization effect equivalent to or greater than the desired F value (Chandarana et al. 2010). The desired F value with the holding temperature t as the reference temperature, $F_{t,\text{desired}}$, is calculated by incorporating the initial load of the target microorganism, normally the most heat-resistant one, in the food to be presterilized, a, the desired final load after presterilization, b, and the decimal reduction time of this microorganism at the holding temperature t, D_t, into the following equation.

$$F_{t,\text{desired}} = D_t(\log a - \log b)$$

Holding Time

The overall sterilization effect in presterilization is actually the integration of the effects throughout the heating, holding, and cooling sections. However, it is often difficult to precisely monitor and control the temperature profiles in the heating and cooling sections. Therefore, FDA, with few exceptions, has evaluated the adequacy of presterilization in aseptic processing based on the F value achieved in the holding section only (Lund and Singh 1993, Morgan et al. 2010). The sterilization effects incurred in heating and cooling sections are taken as safety measures. The holding section is usually in the shape of a tube. The residence time of the food fluid in the holding tube is called the holding time.

Residence Time Distribution

Food products are usually transported in either laminar or turbulent flow. In any case, each volume element of a food fluid may spend different lengths of "residence time" to flow through the system. As a consequence, different F values achieved among different volume elements. Residence time distribution (RTD) in the hold tube is a function of the hold tube length, inner diameter, feed rate, and flow behavior of the product. Minimum residence time (MRT) is the holding time for the fastest moving fluid element containing particles or not. Before actual production, the process authority in the aseptic processing plant ought to determine the dimensions of the holding tube and the flow conditions of the food fluid to yield a MRT no less than the value of $F_{t,\text{desired}}$, or the desired F value specified at the holding temperature, so that every fluid element will receive a sufficient sterilization effect. Pilot runs with the incorporation of a flow indicator, a dye for example, are often necessary to confirm the value of MRT.

ESTABLISHMENT AND MAINTENANCE OF ASEPTIC ZONE

The area housing the equipment that may contact with the food in anywhere along the processing line starting from presterilizers and downstream all the way to the packaging machine is called "aseptic zone." The whole aseptic zone, including the space and the equipment, such as heat exchangers, pumps, fillers and surge tanks with the connected ducts, conduits, and tubing, all have to be cleaned and sterilized prior to operation and kept in sterile condition during the entire running period. Sterilization of the equipment can be accomplished by various methods, or a combination of methods. The common methods include the treatments with steam, hot water, and a chemical sterilants such as hydrogen peroxide and peracetic acid. Most modern equipment can be sterilized in the sterile-in-place (SIP) process before handling the food product. The aseptic space can be established and maintained by using steam, sterile air, or the vapor of a sterilant. To avoid recontamination, a positive pressure is usually kept in the aseptic zone. The use of a laminar flow system with high-efficiency particle air (HEPA) filter is popular in the supply of sterile air for pressurization. The chemical sterilant used in the on-line sterilization of packaging material may evaporate in the aseptic zone and help to maintain the aseptic condition. Special attention in preventing the escape of sterilant vapor into the neighboring working space has to be paid in the design and operation of the chemical sterilization system for avoiding the hazard to human beings and environment.

STERILIZATION OF PACKAGING MATERIALS OR PREFORMED CONTAINERS

The packaging materials available for commercial aseptic products include metal, glass, plastics, and semi-rigid composite multilayer materials such as laminated paper/aluminum/plastic board (Fig. 11.6). The selection of containers is primarily based on the nature, desired shelf life and intended use of the food product, the cost, and the acceptance by the consumer.

Containers may either be preformed from the packaging material before entering the aseptic processing line or be formed from the packaging material on-line right upstream to the aseptic filler of food product. Metal and glass containers for the aseptic packaging are commonly preformed in a way similar to those for the conventional canning. Plastic containers and semi-rigid composite containers can either be preformed or be formed on-line.

Thermoforming, blow molding, and injection molding are common methods to transform plastic materials into containers. Thermoforming is to heat a plastic sheet to a pliable forming temperature, formed to a specific shape in a mold, and trimmed to create a usable product. Plastic containers in a thermoform–fill–seal system can be sterilized by the heat of co-extrusion while they are being formed. Thermoforming is very popular in the making of cups, tubs, and trays, but not so in the making of bottles as compared to blow molding. In blowing molding, a hollow tube of extruded plastic is placed

Figure 11.6. Orange juice products in various aseptic containers (courtesy of Tetra Pak Processing Components).

between the two halves of a mold. The mold then closes and air (or another gas) is injected into the hollow tube to expand the softened plastic into the shape of the mold. Blow molding with sterile air is becoming increasingly important in aseptic packaging because the containers are sterile when made, and therefore packaging sterilization treatments may not be needed.

The nonsterile preformed containers or the nonsterile packaging materials for the on-line formation of containers and filling of food need to be sterilized before or upon entering the aseptic zone. The sterilization processes for containers and packaging materials ought to be (1) with high microbicidal activity and easy removability from the treated surface with minimum residue, (2) noncorrosive and compatible with the treated surface, (3) presenting no health hazard to the consumer and operation personnel around the packaging equipment, (4) exerting no undesirable effect on product quality in the case of unavoidable residue, and (5) reliable and economical (Ansari and Datta 2003).

There are various available methods for the sterilization of nonsterile packaging materials and containers. The treatments with superheated steam, dry hot air, chemical sterilant, a combination among these treatments, and ionizing radiation are the possible choices.

When using sterilants that do not leave any residue on the food contact surface, the FDA considers sterilization as a process that is regulated only when used on low-acid foods (Anonymous 2010a). However, when plastic packaging materials and chemical sterilants are used, the process is regulated as an indirect additive to food (Anonymous 2010b). Hydrogen peroxide is the most popular choice for use as a chemical sterilant. Hydrogen peroxide, usually at a concentration of 30–35%, is applied to the surface of the packaging material or the container in a dipping or spraying operation. The surface is then heated either by radiant heating elements or by hot air jets (60–125°C). The heating process is to help sterilizing the surface and at the same time to evaporate the residual peroxide and preventing it from contaminating the product after filling.

Preformed nonsterile plastic containers are usually sterilized using hydrogen peroxide, or peracetic acid, and heat. Composite laminated boards, both the web-fed and the preformed types, are commonly sterilized using hydrogen peroxide and heat. Metal containers are usually preformed, and then sterilized with superheated steam on-line to packaging. Aseptic bulk storage tanks can be sterilized with iodophore solution.

Gamma irradiation has been used to sterilize the interior of preformed sealed empty containers, particularly those made of materials that cannot withstand the temperatures needed for thermal sterilization. The bags made of plastic laminates for use in aseptic bag-in-container systems are generally sealed and sterilized in a specialized irradiation plant with gamma irradiation at a dose of approximately 25 kGy (2.5 Mrad) or more to ensure sterility before dispatching to the filling plant. These bags remain internally sterile until the seal is opened under protected conditions in the aseptic filler right before the filling operation (Lewis and Heppell 2000). Other types of radiation are not widely used in aseptic systems. Ultra-violet (UV) light has been used to decontaminate food contact surfaces. The low penetration and shadowing problem limits the use of UV light for aseptic packaging systems.

However, the combination of hydrogen peroxide with UV light is an effective way of package sterilization and is now being applied commercially to composite laminated carton containers on-line with aseptic filling.

ASEPTIC PACKAGING

Aseptic packaging is the process of filling the presterilized food product into sterilized containers and then sealing them. The primary purposes of packaging are to protect the product from microbial spoilage and to minimize the chemical deterioration during storage and distribution. The packaging operation is performed in the aseptic zone that prevents microbial recontamination of the product, the containers, and their closures.

The packaging machine, the filling line, and the sterile air/gas supply system are the three main objects of concern in aseptic packaging operation. The SIP process on the packaging machine and the filling line should be synchronized, and fillers ought to handle the product gently. For some products, such as a low-viscosity fluid with particles, filling the liquid part and the particles using separate fillers may be better than the use of single filler. Some packages may require the filling of nitrogen or carbon dioxide gas into the headspace for protecting the content, for carbonation, or for container pressurization. In that case, the gas has to be sterilized through a HEPA filter in advance.

After filling, sealing is another critical step. Heat sealing is practically the only method that allows aseptic bags, pouches, and cartons to be formed. The seal integrity of the formed package must be assured at all times. If seals are defective, the hermetic nature of the container will be lost and the food will be spoiled.

Aseptic packaging system can fill packages as small as 50 mL plastic cup, up to a 300-gallon bag-in-box and bulk storage tanks containing over one million gallons. There are six basic categories among aseptic packaging systems. (1) Sterilization of empty container, filling, and sealing. The preformed container, made of metal, glass, or plastics, is sterilized, filled, and then sealed aseptically. (2) Erection, sterilization of empty container, filling, and sealing. A knocked down blank of incoming packaging material is erected, sterilized, filled, and sealed aseptically. (3) Sterilization of packaging material, forming, filling, and sealing. A roll of incoming packaging material is sterilized, formed, filled, and sealed aseptically. (4) Thermoform, fill, and seal. Roll stock is sterilized or a sterile surface is provided. The material is thermoformed, filled, and sealed in an aseptic zone. (5) Blow molding, filling, and sealing. An extrudable plastic material is blow-molded in aseptic zone to form bottles. The product is filled into the bottle and sealed before the molds are opened, or the sterile bottle is closed in the mold and delivered to a separate aseptic packaging area where the outer surface of the container is sterilized first, and the sterile container is opened, filled, and then sealed. (6) Bulk packaging and storage systems. Presterilized or in-line sterilized bags are aseptically filled and sealed. Drums and totes are first sterilized and then filled and sealed aseptically. The larger size storage tanks are usually sterilized by chemical disinfectants and/or heat. The use of specially designed valves allows aseptic filling and closing of these tanks (Floros et al. 2010).

Laminated carton package, plastic bottle, and bag-in-box are the major forms of packaging for aseptic food products in the present world.

Laminated Carton Package

The laminated carton material is normally a paperboard coated internally and externally with polyethylene, which makes the carton impermeable to liquids and allows thermal sealing, and incorporated with a thin aluminum foil in the laminate to be a barrier of air and other gases. A schematic structure of laminated carton material for aseptic packaging is shown in Figure 11.7. There are two major packaging systems for laminated cartons as described in the following.

Preformed Laminated Cartons Assembled from Blanks

A Category 2 aseptic packaging system as described earlier is used. Combibloc system (SIG Combibloc, Linnich, Germany) is a typical example (Fig. 11.8). The cartons in lay-flat form are manufactured elsewhere, with the longitudinal seams completed and creases applied for folding. Within the aseptic zone, the cartons assumed their final shape with the tops and bottoms formed and bonded. In the filling operation, each carton is preheated, passed under a binary nozzle, which introduces hydrogen peroxide (30–35%) to the entire internal surface of the carton, and then passed through a drying zone, where the sterilization of the internal surface and the removal of residual hydrogen peroxide is achieved by

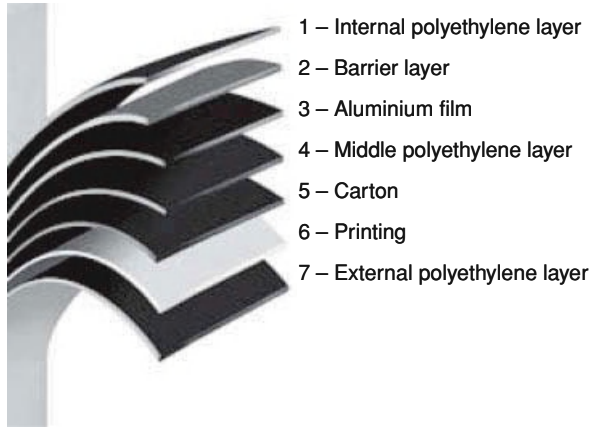

Figure 11.7. Structure of a laminated packaging material.

Figure 11.8. Combibloc aseptic packaging system CFA 512 (Courtesy of SIG Combibloc). The machine can produce packages from 500 to 1100 mL, with a capacity of 12,000 pieces/hour.

blowing sterile hot air (170–200°C) into the carton over several continuous drying stations. Consecutively, the sterilized cartons are filled with presterilized products through filling pipes. Precise quantity metering by fine adjustment of the volume can be done during operation. The headspace in the package is then injected with aseptic steam. In the last step, the filled carton passes to the end of aseptic zone, where the top of container is closed and heat sealed.

Laminated Cartons Formed from Reel

A Category 3 aseptic packaging system is used. Figure 11.9 shows TBA packaging system TBA-19 (Tetra Pak Processing Components, Pully/Lausanne, Switzerland) as an example. The laminated carton material is supplied to the food packer in reels. In the packaging machine, the container material comes out of the reel, moves continuously downward in a strip, and shapes into a cylinder. An overlapping longitudinal seal is formed by heat sealing. At the same time, an additional thin polyethylene strip is heat-bonded along the inside of the longitudinal seam (Fig. 11.10). The purpose of this is to prevent filled product from penetrating the paper layer, or to prevent microorganisms in the paper from contaminating the product. Prior to the formation of that seal, the packaging material is immersed in a hydrogen peroxide bath and then blown with hot sterile air to dry the surface. After leaving this area, the material is already folded as a cylinder around a stainless steel product filling tube. As the continuous cylinder moves downward, a series of transversal seal is made by jaws. These seals have the effect of closing the bottom of the cylinder, so that it can be filled with product. The sterilized product is fed into the empty carton by filler. Forming of the semi-finished package and sealing of the transversal seals is then done below the liquid level to ensure that the package is completely filled. If a package with headspace is to be produced, it can be injected with either sterile air or an inert gas. After that, the individual tetrahedral cartons are divided by knives to form separate packs. All of the individual cartons are then ejected from the cellular transport chain onto a rotary cross unit and discharged onto a single lane exit conveyor.

Plastic Bottle

Plastic containers, with their advantages in weight, volume, simplicity of production, durability, and cost, have replaced glass and metal containers for beverages and many other food products (Bain and Giles 2001, Streeter 2001).

Plastic bottles can be blow-molded with sterile inside and outside, filled with product and sealed in a Category 5 aseptic packaging system. The bottles may also be preformed outside the aseptic packaging system by blowing either with sterile air in a completely sealed form or with nonsterile air as open containers. For sterile-blown bottles, a Category 5 aseptic packaging system is used. The outside surface of the sealed empty bottle is sterilized with a spray of hydrogen peroxide or peracetic acid solution upon entering the aseptic zone. The closed top of the bottle is cut away and the neck trimmed. For nonsterile blown bottles, a Category 1 packaging system is

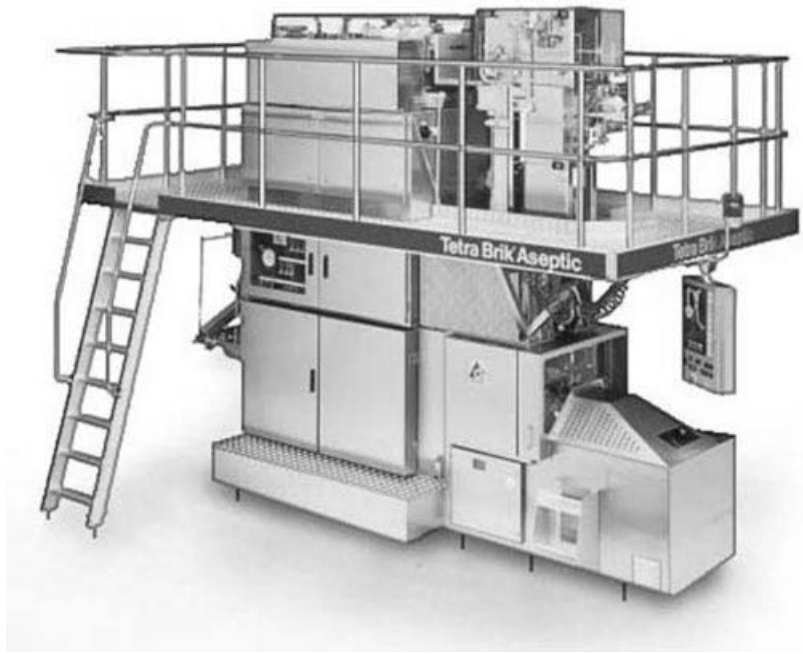

Figure 11.9. Tetra Pak aseptic packaging system TBA-19 (courtesy of Tetra Pak Processing Components). The machine can produce 14 different packages from 125 to 330 mL, with a capacity from 6000 to 7500 pieces/hour.

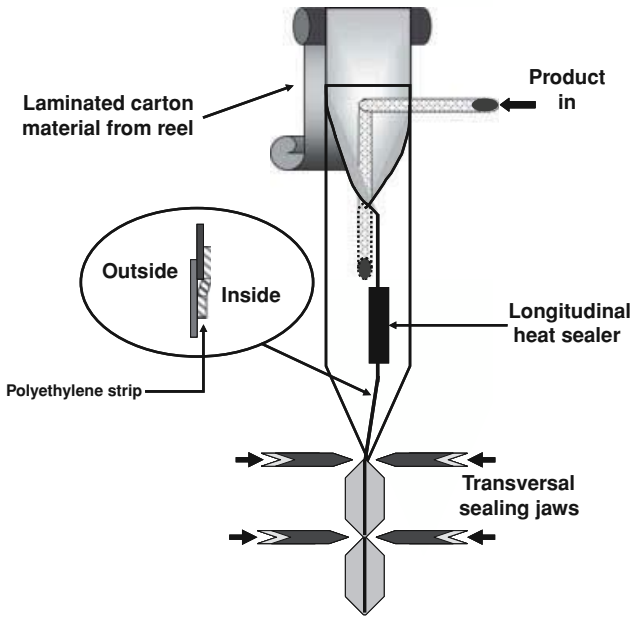

Figure 11.10. A schematic description for the formation and filling of laminated cartons from the reeled packaging material in Tetra Brik Aseptic system.

used. Upon entering the aseptic zone, the bottles are inverted and sprayed inside and outside with hydrogen peroxide or peracetic solution, passed down a hot air tunnel, re-inverted, and then rinsed with sterile water.

In aseptic packaging systems, the sterile plastic bottles are usually filled using rotary volumetric fillers. The headspace can be filled with inert gas if necessary. The bottles are then heat sealed with chemically sterilized plastic film or heat-sealable closure, and outer plug or screw cap can be applied.

The most popular plastic material for the making of aseptic bottles is polyethylene terephthalate (PET) for its excellent recyclability, good heat resistance, low oxygen permeability, and high mechanical strength. There are two basic molding methods for PET bottles: one-step and two-step. In the one-step method, the entire process from raw material to finished container is conducted within one machine, making it especially suitable for molding nonstandard shapes (custom molding), including jars, flat oval, flask shapes, etc. Its greatest merit is the reduction in space, product handling, and energy. It can also produce bottles with visual quality higher than what the two-step system can achieve. In the first step of the two-step method, the plastic material is melted and injection-molded to become miniature PET tubes each closed at one end. The miniature tubes are then blow-molded to form the final bottles in the second step. The preformed tubes are convenient for stock and shipping. The two-step

system may be favored because of the savings in capital investment by the installation of only the second-step machine with the procurement of miniature preformed tubes from a supplier.

Bag-in-container

Aseptic bag-in-containers are characterized by volume versatility (capacity ranges from 1 to 300 gallons) and a very low cost. The bag itself is usually expendable. It is in a laminated structure consisted of layers for barrier, mechanical strength, and sealing. The selection of bag material is primarily based on the required barrier properties. The structure and construction material of the filling valve on the bag varies with the filling, sealing, and sterilizing methods used by the individual manufacturers.

Bags with sterile inside are supplied to the packer in lay-flat form. Outer surface of the tap on the bag has to be sterilized right before filling. Semi-manual or fully automatic filling of bags is then practiced. In some systems, the entire packaging operation takes place within a sterile cabinet. In most systems, the operation is done in open air. In that case, the filling head on the filler is cleaned, sterilized, and then connected to the sterilized tap of the bag to start filling. The connection is loosened and the tap is closed upon the completion of filling. The outer surface of tap is sterilized, and then the tap is capped.

Product flows into the bag, unfolding the bag from the bottom upwards during filling. The filled bag is conveyed out of the packaging system, and then placed in an outer container, such as steel or fiber drum, paperboard box, and wooden, metal, fiber, or plastic bin, before or after filling for support and protection. The outer containers are usually reusable. Empty paperboard boxes may be flattened for space saving.

Figure 11.11 shows a Scholle SureFill® 22 bag-in-box filler (Scholle Packaging, Northlake, IL) for illustration.

STABILITY OF ASEPTIC PRODUCTS

A food product aseptically processed to match with the conventionally processed product in microbial stability often has better overall quality than the conventional product coming out of the production line. However, certain unique problems in regard to quality deterioration may occur in the storage of aseptic products. The oxidation promoted by residual sterilants or by the oxygen permeated from the ambient environment is the most commonly addressed one.

Fruit juice and related products such as fruit puree and nectar are the most common products from aseptic processing

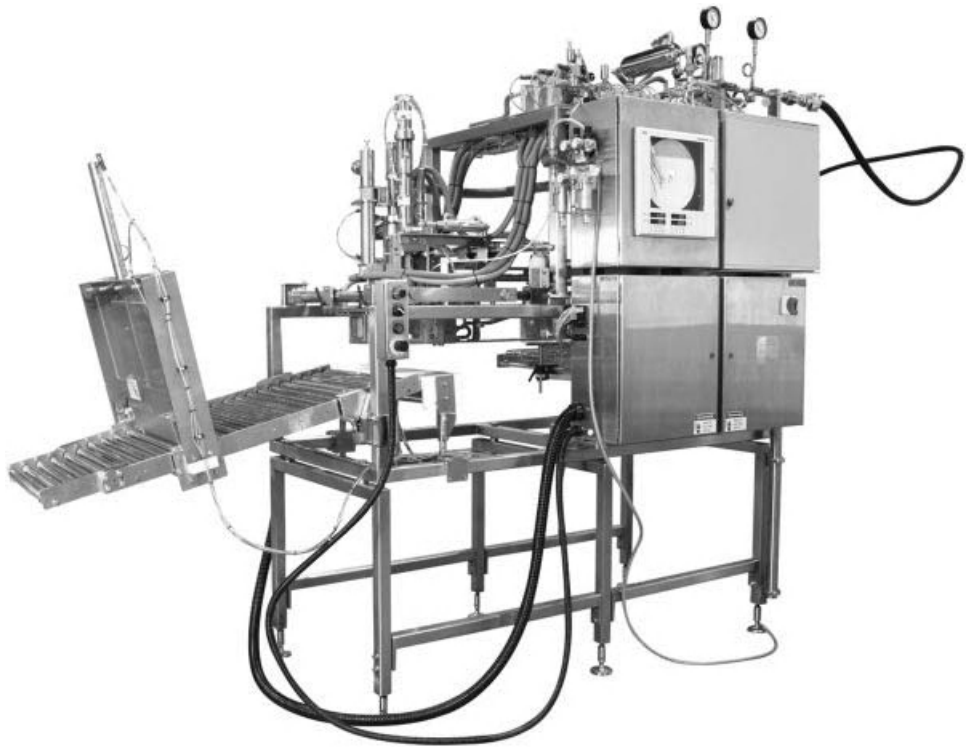

Figure 11.11. Scholle aseptic packaging machine SureFill®22 (courtesy of Scholle Packaging Corporation).

with fruit as the raw material. The oxidative degradations of anthocyanins and ascorbic acid have been recognized among the major routes of storage deterioration of many aseptically processed juices. The oxidative degradations of these chemical components cause discoloration, browning, and loss of nutritional value in the product. An effective preventive measure is to restrict the availability of oxygen.

Oxidation Caused by Residual Sterilant

Hydrogen peroxide is the most commonly used sterilant for the packaging material in aseptic processing. The FDA regulation limits residual hydrogen peroxide to 0.5 ppm in finished food packages (Anonymous 2010c). Sterile hot air is usually introduced for drying and removing the excessive hydrogen peroxide from the food contact surface. However, a small amount of residues may still be left on the packaging material and vapors generated during drying may sometimes get trapped inside the package upon sealing (Toledo 1986).

Ascorbic acid and anthocyanins in fruit juice can be adversely affected by hydrogen peroxide. There are reports confirming the deleterious effect of hydrogen peroxide on ascorbic acid in orange juice (Johnson and Toledo 1975), and on anthocyanins in strawberry juice, orange juice, grape juice, pomegranate juice, sour cherry juice, and sour cherry nectar as well (Sondheimer and Kertesz 1952, Özkan et al. 2000, 2002, 2004, 2005, Özkan 2002).

Anthocyanins are highly reactive to hydrogen peroxide in the formation of colorless end products. Özkan et al. (2000) investigated the degradation of anthocyanins in sour cherry juice at various hydrogen peroxide concentrations and temperatures. Özkan et al. (2005) found that a rapid degradation of anthocyanins may occur in fruit juices even at a hydrogen peroxide concentration as low as the FDA limit and that the presence of ascorbic acid may accelerate the degradation of anthocyanins.

The rates of ascorbic acid and anthocyanin degradations by hydrogen peroxide are highly relevant to temperature. The reduction in temperature may effectively decrease the rates of various kinds of chemical reactions, including oxidation. Cold storage of aseptically packed fruit juices with high ascorbic acid or anthocyanin content is strongly recommended to minimize the degradations and color changes. For example, Toledo (1986) investigated color changes in the storage of aseptically processed cranberry juice cocktail and blueberry juice, and recommended that juices should be stored at a temperature as low as possible for the protection of anthocyanins.

Oxidation Caused by Permeated Oxygen

The shelf life of a product is the time period from production up to the point when the product becomes unacceptable from a safety, sensory, and nutritional perspectives. The correct choice of packaging material is essential for achieving the desired shelf life. The influence of packaging material on the quality and shelf life of aseptically processed products has been the subject of many investigations.

Among the packaging materials available for commercial aseptic products, metal sheets and glass are absolutely impermeable to air and oxygen and composite materials laminated with aluminum foil is virtually impermeable to gases (van Willige et al. 2002), while plastics and composite materials laminated without a metal foil may act as a gas barrier only to limited effectiveness. In a shelf-life study, orange juice aseptically packaged in monolayer PET bottles presented a poor retention of ascorbic acid and shelf life was shorter than the juice bottled in glass or multilayer PET. Only when all remedial measures, including oxygen scavenger, nitrogen flushing in headspace during filling, aluminum foil seal in screw-cap, and refrigerated storage, are applied to the monolayer PET bottles, the shelf life of orange juice can be extended from 6 months to 9 months and the retention of ascorbic acid similar to glass and multilayer PET bottles can be obtained (Ros-Chumillas et al. 2007).

ASEPTIC PROCESSING OF PRODUCTS CONTAINING PARTICLES

Aseptic processing of a food fluid containing particles is much more sophisticated than that of a homogeneous food fluid. From public health standpoint, the system design and F value calculation should be based on the time–temperature history of the slowest heating particle in the heating section and the residence time of the fastest moving particle in the holding section.

In the aseptic processing of a homogeneous food fluid, heat transfer occurs between the heating or cooling medium and the food liquid and within the food liquid as well. When processing a food fluid that contains particles, the heat transfer in the heat exchanger, usually in scraped-surface type but sometimes a tubular heat exchanger may be used, becomes more complicated. In addition to the heat transfer between the medium and the liquid part of the food and within the liquid, there is heat transfer between the liquid and the particles and inside the particles.

The particles are heated in the heat exchanger by surrounding liquid. The center of a particle is heated slowest in the whole body. Therefore, the time–temperature history at the center of the particle is indicative to the effectiveness of the heating section. The settings for the operation of the heating section are supposed to ensure that the center in every particle is heated to a temperature no lower than the predetermined holding temperature before discharging into the holding section. Meanwhile, the settings for the holding section are to ensure that the fastest moving particle resides in this section

no shorter than the expected holding time for achieving the desired *F* value.

The time–temperature history and RTD in the aseptic processing of food fluids containing particles are affected by factors related to the particles themselves (shape, size, density, structure, concentration, and thermal properties), the liquid part or "carrier fluid" as it is often called (density, flow rate, concentration, thermal and rheological properties), and the aseptic system (configurations, operation temperature, mutator speed of the scraped-surface heat exchanger, and the characteristics of pumps).

Numerous studies using various mathematical models, simulated systems, and indicators have been performed to predict the time–temperature history and RTD. Simulated food particles, such as polystyrene spheres, acrylic beads, and rubber cubes, are usually used in the simulated system (Sandeep and Zuritz 1995, Palazoglu and Sandeep 2002, 2004). Some methods have been proposed for time–temperature measurements of food particles in simulated processes, such as ultrasonic tomography (Beller 1993), magnetic resonance imaging (Kantt et al. 1998), and microthermometry (Reiffel 2001, Higgins 2004). Palazoglu et al. (2006) reported a more advanced method that monitors the time–temperature history in real food particles during the processing of a food fluid containing particles in the heating section and holding tube in a tubular heat exchanger by small magnetic particles embedded in these particles.

The reported methods for evaluating the RDT of a food fluid containing particles include visual observation and manual timing, the use of photoelectric sensor, laser beam methods, magnetic tracer, Hall-effect sensor, electrical conductivity measurement, etc. For example, several workers have used a video camera and subsequent frame-by-frame analysis, often with mirrors surrounding the tube to enable the tracing of particles in the holding tube (Lewis and Heppell 2000).

It is difficult to identify the fastest-moving particle in a commercial system operating under actual processing conditions. As an alternative, residence times of numerous particles may be recorded in a tedious task. The residence time of the fastest-moving particle can then be predicted statistically. Fortunately, for most foods, it appears to be conservative and safe just to assume that the residence time for the fastest-moving particle is half of the bulk average residence time for the food fluid containing particles. Any deviation from this assumption in establishing a process would require detailed studies on the RTD and the MRT of particles. Tests should be conducted using the actual food product flowing at the production flow rate (Berry 1989, Singh and Morgan 2010).

An example of aseptic products containing particles is stirred yogurt with diced fruit. In its processing, fruit particles are pumped through a scraped-surface heat exchanger to be heated up to at least 90°C, held for 3 minutes, cooled to 27–33°C, mixed with pasteurized yogurt fluid, and then filled into plastic cups and sealed aseptically (Haque et al. 2001, O'Rell and Chandan 2006, Hui 2007).

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12
Food Additives in Fruit Processing

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Abstract: Food additives play an important role in fruit processing ensuring quality and safety of the products. The food additive industry is a multibillion-dollar industry with advancements in the nature of additives in tune with changing consumer and industry preferences. Over the period of time, there is an evolution in product formulation and the diversity in the range of products demands, newer additives and phasing out of some of the conventional additives keeping in view the modern food regulations and international codes. Food standards and regulating bodies such as Food and Drug Act (FDA) and Codex Alimentarius are in a constant mode of evolving newer strategies in terms of coining standards in the area of food additives. During fruit processing, a number of food additives that are in popular use include preservatives, acidulants, antioxidants, food colors, flavors, sweeteners, hydrocolloids, emulsifiers, enzymes, etc. A number of nutritional additives such as vitamins, amino acids, minerals, and fat substitutes find their way as a modern consumer is in constant search for prophylactic foods or health foods. The chapter deals with a detailed account of various food laws pertaining to food additives, profiles and mechanism of action

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and areas of uses of various additives. A synergy is also brought in between the range of products and the compatibility of various food additives. Adequate emphasis is laid on natural additives and sulfite substitutes as per the concerns of modern food industry.

INTRODUCTION

Food preparation and processing operations have used approved additives and preservatives to impart certain desired attributes and enhance product quality (Giese 1993). These substances, which are of natural origin, include sweeteners, salt, spices, flavors, colors, oils, etc. At present, we have more than 2500 additives for use during production, processing, packaging, and storage of foods. The general definition of an additive is "any substance added to food in restricted quantities other than the original food components during production, processing, packaging, or storage." A food additive can be either a direct or indirect additive:

- *Direct food additives*: A substance added to the food intentionally in smaller quantities for functional purpose during food processing.
- *Indirect food additives*: A substance entering into the food in small quantities during processing or packaging.

Direct additives are further classified according to their functionality (Branen and Haggerty 2002). Flavors are important functional additives as they enrich product profile and marketability. Food additives can bring about many advantages, such as longer shelf life, improved nutrition, extension of product offerings, improved sensory quality, and cost efficiency.

Safe and Nutritious Foods

Food safety goes far beyond food preservation and includes the usage of food additives such as antioxidants, which minimize formation of toxic substances. Vitamins and minerals supplementation caters to nutritional requirements.

Product Diversity

In the case of processed fruits, we have a variety of products, such as beverages (fruit-flavored carbonated beverages and noncarbonated beverages), thermally processed, dehydrated, and frozen products, structured, glazed, and candied fruits, salads, desserts, pies, bars, jams, jellies, and marmalades. Food additives are added to these products to improve sensory properties such as color, aroma, taste, and texture.

In the development of low-calorie products, certain sweeteners and fat substitutes have played an important role. For example, aspartame is used in low-calorie fruit beverages. Similarly, emulsifiers and stabilizers besides fat substitutes such as sucrose polyesters have significantly reduced the use of fat in food formulations. In the next decade, it is likely that functional additives and neutraceuticals will dominate the global market (Sloan 2000). Fruit-based products such as dietary fiber, vitamins, minerals, and natural antioxidants may contribute as health-promoting ingredients.

Economic Benefits

The use of enzymes in juice extraction and clarification provides significant yield and quality improvements. Similarly, nonnutritional sweeteners can provide economic benefits through judicious use of their sweetness potency vis-á-vis conventional sweeteners (DuBois 1992).

Optimization of Unit Operations

Several food additives are used as processing aids. For example, enzymes, pectin methylesterase, and polygalacturonase in juice extraction. Similarly, osmophilic coatings facilitate osmoregulation of solid contents during osmotic dehydration of fruits. Additives such as acidulants and ascorbic acid when added to dip solutions can improve color profiles of products (Sapers and Miller 1995).

Sensory and Convenience Optimization

Color, aroma, taste, and texture, the primary sensory characteristics, can be enhanced by a range of food additives. Certain nonpreservative additives can improve sensory quality of food products (Ollikainen et al. 1984).

Quick cooking of certain legumes can be achieved by additives such as bicarbonates and polyphosphates (Uebersax and Occena 1993).

CLASSIFICATION

Food additives are classified primarily as direct and indirect food additives as per the definitions mentioned earlier. The direct food additives encompass all the intentionally added additives. They are classified based on their chemical nature as well as functionality (Branen and Haggerty 2002; Table 12.1).

The classification of food additives includes multifunctional food additives that can qualify as multifunctional. Sulfur and its compounds have different functionalities such as antimicrobial, antienzymatic, and antinonenzymatic (Josyn and Braverman 1954). Acidulants such as citric acid too have multiple functions, such as acidification, metal chelation, antimicrobial, and antioxidative. However, the multifunctional additives can be included in different functional categories.

GOVERNMENTAL REGULATIONS

Food additives need to be approved by the regulating bodies both in terms of usage as well as dosage, as they are

Table 12.1. Classification of Food Additives

	Food Additives		
	Direct Food Additives		Indirect Food Additives
No.	Chemical Classes	Functional Classes	
1.	*Inorganic*	*Preservatives*	Catalysts
	Phosphates	Antimicrobials	Lubricants
	Sulfites	Antioxidants	Propellants
	Salt, etc.	Antibrowning agents	
2.	*Synthetic chemicals*	*Nutritional additives*	
	Dyes	Vitamins	
	Silicones	Amino acids	
	Benzoates	Fiber	
	Vitamin A, etc.	Minerals	
		Fat substitutes	
3.	*Extraction products*	*Coloring agents*	
	Gums	Natural colorants	
	Essential oils	Synthetic colorants	
	Vitamin E, etc		
4.	*Fermentation-derived products*	*Flavoring additives*	
	Enzymes	Sweeteners	
	Yeasts	Natural and synthetic flavors	
	Citric acid, etc.	Flavor enhancers	
		Texturizing agents	
		Emulsifiers	
		Stabilizers	
		Miscellaneous additives	
		Chelating agents	
		Enzymes	
		Antifoaming agents	

extraneous substances added to foods as processing aids and for a variety of benefits such as sensory quality, nutritional value, and storage stability (Sumner and Eifert 2002). The regulation of food additives is an absolute necessity as misuse can have far-reaching health implications in children as well as adults. At the same time, the food laws need to be flexible enough to support new product development and marketing. Therefore, in order to maintain a dynamic balance between the legislation and the product development, the specifications are periodically subjected to revision by national and international bodies concerned with coining of standards and monitoring of the same.

Every country has specific regulatory norms and lists of approved additives and enforcement procedures. The foremost among the governmental regulations are Food, Drug, and Cosmetics Act (FD & C), European Union standards, and Codex Alimentarius, which constitutes the FAO/WHO joint regulatory body (Somogyi 1996). Certain salient features of FDA and Codex are described below.

Food, Drug, and Cosmetic Act

The Food and Drug Administration (FDA) had come to the fore with the first law tabled during 1906. The Delany Committee report in 1952 gave a comprehensive recommendation to include newer additives in quick succession to fill the vacuum as the food industries felt the increasing demand for food additives in their product developmental activities (FAO 1996). The amendment in 1958 gave rise to three distinct classes of food additives: (a) substances approved by FDA prior to 1958, (b) substances that are generally recognized as safe (GRAS), and (c) substances without prior sanction or GRAS status and defined as food additives.

GRAS Substances

The GRAS feature was introduced by the FDA for review and approval of additives seeking this status (FDA 1995). The major features considered for affirmation as GRAS are

1. General recognition of safety may be based only on the views of experts.
2. General recognition of safety based on scientific procedures shall require the same scientific evidence as is required to obtain the approval of a food additive regulation of the ingredient.
3. General recognition of safety through experience based on common use in food prior to January 1, 1958, may be determined without the quantity or quality of scientific procedures required for the approval of the food additive regulation.
4. Any food substance of biological origin with a record of known use prior to January 1, 1958, for which no known safety hazard exists, shall qualify to be GRAS.
5. Distillates, isolates, extracts, and concentrates of extracts of GRAS substances.
6. Reaction products of GRAS substances.
7. Substances not of a natural biological origin, including those for which evidence is offered that they are identical to a GRAS counterpart.
8. Substances of natural biological origin intended for consumption for other than their nutrient properties.

The GRAS status compliance makes a substance safe, subject to limits prescribed for products with standards of identity. The GRAS list is constantly reviewed with addition and deletions. Natural acids and synthetic color additives are subject to the color additive act of 1960 and are not included in the food additive regulations. Some of the successfully petitioned substances include aspartame, acesulfame-K, gellan

gum, and polydextrose. The safety issues shroud additives such as butylated hydroxy anisole (BHA) and saccharin.

Indirect Food Additives

Indirect additives are important as many extraneous substances, such as lubricating oils and parts of machinery, may come in contact with food and contaminate it during processing (Somogyi 1996). Under the general provisions of indirect food additives (Code of Federal Regulation, CFR 21.174.5), the following aspects are considered:

1. Any substance used as a component of articles that contact with food shall be of pure quality suitable for its intended use.
2. The quantity of any food additive substance that may be added to food as a result of use in articles that contact food shall not exceed, where no limits are specified, that which results from use of the substance in an amount not more than reasonably required to accomplish the intended physical or technical effects.
3. Substances that under conditions of good manufacturing practice (GMP) may be safely used as components of articles that contact food include the following, subject to any prescribed limitations.
   a. GRAS in or on food.
   b. GRAS for intended use in food packaging.
   c. Substances of prior sanction or approval.

Codex Alimentarius

The Codex Alimentarius Commission was established to implement the joint FAO/WHO standards program, the purpose of which is, as set in the statutes of the commission, to protect the health of consumers and to ensure fair practices in the food trade, to coordinate all work on food standards in different countries, to determine priorities in the coining of standards, and to finalize the standards after acceptance by governments (Anon 1992). Basically, the Codex Alimentarius is a collection of internationally adopted food standards presented in a uniform manner to ensure consumer health and fair practices in trade.

The general principles for the use of food additives specify that food additives shall conform to an approved specification, i.e., the specifications of identity and purity recommended by the commission. A list of 450 additives has been indexed since 1997 as a compendium of all specifications prepared by the FAO/WHO Joint Expert Committee on Food Additives (JECFA). The other important bodies/committees associated with the Codex include joint meeting on pesticide residues (Anon 1998) with FAO and WHO jointly constituting the body.

GMP encompasses a number of substances, which allows restricted usage of additives to a quantity not more than what is required to achieve the desired technological effect and in accordance with the Codex general principles for the use of food additives, with emphasis on the allowed daily intake (ADI) of specific substances (Anon 1992). GMP involves the following:

1. The quantity of the additive added to food does not exceed the amount reasonably required to accomplish its intended physical, nutritional, and other technical effects in food.
2. The quantity of the additive that becomes a component of food as a result of its use in the manufacturing, processing, or packaging of a food and which is not intended to accomplish any physical or other technological effect in the food itself is reduced to the extent reasonably possible.
3. The additive is of appropriate food-grade quality and is prepared and handled in the same way as a food ingredient. Food-grade quality is achieved in compliance with the specifications as a whole and not merely with individual criteria in terms of safety.

Codex Alimentarius has adopted an international numbering system for all approved food additives and the food categories have also been specified under food category numbers. Some of the individual numbers for food additives have been specified as follows:

- Glacial acetic acid, 280
- BHA, 320
- Ascorbic acid, 300
- Calcium alginate, 404
- Aspartame, 951
- Carbon dioxide, 290
- Beet red, 162
- Chlorophyll, copper complexes, 1411
- Benzoic acid, 210
- Cyclamates, 952.

The fruit product categories are as follows:

4. Fruits and vegetables (including mushrooms and fungi, roots and tubers, pulses and legumes) and nuts and seeds
   - 4.1. Fruit
     - 4.1.1. Fresh fruit
       - 4.1.1.1. Untreated fruit
       - 4.1.1.2. Surface-treated fruit
       - 4.1.1.3. Peeled or cut fruit
     - 4.1.2. Processed fruit
       - 4.1.2.1. Frozen fruit
       - 4.1.2.2. Dried fruit
       - 4.1.2.3. Fruit in vinegar, oil, or brine
       - 4.1.2.4. Canned or bottled (pasteurized) fruit
       - 4.1.2.5. Jams, jellies, and marmalades
       - 4.1.2.6. Fruit-based spreads other than 4.1.2.5 (e.g., chutney)
       - 4.1.2.7. Candied fruit

4.1.2.8. Fruit preparations including pulp and fruit toppings
4.1.2.9. Fruit-based desserts, including fruit-flavored, water-based desserts
4.1.2.10. Fermented fruit products
4.1.2.11. Fruit fillings for pastries
4.1.2.12. Cooked or fried fruit

STATUS OF FOOD ADDITIVE INDUSTRY

The global market for food additives is expected to exceed $33.9 billion by 2015. The major constituents of additives market include acidulants, fat replacers, sweeteners, vitamins, minerals, colorants, flavors, flavor enhancers, hydrocoloids, emulsifiers, preservatives inclusive of antimicrobial, antioxidants, and enzymes (www.prweb.com 2011). The market trend shows a growth trajectory toward low-calorie, low-fat, natural foods that contain natural additives or no additives. The strongest growth section will include vitamins and minerals. There is an increasing demand for natural flavors and colors at the expense of synthetics. Similarly, the demand for natural antioxidants over synthetic ones is growing. The use of hydrocolloids as fat substitutes along with enhanced growth in artificial sweeteners may dominate the proceedings in the food industry based on food additives. As far as the preservatives are concerned, the sector may further grow from its current position of 2%, as Latin American, Asian, and Eastern European countries may continue their quest toward foods with longer shelf life. There is a growing demand for ethnic flavors, particularly as ingredients in preprepared dressings for salads to restrict microbiological contaminants otherwise originating from spice ingredients (Mannikes 1992).

The demand for food additives in various sectors varies considerably depending on consumer requirements of different countries. The level of utilization also differs within various food-manufacturing sectors depending on the functional requirements of such applications, viz, solubility, thermal and light stability, and compatibility with human metabolism (Robach 1980).

The demand for food additives is primarily distributed among the three sectors: commodity processing sector, pharmaceuticals and drugs sector, and the food manufacturing sector (Fig. 12.1). The blenders and bulk suppliers play a major role in coordinating the overall blending, repackaging, and distribution to the utility sectors. The commodity suppliers are the sources of primary and secondary-processed, value-added commodities such as purees and juice concentrates for the manufacturing sector as such, which may be termed as tertiary processing, during which fruit ingredients are used as per the standards of identity (21 CFR 150.160).

Of the two phases of fruit product manufacturing, i.e., commodity processing and ultimate fruit product manufacturing, the use of additives is more in the second phase, accounting for nearly 60–70% of total food additives used in the fruit-based industries. Among unit operations carried out in commodity processing, operations such as extraction/refining, clarification, and concentration require the bulk of the additives, while formulating, extrusion, freezing, dehydration, and fermentation involve their intensive use for the product manufacture (Somogyi 1996).

The use of additives in fruit processing is expected to grow especially in the areas such as artificial sweeteners, flavors, and texturizing agents. However, the regulations are expected to be more stringent, necessitating the need for more emphasis on the use of natural ingredients, such as natural colors, flavors, and preservatives, which qualify to be in the GRAS list (Robach 1980). The nutritional additives may gain an increased demand, as fruit-based functional foods are likely to constitute a major food category.

Acidulants

Fruit processing as such involves physical, biochemical, and microbial stabilization of the processed products. Acidification has been in practice and its origin dates back to the onset of human civilization. Oriental preserves, such as fermented vegetable products and pickles, indicate the preservation potential of acidulants. Fruit and vegetable products are the major ones to use acidification, as the sensory value of the product is not impaired and the taste is improved as a result of flavor enhancement (Gardner 1972). In fruit products, acidification is usually accompanied by adjustment of the total soluble solids so that the Brix/acid value is comparable to that of fresh fruits. An adjustment in the Brix–acid ratio has been found to take care of the sensory perception, enabling a variety of fruit products to undergo acidification and have the advantages such as preservative and antioxidative effects. The oriental vegetable products such as pickles require a characteristic sourness/tartness to attain an optimal sensory value. The advantages of acidification can be best utilized by an understanding of product profile and an appropriate acidulant can be selected to obtain the optimal sensory perception and shelf life of the finished product (Dziezak 1990).

Selection of Acidulants

Regulatory Considerations

1. The GRAS nature of the acidulant needs to be ascertained. The GRAS substances may be used in foods not covered by standards of identity and which do not have restrictions on their usage levels, provided GMPs are followed.
2. If the acidulant is covered as a food additive, as in the case of fumaric acid, it has to be regulated by the food additive regulation.

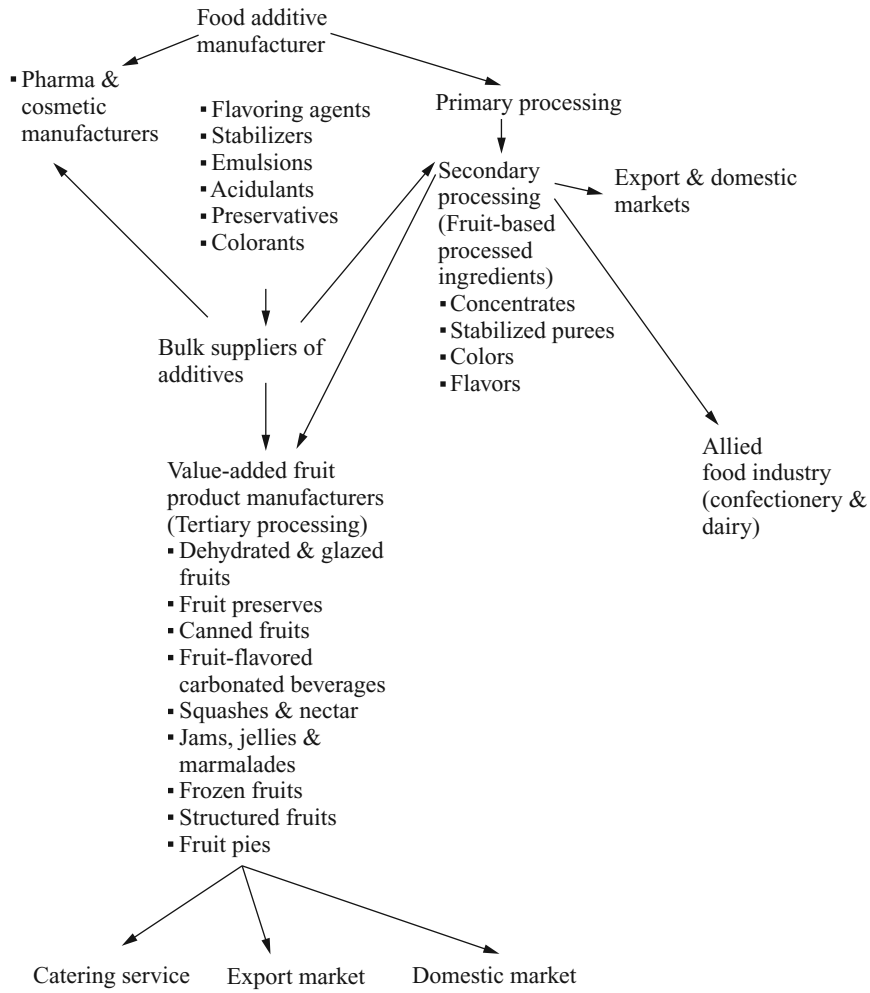

Figure 12.1. Utility profile of additives in fruit processing.

3. For foods covered by standards of identity, the maximum levels prescribed need to be followed.
4. If any local regulations exist, they should be considered while selecting an acidulant.

Functional Considerations

1. Effect of acidulant on the overall product profile.
2. Matching of solubility characteristics with the process conditions and acidulant concentrations required.
3. Hygroscopic characteristic requirements of dry mixes.
4. Suitability of the acidulant to impart an optimal level of tartness at the functional pH.
5. Physical form and particle size for application in dry mixes.
6. Screening of several acidulants based on feedback from the market/user for optimum product applications.

Functions

Different acidulants offer a host of functional diversity in various food applications, but primarily as antimicrobial (Levine and Fellers 1940) and flavoring (Hartwig and McDaniel 1995). The major functions of acidulants are

1. Flavoring to provide a desired taste and intensity, which enhances, blends, or modifies the overall flavor of the product?
2. Reduction in pH to prevent or retard the growth of microorganisms as well as germination of spores and to increase the lethality of the process.
3. Maintenance or establishment of pH through buffering action. Usually, a combination of free acids and salts are used.
4. Chelation of metal ions to assist in minimizing lipid oxidation (Cu and Fe), reducing color changes, and controlling texture of some fruits and vegetables.

5. Alteration of the structure of foods including gels made from gums (pectin and carrageenan) and proteins.
6. Modification of sugar crystallization in hard candy manufacture.

Mechanism of Action

At equal concentrations, the acidulants vary in their ability to depress pH and the degree/intensity of the tartness produced. The percentage required to replace anhydrous citric acid varies from 55% to 60% in case of phosphoric acid, 67–72% for fumaric acid, 80–85% for tartaric acid, 78–83% for malic acid, and 110–115% for adipic acid. The use of glucono-delta-lactone (GDL) is gaining popularity due to the novel features such as slow hydrolysis and mild acid flavor. In fruit processing, acidulants are used extensively and the Brix–acid ratio is maintained at appropriate levels to optimize the sensory perceptions. The products include nectars, squashes, jams, and jellies (Seiferi 1992).

The other function of acidulants is preservation and safety assurance. In 1970s, considerable research took place on the action of organic acids on the microbial cell at the molecular level. The mode of action of an acid was related to the undissociated portion of the molecule (Huntur and Segel 1973). This action is deemed more important than any other external change in pH brought about by the addition of acids. The undissociated moiety of a weak acid penetrates rapidly to the interior of the cell because of its lipid solubility and discharges the gradient diffusion through the plasma membrane and dissociates internally. The dissociated forms of weak acids, on the other hand, could not be absorbed by microorganisms to any great extent.

Murdock (1950) found that citric acid inhibited the flat-sour organisms isolated from tomato juice, and this inhibition appeared to be related to the inherent pH of the product. Citric acid, rather than acetic or lactic acids, also inhibited thermophilic bacteria (Fabian and Graham 1953). In addition to the pH-lowering effects of citric acid, a secondary inhibitory effect is attributed to the chelation of essential minerals. It is believed that inhibition may have been attributable to chelation of essential metal ions by citrate rather than inherent acid inhibition. Chelation has also been believed to be an influencing factor in inhibiting the growth of *Staphylococcus aureus* (Rammell 1962). There have been a number of studies that have attributed the antimicrobial activity of citric acid to the chelation of metal ions, which are essential for microbial growth (Beuchat and Golden 1989).

Citric acid is also used conventionally as a synergist for antioxidants and to retard browning reaction. Usage levels for citric acid have been found to be 0.1–0.3% with an antioxidant level of 100–200 ppm (Dziezak 1986). The specialized uses include the function as a gelling agent. The structured fruits can be taken as an example to illustrate the specific aspect. Alginates are gelled with calcium salts under acidic pH (Kaletunc et al. 1990). Pectinacious fruits are largely subjected to structuring using a variety of acidulants, especially GDL.

Range of Products

A wide variety of fruit-based products possess acidulants as a direct food additive:

1. Beverages
   a. Fruit-flavored carbonated beverages
   b. Fruit-flavored noncarbonated beverages
   c. Beverage powders
   d. Low-calorie beverages (diet beverages).
   Among the above mentioned products, fruit-flavored carbonated beverages are the recent ones. Usually, these beverages are made with 10% natural juices for health-conscious consumers. Citric and malic acids are used in fruit-flavored carbonated beverages. Tartaric acid is generally used in lime-flavored beverages. The noncarbonated beverages include fruit drinks, nectars, and isotonic beverages as "thirst quenchers." Fruit-flavored dry beverages make use of acidulants such as citric, malic, and fumaric acids for imparting tartness along with the release of carbon dioxide from carbonate salts of sodium and calcium. Fruit-flavored diet beverages yielding 50% fewer calories than comparable products make use of acidulants to control pH of the beverage so that desired sweetness characteristics can be achieved (Dziezak 1990).
2. *Candies, structured fruits, and fruit gums*: A wide variety of acidulants are used in these fruit-based products. Fruit-flavored candies are popular products and several patents exist in this area (Dwivedi 2003). The candied fruit products are extruded in a ribbon/belt format, capable of being extruded and rolled on to it to form a candy roll. The product as such includes sweeteners, fruit flavors, binders, water, stabilizers, and acidulants. Fassin and Bachmueller (2000) described the manufacture of fruit gum confectionary, based on the preparation of fruit gum mass by heating water, sweetener, gelling agent, acidulants, flavorings, and fruit/vegetable extracts.

   In the case of structured fruits, GDL has been used as an acidulant to prepare structured hydrocolloid gels with fruit pulp and sugar as the major ingredients (Nussinovitch et al. 1991). Apple sauce and grape juice concentrates have been texturized to obtain gelled products with excellent consistency using GDL as an acidulant and gelling agent to liberate calcium from calcium hydrogen phosphate that ultimately caused the gelation of the product (Kaletunc et al. 1990).
3. *Thermal processed fruits*: Acidulants are also widely used in thermally processed fruit and vegetable products. In the canning process, citric, lactic, malic, and

Table 12.2. Physical and Functional Characteristics of Major Acidulants Used in Fruit Processing

No.		CFR	Physical Form	Pka	Range of Application in Fruit Industry	Taste	Type of Products
1.	Citric acid	184.1033 (GRAS)	Crystalline powder	3.14 4.77 6.39	Very high	A burst of tartness	Carbonated and noncarbonated beverages Wines, jams, and jellies Desserts and fruit squashes Canned and frozen products
2.	Fumaric acid	172.350 (food additive)	White granules or crystalline powder	3.03 4.44	Low	Tart	Frozen concentrates Cider and apple drinks
3.	Malic acid	184.1069 (GRAS)	Crystalline powder	3.4 5.11	Medium	Smooth tartness	Fruit-flavored sodas
4.	Phosphoric acid	182.1073 (GRAS)	Liquid	2.12 7.21 12.67	Low	Acrid	Buffering agent in jams and jellies
5.	GDL	184.1318 (GRAS)	White crystalline powder	3.7	Medium	Neutral taste acidic paste upon hydrolysis	Salad dressings
6.	Tartaric acid	182.1073 (GRAS)	Crystalline powder	2.98 4.34	Medium	Extremely tart	Cranberry and grape-flavored fruits Jams and jellies
7.	Acetic acid	184.1009 (GRAS)	Clear colorless liquid	4.75	High	Tart and sour	Pickled fruits

other organic acids are used to lower pH to 4.6 or below. This addition allows lower temperatures and shorter processing times to be used for the inhibition of sporulation and growth of microorganisms without any loss of flavor, color, and texture in the finished product (Rajashekhara et al. 2000).

Commonly Used Acidulants

The most commonly used acidulants are acetic acid, citric acid, malic acid, phosphoric acid, fumaric acid, and tartaric acid. The physical and functional characteristics of the commonly used acidulants are described in Table 12.2. Except fumaric acid, the other acidulants are GRAS. Citric, malic, and acetic acids are widely used in canned and frozen products, fruit-flavored carbonated and noncarbonated beverages, jams, jellies, and pickled fruits. Sudden burst of tartness is a major characteristic of acidulants such as citric acid, and the use of GDL is gaining increasing popularity to overcome the problem.

Glucono-Delta-Lactone It is an inner and neutral ester of gluconic acid and gets hydrolyzed in aqueous solutions to form gluconic acid (Fig. 12.2). Gluconic acid is a natural constituent of juices and honey and an intermediate in glucose oxidation. The functionality involves slow hydrolysis under moist conditions, resulting in a gradual and continuous decrease in pH. At the end of hydrolysis, equilibrium mixture exists, consisting of gluconic acid as well as delta- and gamma-lactones. The rate of acid formation increases

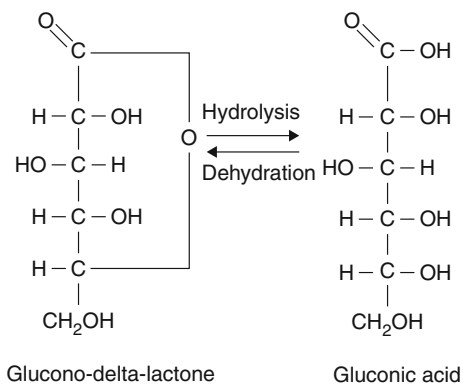

Figure 12.2. Hydrolysis of glucono-delta-lactone.

with temperature and the intensity of acidification depends on the concentration of GDL and the temperature.

The slow rates of acidification by GDL and its mild taste set it apart from other acidulants. The use of GDL is gaining increasing popularity. In case of fruit products apart from the juices, it is widely used in jellies and structured fruits. The relatively higher cost of GDL is a drawback for its extensive use in lieu of acidulants such as citric and malic acids (Montinez et al. 1997).

PRESERVATIVES

Chemical preservatives are defined by FDA (1979) as "any chemical that when added to food tends to prevent or retard deterioration but does not include common salt, sugars, vinegars, spices and oils extracted from spices, substances added to food by direct exposure thereof to wood smoke, or chemicals applied for their respective insecticidal or herbicidal properties." The antioxidants and antibrowning agents constitute the preservatives responsible for restricting the chemical deterioration of the products, whereas the antimicrobials are responsible for the protection from biological hazards. Often, the synergistic effects of antioxidants with antimicrobials could give the best result in terms of shelf life (Branen et al. 1980).

During fruit processing, a number of antimicrobials, antioxidants, and antibrowning agents are used as additives. The number of antimicrobials approved for use in food is remarkably limited. The primary food additives cited in FDA are (1) sodium benzoate, (2) calcium and sodium propionates, (3) sorbic acid and potassium sorbate, and (4) parabens. These preservatives are often used in combination with other methods of preservation such as refrigeration, freezing, and dehydration to obtain better control of deleterious organisms. Certain important preservatives such as organic acids and sulfites are multifunctional and their functionalities include preservation as well as antioxidation and antibrowning activities.

Antimicrobials

Selection of Antimicrobials

The selection of antimicrobials has to be carried out appropriately to obtain the best possible preservative function. The following criteria need to be followed for the selection of approximately 30 compounds, which can legally be used as antimicrobials in food products (Fulton 1981):

1. Antimicrobial and chemical properties of the compound.
2. Composition of the target food.
3. The type of preservation technique adopted for the product.
4. The type and quantum of microbiological load.
5. The safety and regulatory aspects of the antimicrobial for use in the specific product.
6. Cost effectiveness of the antimicrobials.

Mode of Action

1. The mode of action of antimicrobials can be either bactericidal or bacteriostatic and generally falls into one of the following categories (Davidson et al. 2002).
2. Reaction with the cell membrane causing increased permeability and loss of cellular constituents.
3. Inactivation of essential enzymes.
4. Destruction of functional activity.

Antimicrobials in Processed Fruit Products

In processed fruits, the widely used antimicrobials are benzoates, sorbates, propionates, and parabens, apart from acidulants and sulfites. The selection of appropriate antimicrobial for use in fruit products takes notice of the low pH as well as the target organisms, mostly yeasts and fungi due to the low pH.

Benzoates

Benzoates have a typical aromatic ring structure. Benzoic acid and sodium benzoate are widely used in a number of fruit products with an effective functional pH range of 2.5–4.0. These compounds are used primarily as antimycotic agents, and most yeasts and fungi are inhibited by 0.05–0.1% of the undissociated acid. Food-poisoning and spore-forming bacteria are generally inhibited by 0.01–0.02% of undissociated acid, but many spoilage bacteria are much more resistant. Therefore, benzoic acid cannot be relied upon completely for effective preservation of foods capable of supporting bacterial growth (Baird-Parkar 1980). The antimicrobial properties have been attributed to undissociated benzoic acid according to the results of a study involving the uptake of benzoates by *Saccharomyces cereviceae* (Macris 1975). Benzoates have an advantage of low cost compared to other antimicrobial additives. The lower pH makes benzoates suitable for use in maraschino cherries, fruit pie fillings, fruit-based carbonated and noncarbonated beverages, pickles, sauces, fruit preserves, and minimally processed acidified vegetables (Raju et al. 2000). The benzoate compounds are most effective in the low-pH acid foods such as apple cider, soft drinks, tomato sauce/ketchup, and the like and not as effective in low-acid vegetables such as peas, beans, lettuce, etc. The pKa value of benzoate is 4.2, making a pH range of 4.0–5.0 as the functional pH, and most of the fruit products fall within this range. At a pH of 6.0, which is normal for many vegetables, only 1.5% of the benzoate is undissociated (Jay 1986). Care should be taken with the addition of benzoates to acid foods because they can deliver a "peppery" or a burning taste sensation at levels of about 0.1%.

Benzoates are considered GRAS with a maximum limit of 0.1% (21 CFR 184.1021 and 21 CFR 189.1733). Sodium benzoate is used as an antimicrobial in carbonated and still beverages (0.03–0.05%); syrups (0.1%); cider (0.05–0.1%); jams, jellies, and preserves (0.1%); and pie pastry fillings and salads (0.1%).

Parabens

Alkyl esters of *p*-hydroxy benzoic acid are collectively known as parabens and are permitted in the United States with reference to methyl, ethyl, and heptyl parabens. Parabens are most effective against molds and yeasts and as such less effective against bacteria, especially the gram-negative bacteria. The pKa of these compounds is about 8.47. Their antimicrobial activity tends to increase with the length of the alkyl chain and extends up to pH 7.0 (Dziezak 1986). It is also known that the parabens are effective inhibitors of growth and toxin production of *Clostridium botulinum* (Robach and Pierson 1978).

Parabens are used in fruit juices, salads, and artificially sweetened jams and jellies. The methyl and propyl esters of parabens are considered GRAS with a maximum total content of 0.1% (21 CFR 184.1490 and 21 CFR 184.1670).

Sorbates

Sorbic acid is a monocarboxylic fatty acid that is used to preserve foods. Sorbic acid is slightly soluble in water, whereas the potassium salt is highly water soluble up to 58.2 g/100 mL at 20°C (Chichester and Tanner 1975). The optimum pH range for effectiveness extends up to 6.5, higher than the upper range of benzoates and propionates but below that of parabens. A number of reports exist regarding the antimicrobial activity of sorbates. Spoilage-causing and heat-resistant fungi such as *Neosortorya fischeri* along with the ascospores were subjected to studies on thermal death rate, and the sorbate was found to control the organism without impeding the sensory value of preserved fruit juices such as grape and mango (Rajashekhara et al. 1998). Effective inhibition of fungi was also observed in low-sugar preserves through the synergistic effects of sorbates and water activity regulation. Sorbates are currently used to preserve dehydrated prunes, figs, and many beverages, such as orange juice, lemonade, and apple juice (Robach 1980).

Sorbates are considered GRAS substances (21 CFR 182.3089), and they have been used in more than 90 food products having standards of identity. Sorbic acid is considered as one of the least harmful antimicrobial preservatives, even at levels exceeding those normally used in foods (Sofos and Busta 1981).

Acidulants

The preservative role of acidulants is discussed earlier under the category of acidulants. The undissociated moiety is responsible for the bactericidal property of acidulants. They act to reduce the pH, minimizing microbial growth and often enhancing the effect of weak acid preservatives. The mechanism of action leading to preservative function may be attributed to lowering of pH as well as metal ion chelation. Citric acid has been primarily used in many fruit-based products, representing more than 60% of all food acids used. Malic acid and GDL are relatively newer and emerging acidulant preservatives, with the potential to impart excellent sensory property to the fruit products. The GRAS status of food acidulants along with their cost effectiveness favors the widespread use in a variety of fruit products, including fruit-flavored carbonated and noncarbonated beverages.

Sulfites

Elemental sulfur and sulfur compounds are known to show antimicrobial activity, and sulfur obtained from volcanic lava as well as hot spring water containing sulfur are used extensively for various dermal infections and wounds. The pKa values for sulfur dioxide are 1.76 and 7.2, indicating a rather weak dibasic acid. It is useful to have sulfur dioxide in a salt form. The dry salts are easier to store and less of a problem to handle than the gaseous or liquid forms (Ough 1983). In water solutions, sulfur dioxide shows the following reaction equilibriums:

$$SO_2 + H_2O \rightleftarrows [H_2SO_3]$$

$$[H_2SO_3] \rightleftarrows HSO_3^- + H^+$$

$$HSO_3^- \rightleftarrows SO_3^{-2} + H^+$$

The growth inhibiting or lethal effects of sulfurous acid are most intense when the acid is in the unionized form (Hailer 1911). It was also noted that bacteria were much more sensitive to sulfur dioxide than yeasts and molds. It is also known that the bisulfites had lower activity than sulfur dioxide against yeasts and the sulfites had none. The three main groups of microbes of interest in the high acidic beverages and fruits are (1) acetic acid-producing and malolactic bacteria, (2) fermentation and spoilage yeasts, and (3) fruit molds.

As far as food applications are concerned, sulfites are used in a number of fruit products, i.e., dried fruits, frozen fruits, fruit-based beverages, glazed fruits, jams, and jellies within the purview of GMP and GRAS. However, any product with sulfur dioxide levels above the detectable limits needs to specify on the labels the nature of sulfitation and the residue levels (Taylor et al. 1986).

The FDA considers sulfur dioxide and several sulfite salts as GRAS (21 CFR 182). However, sulfites cannot be used in fruits and vegetables intended to be served, presented, or sold raw/fresh to the consumers. They are allowed in fruit juices and concentrates, dehydrated fruits, vegetables, and wine. The maximum level of sulfur dioxide allowed in wine

has been set at 350 mg/L by the regulating body for the United States alcoholic beverage industry. Sulfur elicits allergenic responses in certain individuals, especially steroid-dependent, and therefore, the usage levels in ready-to-eat fruit and vegetable products have been under stringent scrutiny (Anon 1990).

Biopreservatives

These are basically of biological origin and therefore can easily be considered GRAS as compared to the chemical additives. The biopreservative "nisin" is the foremost among them as the use of nisin is gaining momentum for a range of food applications. The compound is a peptide produced by the lactic bacteria *Lactococcus lactis* sp. *lactis*. The structure and amino acid content of nisin was determined by Gross and Morell (1971). The solubility is 56 mg/mL at pH 2.2, while at pH 5.0, the solubility is 3 mg/mL.

Nisin by itself has a narrow spectrum affecting only gram-positive bacteria, including *Bacillus*, *Clostridium*, *Enterococcus*, *Lactobacillus*, *Listeria*, *Pediococcus*, and *Staphylococcus*. The spectrum of activity of nisin can be expanded to include gram-negative bacteria by combining it with chelating agents, such as ethylene diamine tetra acetic acid (EDTA; Carneiro de melo et al. 1998).

Nisin as a food additive has been approved in many countries. The FDA has approved nisin as a preparation (21 CFR 184.1538) with nisin content of not less than 900 IU/mg in the formulations. It is approved to inhibit the growth of *C. botulinum* spores in pasteurized cheese spreads with fruits and vegetables. It has been accorded a GRAS status with a maximum use level of 250 ppm. As such, it is used to reduce the thermal process levels in different canned products and the future for nisin appears bright as a need is being felt to decrease the thermal processing levels to protect finished product flavor (Davidson et al. 2002).

Antibrowning Agents

Antibrowning agents are of special significance in fruit products as a majority of them are susceptible to browning reaction during processing and storage. The fruit products are highly susceptible toward the browning reactions of both the nonenzymatic and enzymatic nature. The major reasons for higher rate of browning in fruit products can be cited as abundance of sugars with particular reference to reducing sugars.

Nonenzymatic browning is a Maillard reaction between carbonyl and amino groups with a host of intermediates, finally resulting in the formation of nitrogenous polymers and copolymers known as melanoidins. Nonenzymatic browning reactions can also result in the loss of vital nutrients such as ascorbic acid, which gets oxidized to dehydroascorbic acid, which further undergoes aldol condensation or reaction with amino groups to form brown pigments (Loescher et al. 1991).

Browning due to ascorbic acid is very important in processed fruit juices enriched with vitamin C. Nonenzymatic browning can also take place due to sugar degradation, iron complexing of polyphenols (Smith 1987), and oxidation of polyphenols by hypochlorites (Choi and Sapers 1994).

Nonenzymatic browning reaction in fruits and vegetables depends on a number of factors such as (1) product composition, (2) moisture content of the product, and (3) storage temperature and exposure to oxygen. The compositional factors include Maillard precursors or ascorbic acid (Kennedy et al. 1990). Nonenzymatic browning in fruits and vegetables can be inhibited by refrigeration and through the control of water activity in dehydrated foods (Labuza and Saltmarch 1981). Other methods of control include use of glucose oxidase for reduction of glucose levels, reduction of amino nitrogen content in juices by ion exchange, packaging with oxygen scavengers, and use of sulfites (Bolin and Steele 1987). Sulfhydryl-containing amino acids have been found to be nearly as effective as bisulfite in inhibiting nonenzymatic browning in a model system (Friedman and Molnar 1990). However, cysteine treatment was ineffective in dried apple (Bolin and Steele 1987).

Additives to control nonenzymatic browning are used in a number of fruit products, such as dehydrated fruits, glazed fruits, beverages, fruit bars, texturized fruit products, and fruit candies. The sulfite treatment levels vary in foods widely depending on the application. Residual levels usually do not exceed several hundred parts per million but may approach 1000 ppm in certain fruit and vegetable products (Taylor et al. 1986). The FDA has proposed that maximum residual sulfur dioxide levels of 300, 500, and 2000 ppm be permitted in fruit juices, dehydrated potatoes, and dried fruits, respectively (FDA 1988).

Antioxidants

Antioxidants as food additives have a highly significant role in preserving many oxidation-susceptible fruit products. However, fruit products are different compared to cereal and meat products in terms of lipid contents, and the use of antioxidants is primarily aimed at restricting the discoloration due to enzymatic browning, besides the loss of carotenoid contents.

The FDA has defined the antioxidants as substances used to preserve food by retarding deterioration, rancidity, or discoloration due to oxidation (CFR 21.170.303). These reactions cause browning, discoloration of endogenous pigments, loss of nutritional value from destruction of vitamin A, C, D, or E, and essential fatty acids such as linolenic acid. Special problems arise in fruits such as avocado due to higher lipid content, leading to the possible development of rancid off-flavors and toxic oxidation products (Dziezak 1986).

The basic antioxidant effect arises out of four types of antioxidants, i.e., free radical scavengers such as BHA and butylated hydroxyl toluene; reducing agents such as ascorbic

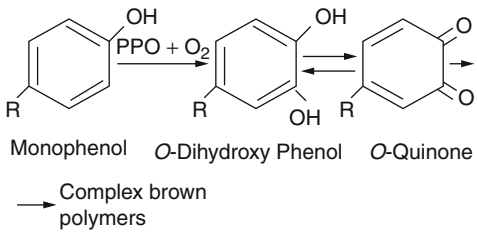

Figure 12.3. Enzymatic browning reaction.

acid; chelating agents like EDTA; and secondary antioxidants like dilauryl acid. In case of fruit products, reducing and chelating agents are of prime importance due to their functionality in the prevention of enzymatic browning.

Enzymatic Browning

Enzymatic browning is the discoloration that results in the oxidation of monophenolic compounds of plants or shellfish in the presence of atmospheric oxygen and polyphenoloxidase (PPO). The monophenolic compounds are hydroxylated to *o*-diphenols and the latter are oxidized to *o*-quinones (Fig. 12.3; Mayer and Hanel 1979). PPO (EC 1.14.18.1) is also known by other names such as tyrosinase, PPO, catechol oxidase, etc. The quinones condense and react nonenzymatically with other phenolic compounds, amino acids, etc., to produce pigments of indeterminate structure. A variety of phenolic compounds is oxidized by PPO (Fig. 12.4), the most important substrates being catechins, cinnamic acid esters, 3,4-dihydroxy phenyalanine, and tyrosine. The optimum pH for PPO activity is between 5 and 7. The enzyme is relatively heat labile and can be inhibited by acids, halides, phenolic acids, sulfites, chelating agents, reducing agents such as ascorbic acid, and quinone couplers such as cysteine and various substrate-binding compounds.

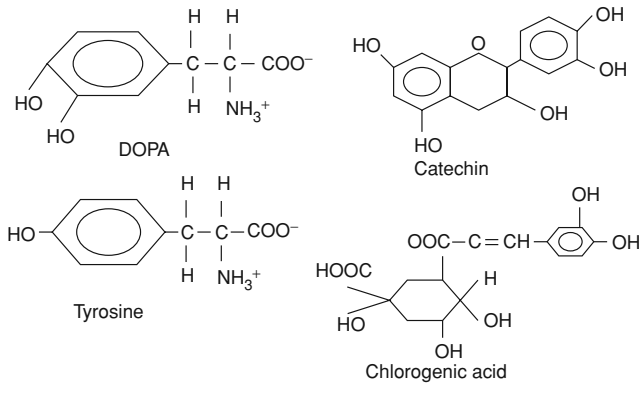

Figure 12.4. Common substrates for polyphenol oxidase.

Enzymatic browning is a significant problem in a number of important commodities, specifically fruits such as apples, pears, peaches, bananas, and grapes. The discoloration limits the shelf life of many minimally processed foods (Huxsoll et al. 1989) and is also a problem in the production of dehydrated and frozen fruits and vegetables (Shewfelt 1986). Enzymatic browning can be controlled in some fruit and vegetable products by blanching to inactivate PPO (Hall 1989). However, blanching cannot be used for certain products with delicate flavors as the heat can be detrimental to some, necessitating the need for the use of chemical additives, apart from the physical measures such as moisture regulation, molecular oxygen exclusion, and lowering of storage temperatures.

Sulfites are effective inhibitors of PPO and hence widely used for the regulation of enzymatic browning in a variety of fruit products. Sulfiting agents such as sulfur dioxide, sodium sulfite, sodium and potassium bisulfites, and metabisulfites are used extensively to prevent enzymatic browning apart from their effective role in restricting the nonenzymatic browning process. These additives can also act as bleaching agents, antioxidants, and reducing agents as well as to check the microbial growth (Taylor et al. 1986). However, the increasing awareness toward the health hazards of sulfur compounds as food additives has necessitated the search for potential substitutes.

Sulfite Substitutes

Sulfite substitutes for the prevention of enzymatic browning include a host of additives, viz, ascorbic acid, metal chelators, sulfhydrl amino acids, and acidulants. Such substitutes must be cost effective and approved for food use by FDA (Sapers 1993). The search for sulfite alternatives has largely remained inconclusive, as sulfites are multifunctional, whereas the alternatives are effective substitutes only for one or two of the functionalities obtained with sulfites. It is unlikely that a multifunctional sulfite substitute can be developed easily. Rather, a combination of several active ingredients formulated to meet the needs of specific commodities and product types could be developed.

The best known alternative to sulfites is ascorbic acid, which is a highly effective inhibitor of enzymatic browning, primarily because of its ability to induce quinones, generated by PPO-catalyzed oxidation of polyphenols, back to phenolic compounds before they can undergo further reaction to form brown pigments. However, ascorbic acid once added is completely oxidized to dehydro ascorbic acid (DHAA) by the reaction, quinones can accumulate and undergo browning. In addition, DHAA can itself lead to nonenzymatic browning. At high concentrations, ascorbic acid can directly inhibit PPO (Vamos-Vigyazo 1981).

Ascorbic acid and its isomer erythorbic acid have been used for a long time as inhibitors of enzymatic browning

Table 12.3. Selected Sulfite Substitutes and Their Functionalities

No	Additive	Functionality
1.	Ascorbic acid	PPO inhibition, O_2 exclusion
2.	Sodium chloride (inorganic halide)	PPO inactivation
3.	Carrageenan (sulfated polysaccharide)	O_2 exclusion
4.	Xanthan gum	O_2 exclusion
5.	Protease enzymes	PPO inactivation
6.	4, *O*-Hexyl resorcinol	PPO inhibition, O_2 exclusion
7.	Kojic acid	PPO inhibition, reduction of *O*-quinones to *O*-diphenols
8.	EDTA	PPO inhibition by chelation
9.	Polyvinyl pyrollidone	Polyphenol binding
10.	Cyclodextrins	Complex formation with PPO
11.	Cysteine and *N*-acetyl cysteine	Complexing with PPO
12.	Sodium pyrophosphate	PPO inhibition by chelation

(Sapers and Miller 1995). This compound is added to syrups or applied by dipping the fruit in solutions containing the browning inhibitor. Penetration can be enhanced by vacuum infusion (Guadagri 1949).

Most of the ascorbic acid formulations contain ascorbic acid or its sodium salts; an acidulant such as citric acid, a calcium salt, a phosphate salt, sodium chloride, and cysteine; and preservatives such as benzoates or sorbates. A list of potential sulfite substitutes is given in Table 12.3.

FOOD COLORS AND FLAVORS

Colors occupy an important place among the food additives and play an important role in the sensory perception of the products. The functions to be considered for understanding human reactions to foods can be listed as follows:

- Perception—food selection
- Motivation—increase or decrease in appetite
- Emotion—attractive foods for pleasure
- Learning—prediction of food properties based on color and
- Thinking—understanding of unusual food properties based on color.

Both artificial and natural colors are used extensively for several food applications, including fruit products. Prior to deciding the type of color to be used for a specific food, the following considerations need to be made (Meggos 1994):

- Target shade
- Physicochemical attributes of food
- Marketing requirements
- Target countries
- Food processes involved
- Packaging type
- Storage conditions.

The FDA defines any color additive as "dye, pigment or any other substance made by a process of synthesis or similar artiface, or extracted, isolated or otherwise derived with or without intermediate or final change of identity, from a vegetable, animal, mineral, or other source and that, when added or applied to a food, drug, or cosmetic or to the human body or any part thereof, is capable of (alone or through reaction with another substance) imparting color thereto." (FDA 1986)

As per the federal regulations, food colors are termed as certified and uncertified colors. The permanent list of dyes consists of the following and the specific dyes are provisionally listed as follows (von Elbe and Schwartz 1996).

Dyes	Status
Blue no. 1 (brilliant blue FCF)	Provisional
Blue no. 2 (indigo)	Provisional
Red no. 3 (erythrosine)	–
Red no. 40 (allura red AC)	Provisional
Yellow no. 5 (tartrazine)	Provisional
Yellow no. 6 (sunset yellow FCF)	Provisional
Green no. 3 (fast green FCF)	Provisional

The approved dyes and lakes are used depending on the nature of the food product. Dyes are water-soluble compounds. The dyes are used to color a variety of fruit products including beverages and jellies with the maximum GMP limit of 300 ppm. Lakes are extensions of FD & C and are water-soluble dyes on a substrate of alumina hydrate. Lakes are used in oily products or products with less moisture. Lakes are also used in products requiring a distinct separation of color.

Uncertified Colors

The permanent list of uncertified colors include a number of natural or natural-identical colorants, inclusive of pigments derived from different fruits, vegetables, spices, algae, flowers, food grains, and oil seeds such as corn, cotton seed, etc. Apart from the derivatives of sugar-like caramel, the list also includes compounds such as ferrous gluconate. The permanent list of uncertified colors consists of (von Elbe and

Schwartz 1996) (a) annatto extract, (b) canthaxanthin, (c) β-carotene, (d) β-apo-8-carotenal, (e) beet powder, (f) ferrous gluconate, (g) grape color extract, (h) grape skin extract, (i) saffron, (j) fruit and vegetable juices, (k) paprika, (l) oleoresin, (m) riboflavin, (n) carrot oil, (o) caramel, (p) turmeric, (q) turmeric oleoresin, (r) cochineal extract, (s) defatted and cooked cotton seed flour, (t) synthetic iron oxide, (u) dried algae, (v) aztec marigold extract, (w) corn endosperm oil, and (x) titanium dioxide.

Among the uncertified colors, three synthetic carotenoids appropriately termed as natural-identical compounds are permanently listed by FDA as food color additives that are exempt from certification. They are β-carotene, β-apo-8-carotenal (apocarotenal), and canthaxanthin (FDA 1986). Carotenoid crystals are sensitive to light and oxidation and require storage under vacuum or inert gas (Emodi 1978). Carotenoids can be converted into products with both water and fat dispersibilities. Carotenoids are generally used within a range of 1–25 ppm and are among the colorants with the highest tinctorial potency (Dziezak 1987). β-carotene, apocarotenal, and canthaxanthin were approved by FDA in 1956, 1963, and 1969, respectively. The maximum usage levels are guided by GMP and standards of identity.

A variety of natural plant extracts and fruit/vegetable juices chiefly constitute natural colors of biological origin among the uncertified colors. The stabilized forms of natural colorants are gaining increasing popularity and soon may dominate the food colorant industry as such.

The uncertified colors are covered under Title 21 section 401. However, wherever the standards of identity are promulgated, the added color needs to be authorized by such standards. The maximum use levels of some specific colorants are canthaxanthin at 66 mg/kg solid or pint of liquid; similarly, apocarotenal is slated at a maximum level of 33 mg/kg food. Titanium dioxide should not exceed 1% by weight of the food.

Flavors

Flavors are aroma-rendering additives in the form of extracts or concentrates. They are complex ingredients that play a key role in food acceptance. When flavors are perceived as the food is eaten, their sensation immediately evokes feelings about the degree of pleasure in the immediate moment and at the same time strongly influences the intentions about the consumption of that type of food at a later date.

The flavors are usually classified using a definitive scheme based on both origin as well as usage (Hall and Merwin 1981), as shown in Table 12.4.

Commercial Forms

Flavors are available in different commercial forms and their usage depends on the nature of the flavor as well as the type of product, as shown in Table 12.5.

Table 12.4. Some Important Natural Flavors

Types	Examples
Condiments	Mustard, catsup, and vinegar
Spices	Black pepper, ginger, celery, basil, and caraway
Fruit juice concentrates	Concentrated lemon, orange, cherry, and apple flavorings and juices
Processed flavors	Starter distillate and hydrolyzed vegetable protein
Oleoresins	Oleoresins of cinnamon, celery, ginger, and black pepper
Essential oils	Nutmeg, celery, and cinnamon
Aromatic chemicals	Vanillin, anethol, menthol, citral, and isobutyl methoxy pyrazine

Functionalities of Flavors

1. To render new taste to the product or to enhance the already existing flavor.
2. To substitute for flavor losses during processing.
3. To replace the components missing from the overall flavor of the product.
4. To mask the undesirable flavors.

As far as product applications are concerned, fruit flavors, both natural and synthetic, represent around 48% of the total sales value. Fruit beverages constitute the largest user of fruit flavors followed by desserts, jams, and jellies. Citrus flavors are the most popular flavors among the fruit flavors.

The FDA has been working closely with Flavor and Extract Manufacturers Association (FEMA) to obtain information on the identity and safety of flavors (Sethi and Sethi 2004). Some of the GRAS flavors are mentioned in Table 12.6.

SWEETENERS

Sweeteners are one of the earliest food additives subjected to extensive use. The preservative function was the major

Table 12.5. Forms of Commercial Flavor Products

1.	Solid form	Encapsulated flavors, crystals, spray-dried powders, dried extracts, plated powders, and freeze-dried powders.
	Advantage	Highly volatile compounds such as dimethyl sulfide and methyl mercaptan can be encapsulated to provide flavors in solid form
2.	Semisolid paste	Oleoresins and fruit concentrates
	Advantage	Easy dispersion and uniform flavoring
3.	Liquid flavors	Flavors in emulsified form with a compatible solvent base
	Advantage	Suitability for beverages and other liquid products

Table 12.6. Selected GRAS Flavoring Substances

FEMA No.	Substance Primary Name
3909	Cyclo hexanone
3912	9-Decenal
3923	3-Hexenal
3941	Maltol propionate
3958	Phenyl acetate
3961	2-Propyl pyragine

one put to practice for natural sweeteners such as sucrose. Ever since, extensive research has led to the development of several sweeteners of natural or synthetic origin (Fig. 12.5).

Characteristics of Sweeteners

1. Sweeteners are of nutritive as well as of nonnutritive nature. In other words, they are either metabolized for obtaining energy or not metabolized.
2. Sweeteners can be of natural or synthetic origin. Products arising out of modification of natural sweeteners are also considered as natural.
3. Low-calorie sweeteners are also known as dietetic sweeteners. The high-intensity sweeteners pave way for low-calorie inputs due to lesser quantity of sweetener used (Table 12.7).
4. Fruit products such as juice concentrates and dehydrated juice powders can also be used as natural sweeteners.
5. Sweeteners such as sugars have high degree of humectant function and are, therefore, used successfully as preservatives to regulate water activity in the food products, which ultimately leads to the protection against microbial spoilage.

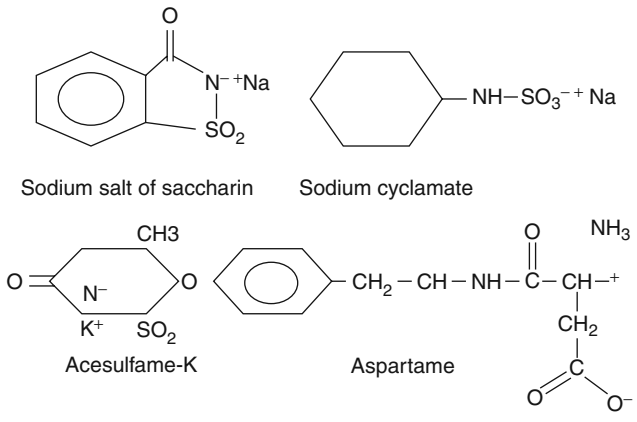

Figure 12.5. Chemical structures of widely used synthetic sweeteners.

Table 12.7. Features of Selected High-Intensity Sweeteners

Sweeteners	Relative Sweetness	Application	Regulatory Status
Acesulfame-K	200	Canned fruits, low-sugar jams and jellies, and dry beverage mixes	FDA approved
Aspartame	200	Tabletop sweeteners and dry beverage mixes	FDA approved
Cyclamates	30	Fruit flavor enhancer, making of tartness in citrus products	Approval pending
Saccharin	200–700	Stewed fruits, canned fruits, jams, jellies, and diet drinks	FDA approved
Sucralose	600	Jams, jellies, and canned fruits	Approval pending
Stevioside	300	Less use in fruit products	Approval pending

6. Sweeteners are successfully used as effective tools in fruit product design, paving way for the development of a variety of beverages and concentrates.

Polyols

Polyols (sugar alcohols) are reduced carbohydrates and are used widely for food applications due to their special sensory and dietary functions, for example, sorbitol, xylitol, mannitol, and lactitol (Giese 1993). They are used in glazed/dried and texturized fruits. The FDA had accorded an "interim approval" for sorbitol, xylitol, mannitol, and lactitol within an overall range of 1.8–2.4 kcal/g. The additional functionalities of polyols include high viscosity, hygroscopicity, cool taste, sequestering ability, retardation of crystallization, and bulking ability. Polyols such as sorbitol are widely used in dietetic foods, as it can be metabolized without insulin and is noncariogenic. However, excessive intake of polyols has laxative effect.

Although honey, sugar, and other traditional sweeteners have been used for their taste, caloric value, and functional abilities in foods for hundreds of years, the discovery and use of most alternate sweeteners date back to the past century. Three alternate sweeteners (Fig. 12.5) are currently approved for use in the United States, i.e., acesulfame-K,

aspartame, and saccharin. Cyclamates were considered GRAS at one time but are now banned from use. Apart from steviocide, thaumatin is a natural alternate sweetener obtained from the fruit proteins of the West African plant *Thaumatococcus danielli*. Under the trade name "Talin," thaumatin has undergone numerous safety tests and results indicate that it is safe at the levels that it would be consumed (Higginbotham 1986). Talin has an unusual taste profile, with a lingering sweet taste 2000 times sweeter than that of sucrose. Use of this compound as a flavor enhancer is permitted in chewing gum in the United States, where it is in the FEMA's GRAS list. Thaumatin is likely to attract further attention in the area of natural alternate sweeteners. Stevia is a natural sweetener present in the leaves of *Stevia* sp. such as *Stevia rebaudiana*. Stevioside is a predominant glycoside, which is 300 times sweeter than cane sugar. Structurally, stevioside is a glycoside with a glucosyl and a sophorosyl residue attached to the aglycone or steriol, which has a cyclopentanone hydro phenanthrene skeleton. Stevioside is stable up to 120°C and significant decomposition starts at 140°C and beyond. Stevioside as such is a natural sweetener, which is believed to have immense market potential, attracting the attention of farming of the same besides the food additives industry.

HYDROCOLLOIDS: THICKENERS, STABILIZERS, AND GUMS

Thickeners, stabilizers, and gums are the basic texturizing additives used in fruit processing. These hydrocolloids are long-chain polymers that function as thickeners and stabilizers.

Functions of Hydrocolloids

1. Suspension of particulate matter in food products along with the regulation of crystallization.
2. Optimization of rheological properties of solid as well as liquid food products. The major parameters include flow and mouth-feel properties.
3. Stabilizers for oil and water emulsion systems.
4. Binding of dry and semi-dry products.
5. Optimized gelation to give both hard and soft gels.
6. Foam stabilization and flavor fixation.

The major sources of hydrocolloids are plant products, viz, gum exudates, seeds, and seaweeds. Products obtained by fermentation and chemically modified polysaccharides also contribute to the development of hydrocolloids for different food applications. A variety of terms are often used to describe hydrocolloids. The terms are based either on the origin of the product or on the function for which it is being used. Three of the most common terms employed are gums, stabilizers, and hydrocolloids. The term "gum" describes a wide variety of water-soluble thickening and gelling polysaccharides (Carr 1993).

"Stabilizer" is another term used in the food industry to describe products that prevent separation of multicomponent food systems during storage. Another term that addresses both the behavior and physical characteristics of food gums is "hydrocolloids." This term is a contraction of two terms "hydrophilic colloid" and describes the water-loving nature and colloidal characteristics of this class of compounds (Table 12.8).

Besides use of pectin in fruit bars for texturization and in jams for gelling, newer fruit products such as structured fruits involve novel applications of state-of-art gelling agents. Ample information is available on the mechanical properties of gelling agents such as alginates with or without other polysaccharides (Pelaez and Karel 1981). Nevertheless, for texturizing pulp or concentrated fruit juice, optimal gelling conditions such as pH of the pulp/juice concentrate is important. Calcium alginate gels have been found to be superior, causing continuity in gel formation (Wood 1975). Fruit pulps such as mango pulp have been texturized using hydrocolloids such as alginates (Mouquet et al. 1992).

The above-listed hydrocolloids are approved by FDA and are classified as either food additives or GRAS substances (CDR 121.172.580–CDR 121.172.874). Their safety has been promulgated by JECFA and European Economic Community.

Emulsifiers

Emulsions are necessary for obtaining homogeneity in liquid foods having a tendency toward phase separation during processing/storage. Emulsifiers have lipophilic as well as hydrophilic groups enabling the products to bring together the water and oil moieties without phase separation.

Besides phase separation, the other functions of food emulsifiers are to enhance stability of flavors, and fats and oils by limiting the onset of rancidity. Emulsions are also used for better crumb texture in baked products due to optimal starch complexing property (Thompson and Buddemeyer 1954). Usually, except lecithin, most emulsifiers are used in combinations. The important emulsifiers used widely are as follows:

- Mono- and diglycerides
- Acetylated monoglycerides
- Sucrose fatty acid esters
- Stearoyl-2-lactylates
- Propylene glycol esters
- Sorbitan esters
- Diacetyl tartaric acid esters of monoglycerides (DATEM)

The FDA permits lecithin, mono- and diglycerides, and DATEM as GRAS. The other emulsifiers are approved under the standards of identity at specific levels. In fruit products, emulsifiers find applications in flavor emulsions, beverages, pie fillings, fruit desserts, and salad dressings (Mahungu and Artz 2002).

Table 12.8. Classification of Hydrocolloids

No.	Type of Hydrocolloid	Functions	Sources	Food Applications
1.	Unmodified starch	Thickener Gelling, adhesive, and film former	Potato, cereals tapioca, and arrow root	Pie fillings Jams and jellies
2.	Modified starch	Bodying and gelling Improvement of viscosity and other rheological parameters, Thermal resistance against higher as well as lower temperatures, Modification in gelling, To improve solubility and gelling in cold water.	Products of chemical modification of natural polysaccharides	Pie fillings Canned fruits Fruit-based desserts
3.	Casein	Film former with cohesive and adhesive properties	Milk	Edible films for packaging of precut fruits and vegetables
4.	Guar gum	Stabilizer	Guar beans	Beverages Water-based frozen fruit desserts
5.	Gum arabic	Stabilizer Emulsifier	Exudate from genus *Acacia*	Beverages Emulsifier for citrus oils and flavors
6.	Carrageenan	Gelation	Irish moss	Frozen desserts Structured fruits
7.	Pectin	Gelation Texturization as binder Stabilizer	Fruit wastes	Jams and jellies Beverages Fruit bars Fruit snacks and desserts
8.	Xanthan gum	Stabilizer Gelation	Fermentation product from *Xanthomonas comprestris*	Beverages Puddings Dry mixes of beverages
9.	Carboxy methyl cellulose	Thickener Stabilizer	Modified cellulose	Dry drink mixes Fruit-flavored syrups

Enzymes

Enzymes are biological catalysts and proteinaceous in nature. The use of enzymes in food processing in general and in fruit industries in particular is an offshoot of advances in fermentation/biotechnology. Enzymes, which exist within the fruits, perform a number of functions, such as softening, flavor development, ethylene biosynthesis, etc. Vegetables and fruits are also rich in oxidases, a class of enzymes, such as PPO and peroxidase, which cause browning reaction and off-flavor development, which is detrimental to the fruit quality (Whitaker 1996).

In case of fruit processing, enzymes are used mainly as processing aids aimed at specific functions, such as

- Improvement in juice extraction yields
- Increment in solids recovery
- Improvement in filtration
- Removal of nonnutritional factors
- Flavor enhancement
- Viscosity modifications
- Anticlouding operations
- Antifouling operations for membrane concentrations.

Enzymes of commercial importance used in fruit processing are (a) pectinases, (b) cellulases, (c) amylases, and (d) glucose oxidase. Pectic enzymes, i.e., pectin methylesterase and polygalacturonase are used often in combination with amylases and cellulases in fruit and vegetable juice clarifications to obtain higher juice yields and clarity. The turbidity/cloudiness of fresh fruit juices can be decreased with pectinase treatment due to the removal of negatively charged pectin deposits on particulate matter, which ultimately results in the coagulation of turbidity-causing materials (Yamasaki et al. 1967). Enzymatic treatment of soft fruit pulp facilitates pressing and improves juices and anthocyanin pigment yields (Neubeck 1975). Pectin-degrading enzymes are also used to degrade highly esterified apple pectin and increase juice yields (Devos and Pilnik 1973). Amylases are often used along with pectinases to clarify juices such as banana to

obtain optimal juice yields. Similarly, application of cellulases also facilitates higher recovery of juices due to the degradation of cellulosic matrix. Cellulases are also used for waste treatments from fruit processing units for the development of value-added products. Glucose oxidase in combination with catalase is used to protect citrus juices from off-flavor development (Scott 1975) and in the prevention of enzymatic browning in frozen fruits (Somogyi 1996).

Enzymes are considered as direct food additive as per FDA. The source organisms play an important role in the affirmation of GRAS status. Pectinases as well as glucose oxidase derived from *Aspergillus niger* are considered as GRAS. The same holds good for β-amylase and cellulase derived from *A. niger*.

Nutritional Additives

Nutritional additives have attained enhanced importance over the years due to the advances in product development with extended nutritional and nutraceutical values. The domains of nutritional and nutraceutical additives often overlap each other as many of the nutritional additives possess nutraceutical importance. Traditionally, nutritional additives are in the form of vitamins, minerals, amino acids, and fatty acids. Consumption of conventional traditional foods used to take care of nutritional requirements subject to different culinary items consumed at different time intervals in a daily diet routine. Problems have cropped up as some of these items got substituted due to consumption of new type of products in the dietary balance and inadvertently underwent imbalances, giving rise to a variety of deficiency syndromes. Food fortification had its origin in the form of addition of iodine to table salt to prevent goiter. Sodium iodide was recognized as an effective means of iodization of salt. Similarly, vitamin D was supplemented in margarine, milk, and milk products. Later, a number of fortifications included vitamin B components, vitamin A, and vitamin C; trace minerals gained popularity due to the nutritional labeling.

Vitamins

Fruits are rich sources of both water-soluble as well as fat-soluble vitamins. Vitamin A precursors in the form of carotenoids are available in significant proportions in several fruits. Fruits are also rich sources of vitamin C. Certain fruits like seabuckthorn are known to be a good source of vitamin E.

The processing loss of water-soluble vitamins is significant and supplementation is required to maintain the nutritional balance. Thermally processed fruit extracts need such supplementations due to heavier loss of vitamins during heat processing as well as subsequent storage of the product (Kanner et al. 1982).

Vitamin C is widely used as ascorbic acid in dextro- or levo-rotatory forms as a natural antioxidant. Vitamin E (tocopherols) is also known as a potential antioxidant. Ascorbic acid on oxidation can inhibit PPO activity by restricting the availability of molecular oxygen required for the reaction. Fruit processing unit operations such as blanching, thermal processing, and freezing considerably reduce vitamin C content. The storage losses add to the processing losses, demanding necessary supplementation (Kacem et al. 1987). The other functionalities include use of riboflavin-5-phosphate as a colorant.

The FDA considers vitamins as GRAS and nutritional supplements. Pantothenate is allowed as a food additive and requires label-mediated expression with regards to the concentration used. Some of the commercial forms are marketed as follows:

- Vitamin A as vitamin A acetate
- Thiamine as thiamine hydrochloride
- Pantothenic acid as calcium pantothenate
- Pyridoxin as pyridoxine hydrochloride
- Ascorbic acid as ascorbic acid, calcium ascorbate, and sodium ascorbate
- Vitamin E as tocopherol acetate, DL-α-tocopherol

Vitamin A supplementation gained worldwide publicity as many of the developing and underdeveloped countries found deficiency of vitamin A to be one of the main factors in the malnutrition of infants causing blindness or partially impaired vision. Vitamin A is usually marketed in the form of retinol acetate or palmitate and both of them are permitted for use in food. β-Carotene, which is the precursor for vitamin A, could be expressed in terms of equivalent values. The commonly used unit for vitamin A is the international unit (1 IU = 0.33 μg of retinol or 1 retinol equivalent). The recommended daily allowance for vitamin A is 5000 IU. In case of β-carotenes, 1 μg of β-carotene is equivalent to 0.167 μg of retinol, 0.167 retinol equivalent, or 1.67 IU, and the RDA is the same as in the case of vitamin A. Milk and milk products had been the traditional media for the fortification of vitamin A. The other vitamins for fortification include vitamin D, E, and K besides vitamin C. Some of the salient features of different vitamins in terms of nutritional supplementation include the implications of toxicity upon excessive consumption (Table 12.9).

Minerals

Mineral supplementation had been given due consideration in fortification of several products inclusive of cereal products. The most common minerals for fortification are Ca, Mg, and P, and minerals such as Cu, Fl, I, Fe, Mn, and Zn are usually provided as trace minerals (Table 12.10). The form of the mineral usually pertains to various salts, and the ideal salts are selected with beneficial effects in terms of bioavailability, solubility, and conformity with the food product as such. Calcium fortification has considerable significance in infant nutrition and also lactating mothers. The adverse effects of

Table 12.9. RDA and Toxicity of Vitamins

Vitamin	Commercial Forms	Units	Solubility	RDA	Toxicity	Symptoms
Vit A	Retinol acetate Retinol palmitate	IU (1 IU = 0.33 μg retinol)	Fat soluble	5000 IU	>25,000 IU	Headache, nausea, sleeplessness, tenderness of bones
Vit D	Ergocalciferol (Vit D_2) Cholecalciferol (Vit D_3)	IU 1 IU = 1 mg DL α-tocoferol acetate	Fat soluble	13 IU	>400–1000 IU	Calcification of soft tissues such as heart, lung, kidneys
Vit K	Menadione sodium bisulfite, menadione dimethyl pyrinidole bisulfite, phylloquinone (vit K_1)	mg or μg	Fat soluble	0.5–1 μg/kg body weight	Relatively nontoxic	–
Vit C	L-ascorbic acid, sodium ascorbate, nicotinamide ascorbic acid complex	mg	Water soluble	60 mg	Relatively nontoxic	–
Vit B components Thiamine	Thiamine hydrochloride, Thiamine nitrate	mg	Water soluble	1.5 mg	Relatively nontoxic	–
Riboflavin	Riboflavin, riboflavin phosphate, riboflavin butyrate	mg	Water soluble	1.7 mg	Relatively nontoxic	–
Niacin	Nicotinic acid, niacin, nicotinamide	mg	Water soluble	20 mg	Relatively nontoxic	–
B_6	Pyridoxin hydrochloride	mg	Water soluble	2 mg	Relatively nontoxic	–
Pantothenic acid	Calcium pantothenate, pantothenol	mg		10 mg	Relatively nontoxic	–
Folic acid	Folic acid	μg	Water soluble	400 μg	Low toxicity above 400 μg/day	–
B_{12}	Folic acid	μg	Water soluble	6 μg	Relatively nontoxic	–
Biotin	D-biotin	μg or mg	Water soluble	0.3 mg	Relatively nontoxic	–

Table 12.10. Minerals and Their Physiological Role

Mineral	RDA	Major Commercial Sources	Physiological Role
K, Na, and Cl	1.1–3.3 g Na, 1.875–5.625 g K, 1.7–5.1 g Cl	Potassium chloride, potassium carbonate, sodium chloride, sodium carbonate, potassium citrate	Sodium–potassium balance is an important feature of body electrolyte balance. Chlorides are potential cofactors.
Fe	18 mg	Ferrous sulfate, ferrous lactate, ferrous gluconate	Iron constitutes an important entity as an electron carrier in oxidative phosphorylation besides being cofactor for several enzymes. Iron also helps in assimilation of ascorbic acid and certain amino acids.
Zn	15 mg	Zinc chloride, zinc oxide, zinc gluconate	Cofactor in enzymatic functions
Cu	2 mg	Copper gluconate, copper sulfate	Cofactor for many enzymes and also plays an important role in iron metabolism and heme biosynthesis
I	150 mg	Potassium iodide, cuprous iodide	Has an important role in the formation of thyroid hormone.
Mn	2.5–5.0 mg	Manganese chloride, manganese citrate, manganese gluconate	An important cofactor for enzymes

ageing result in development of osteoporosis and fragility of bones. Ranhotra et al. (1980) evaluated a number of calcium sources in terms of bioavailability. The various forms of calcium permitted include calcium carbonate, calcium chloride, calcium citrate, ground limestone, calcium hydroxide, calcium sulfate, etc. The U.S. RDA for calcium is 1000 mg. Along with calcium intake, it is recommended that the ratio of calcium to phosphorus be 1:1 in adults and 1:0.5 for infants. Phosphorus is amply present in different foods and therefore is being used as nutritional additive only in some infant formulae. The U.S. RDA for phosphorus is 1.0 g and the usual forms of application are sodium and potassium phosphates and pyrophosphates. Magnesium is also available in abundance in various foods and the U.S. RDA for magnesium is 400 mg. Seelig and Haddy (1980) reported that magnesium deficiency causes cardiovascular damage. The major sources of magnesium supplementation include salts such as magnesium carbonate, magnesium chloride, and magnesium hydroxide. Magnesium gluconate is considered by FDA as a GRAS nutritive additive.

The trace minerals are important to augment overall well being of humans and appropriate supplementation need to be carried out to avoid deficiencies. The regulations controlling nutritional additives suggest two routes, out of which pill forms constitute the first and food supplements constitute the second option. Mineral pills shall be considered as foods as long as specific claims are not made for disease resistance. Food standards illustrate the threshold values for such supplementation in foods. Some of the FDA standards for the minerals in the case of adult males could be calcium 1300 mg/day, phosphorus 1250 mg/day, magnesium 240 mg/day, potassium 4500 mg/day, sodium 1500 mg/day, chloride 2300 mg/day, iron 8 mg/day, zinc 11 mg/day, copper 900 μg/day, iodine 150 μg/day, and manganese 2.3 mg/day. The recent advances with regards to mineral nutrition are to enhance the bioavailability by using appropriate crystalline forms of salts. In the case of calcium, the carbonate salts are being structured as layers and new commercial forms with improved bioavailability are available.

NEW GENERATION NUTRA-ADDITIVES

Food supplements with health-promoting substances have gained popularity over the years. These supplements or nutra-additives could be dietary fiber (soluble and insoluble forms), natural antioxidants, antihypertensive, antihypercholestremic ingredients, omega-3-fatty acids, essential fatty acids, amino acids, etc. The discovery of several new molecules, which are present naturally in the foods and are of herbal origin, offer vast scope for the development of innovative nutri-additives and formulations, functional foods, and nutraceuticals. Several natural extracts such as aloe vera, Indian noni, and different herbal ingredients known for their therapeutic values could be used as fortifying principles in various foods. The changing consumer perceptions with regards to foods as a carrier of wellness principles are in fact revolutionizing product development in these areas. Consumers are aspiring for prevention of diseases by means of preventive measures rather than curative measures. Therefore, consumption of food is no more seen as a means of meeting the energy requirements of the body and to support basic metabolism involved in human physiology. Cardio vascular diseases, obesity, diabetes, hypertension, nervous disorders, osteoporosis, muscular dystrophy, slow down in hepatic activity, appetite, etc. are being targeted to be at optimal levels by means of appropriate food consumption. Therefore, a dietician job has become more complex to incorporate various nutra/nutraceutical additives from a host of processed and fresh foods.

Functional foods are basically targeted toward specific enhancement in body functions for various age groups of consumers and the type of activities they are involved with. Functional foods are ahead of health foods in having specific targets in the promotion of human activities. These functions could be physiological or psychosomatic in nature. Some of the major functional foods include performance-enhancing, mood-elevating, fatigue-diminishing, thirst-quenching foods, etc. The functionality of various biochemical components are being emphasized upon to seek possible use in functional foods at physiologically active concentrations and also the threshold values of dosages.

Essential amino acids such as leucine, isoleucine, and valine were described to be potential fortification agents as functional ingredients. A number of specific functions were attributed to various functional formulations, which are cocktails of vitamins, essential amino acids, energy-yielding, and thirst-quenching components. Fuch and Wallner (2003) described a functional beverage for increasing the body's capacity to break down the alcohol. There are several health food formulations for various purposes, such as Ca, Mg, fortified beverages (Sher et al. 2001), fitness drink powders (Prinkkilla and Pajunen 1989), carbohydrate- and carotenoids-rich drink (Takaichi et al. 1995), and antifatigue products (Guinot 1987, Jones and Dobler 2006).

Amino acids such as L-glutamine are being incorporated in several functional food formulations because of its ability to get converted into glucose upon metabolic demand crossing the brain–blood barrier effectively. Amino acids such as taurine are widely used in several energy supplementing beverages and food formulations. Mood-elevating foods in the modern days of stressful living and work conditions gained increased popularity. These foods may contain refreshing and exciting principles such as caffeine and the second type could be antidepressive or antianxiety based. Neurohormones such as serotonin are being given due consideration, and the regulation of the same is being recommended through intake of appropriate precursors at prescribed

dosage and the components include amino acids such as tyrosine.

The search for natural antioxidants, dietary fiber, anticholesterol, and antihypertensive agents is being continued. Stabilized black grape skin, green tea extracts, etc. are being recommended for daily intake. Kouri et al. (2007) described effective natural antioxidants from the plant *Origanum dictamnus* and reported their effectiveness in terms of free radical-scavenging ability. The advent of these products poses challenges for existing food laws and standards as these products make inroads in to the drug regime, warranting the governing councils to be cautious as several of the components, though of natural origin, require stringent regulation in terms of ADI and RDA values. Another issue is establishment of physiologically active concentrations, characterization of active principles, and necessary clinical and toxicological studies. Over emphasis on ancient texts and use of herbals as such without purification of active principles may pose public health hazards.

New class of prebiotics in the form of designer oligosaccharides are being developed (Barretean et al. 2006). Some of these oligosaccharides include arabinogalacto oligosaccharides, arabino zyloligosaccharides, galactouronone oligosaccharides, rhamnogalacturano oligosaccharides, and pectic oligosaccharides. Fresh yogurts are difficult to handle despite their probiotic functionality. Therefore, processed yogurts and seeding of these products with encapsulated probiotic cultures have gained popularity. The same strategy could be adopted for most of the fermented foods to offer longer shelf life and convenience besides effective probiotic functionality to the consumers of probiotic foods.

NOVEL FOOD ADDITIVES

Highly interesting additives such as bacteriophages as a biological control for pathogenic organisms such as *Campylobactor* species were reported (Carrillo et al. 2005). Similarly, *E. coli* could be controlled by application of oral doses of bacteriophage specific to *E. coli* (Raul et al. 2006). Bacteriophage therapy can also be applied for the eradication of *Listeria monocytogenes*. FDA recently amended the food additive regulation to permit safe use of a bacteriophage preparation as an anti-listerial agent in RTE meat and poultry products (Walker 2006).

The development of newer food additives is more focused on food additives of natural origin that qualify for the GRAS status. Martin Diana et al. (2008) described green tea extracts to extend the shelf life of fresh-cut lettuce. Antimicrobial agents of biological origin are being given higher attention, such as bacteriocins combined with residue-less chemical sanitizers such as ozone (Zhuang et al. 2007). As far as the synthetic antimicrobial agents are concerned, a new approach is being followed, which targets at residue-less product: the antimicrobial function is discharged by the end of the process and the antimicrobial agent dissociates toward the end of the process in to harmless byproducts without impeding the sensory attributes. Different types of additives inclusive of emulsifiers, bulking agents, stabilizers, etc. are being derived as organic additives from various natural sources. Granato et al. (2007) described sulfite-free organic additives for use in wine processing. Food processing itself is moving toward organic processing where all the additives and process aids shall be organic in nature. This can lead to a completely different domain of food additive industries.

SAFETY AND HEALTH IMPLICATIONS OF FOOD ADDITIVES

The FDA as well as Codex Alimentarius and other national and international bodies stress the need for ADI as a premier aspect to restrict cytotoxicity-induced health hazards. ADI limits are usually expressed in terms of chemical exposure of body on unit body weight basis and are based on authentic risk assessment (Winter and Franci 1997).

The concept of ADI renders more flexibility to maximum limits prescribed for various food categories with regards to standards of identity. Lowest observed effect level and no observed effect level (NOEL) form the bases of risk assessment in framing the ADI levels. ADI is the NOEL value divided by 100 when the NOEL is derived from animal studies or the NOEL value divided by 10 when the NOEL relates to human data (Renwick 1996).

The risks involved in overuse or underuse of additives can give rise to several types of risks: (a) microbial hazards, (b) nutritional hazards, (c) color additive hazards, (d) environmental hazards, and (e) immunological/physiological hazards. The typical symptoms of health-based hazards include hypersensitivity and associated allergic reactions. The allergic reactions may cause respiratory problems such as asthma. The cross-reactions of sulfites and steroid dependency in asthma patients have given rise to debates and amendments in regulations, which ultimately resulted in the ban of sulfites in ready-to-eat fruit- and vegetable-based products (Anon 1990).

Colorants, antimicrobial compounds, antioxidants, antibrowning agents, and sweeteners continue to receive regulatory restrictions. The advent of functional foods, dietary supplements, and transgenic products offer plethora of challenges to ensure safety to the consumers. Food sector is basically a buyers market, and it is important to keep the "psyche" of the consumer in a satisfaction mode. Mere toxicological certification may not necessarily satisfy the consumer. Therefore, the regulatory authorities are striking a fine balance between consumer safety and the manufacturer's product requirements for optimal quality and commercial feasibility (Branen and Haggerty 2002).

FUTURE TRENDS

The future trends in research and development as well as in commercial application involving direct food additives may be outlined as follows:

1. Increased stress on natural preservatives, sweeteners, colorants, and antioxidants.
2. Minimal or no use of chemical additives with emphasis on physical conditioning of the products.
3. Advanced research on gene products for transgenics and comprehensive studies on the health implications thereof.
4. Restriction in additive use by adopting hurdle-based processing.
5. Labeling strategies to counter growing toxicological concerns.
6. Consumer awareness and technical strategies to prevent misuse of food additives.

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Part 3
Processed Fruit Products and Packaging

13
Manufacturing Fruit Beverages and Concentrates

Emőke Horváth-Kerkai and Mónika Stéger-Máté

Abstract: This chapter is a review of the processing technologies of different fruit drinks. First, the main fruit drink categories, juices, nectars, and soft drinks and the most important quality requirements of raw materials are discussed. The preparation steps of the filtered and cloudy fruit drink technologies are described. The different technologies of the juice concentration, for example, evaporation, concentration by freezing, and reverse osmosis are also discussed. Afterward the main steps of fruit juices with fibers are studied. Finally, the production of liquid fruit products and fruit beverages is summarized.

INTRODUCTION

Fruits have always played an important role in human nutrition. However, before the 20th century, drinking squeezed fruit juices was the privilege of only a few.

Welch was the first to preserve grape juice with heat treatment in America in 1869, followed by Müller-Thurgan in Switzerland in 1896 (Kardos 1962). Thus began the production of preserved fruit juices, which was followed by many developments in this category in the 20th century. The role of vitamins and minerals in the human body was discovered at that time, which triggered substantial changes in eating habits. Consequently, fruit consumption has become an everyday need.

Because of the innovations and developments in process technology (especially the aseptic technique that enabled the production of fruit juices without preservatives), equipment design, and product formulation (use of enzymes, clarifying

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

and flavoring agents, etc.), production and consumption of various types of juice is now widespread.

MAIN FRUIT DRINK CATEGORIES

There are countless fruit juice products in the markets. They may differ substantially in terms of raw material, composition, quality, nutrient content, sensory quality, and packaging. In some cases, the major difference is the brand name.

Generally, fruit juice-based drinks are classified according to their fruit content. Thus, we can declare three categories:

- Juices and fruit musts,
- Fruit nectars, and
- Soft drinks with fruit content.

Juices and fruit musts are obtained by mechanical procedures. They possess the color, taste, and aroma of the original fruit and their composition is identical as well. In the case of certain products, sugar addition and vitamin enrichment are allowed, but these have to be declared on the labeling. Juices and fruit musts are not allowed to contain additives (preservatives, aromas, and coloring agents). Therefore, it is consumed in fresh form soon after production or it is preserved by heat treatment. The permitted ingredients of different fruit beverages are shown in Table 13.1.

According to the type of fruit, these products can be divided into two subcategories. They can be filtered to be transparent (e.g., grape, apple juice) or they can be cloudy juices containing colloids like all citrus-based juices. Products belonging to this latter group may contain fruit fibers.

Fruit nectars are made of sieved juices or from fruit juices that are diluted with sugar syrup. They usually contain only one fruit such as orange, apple, or peach, but they can also be made from blends of more than one fruit juice or pulp (Szenes 1991). Therefore, fruit drinks can be produced directly from the raw material or indirectly from preserved, semifinished products. In case of indirect production of fruit drinks, raw materials have to be preserved after processing. Filtered-clarified juices are usually concentrated, sieved puree, and low concentration concentrates are preserved by aseptic technology.

Table 13.1. Permitted Ingredients of Different Fruit Beverages in Europe

Components	Juice or Fruit Must	Nectar	Soft Drinks
Fruit, min. (%)	100	25–50[a]	Free
Sugar, max. (%)	1.5	20	Free
Acid, max. (g/L)	3[b]	3[b]	Free
Preservatives (mg/L)	–	–	++
Food additives	–	–	++

Note: ++ indicates according to the legislation of additives.
[a]Depending on fruits.
[b]With natural lemon juice.

Fruit juice properties, such as raw materials, other ingredients, permitted technological procedures, product denomination, and minimum fruit content, in case of fruit nectars, are regulated by national and corporate standards. In order to conform to the requirements of international trade, these standards are harmonized with the recommendations of Codex Alimentarius, which is supervised by FAO/WHO Food Standard Program (Várkonyi 2000). For European Union member states, the basic principles of this regulation are declared by "Council Directive 2001/112/EC relating to fruit juices and certain similar products intended for human consumption," issued by the European Council in 2001.

FRUIT DRINKS' RAW MATERIALS

The most important raw materials of fruit drinks available in international trade are citrus, pomaceous fruits, stone fruits, grape, and berries. However, all cultivated and wild grown fruits are used for drink production. Some of the raw materials used are suitable for juice production, for example, apples and oranges that are used extensively for juice production. However, juice of other fruits, e.g., sea blackthorn, currants, etc., is delicious only if blended with other juices or sugar syrup.

The quality of fruit drinks, made without additives, is determined by the quality of raw materials. Generally, acidic, juicy fruits with high-sugar content and distinctive aromas are suitable for drink production. The ripeness of raw materials is of critical importance because optimally ripe fruits possess the ideal sugar/acid ratio and the desirable flavor and aroma components. Prior to the optimal ripeness, the fruit contains much less aromas and sugar. On the other hand, overripe fruits may have reduced acidity (e.g., vitamin C), coloring agents, and consumption value (Stéger-Máté et al. 2002).

Because of the developments in fruit drink consumption, raw material production and juice consumption were separated both geographically and in time. Fruit pulps and concentrates that are easier to store and transport came to the front of production. Fruit drinks, made of these preserved semifinished products, can only be competitive if their composition and sensory traits are close to those made of fresh fruits. According to different surveys, 70% of fruit drink quality complaints are rooted in the raw materials. These facts made experts, involved in production, quality control, and sales, to set up uniform quality requirements for the clarity and origin of fruit drinks. Recommendations of this RSK (Richtwerte und Schwankungsbreiten bestimmter Kennzahlen) system worked out in Germany for compositional features are generally accepted in the European commercial practice (Bielig et al. 1987). However, fruit variety, origin, climate,

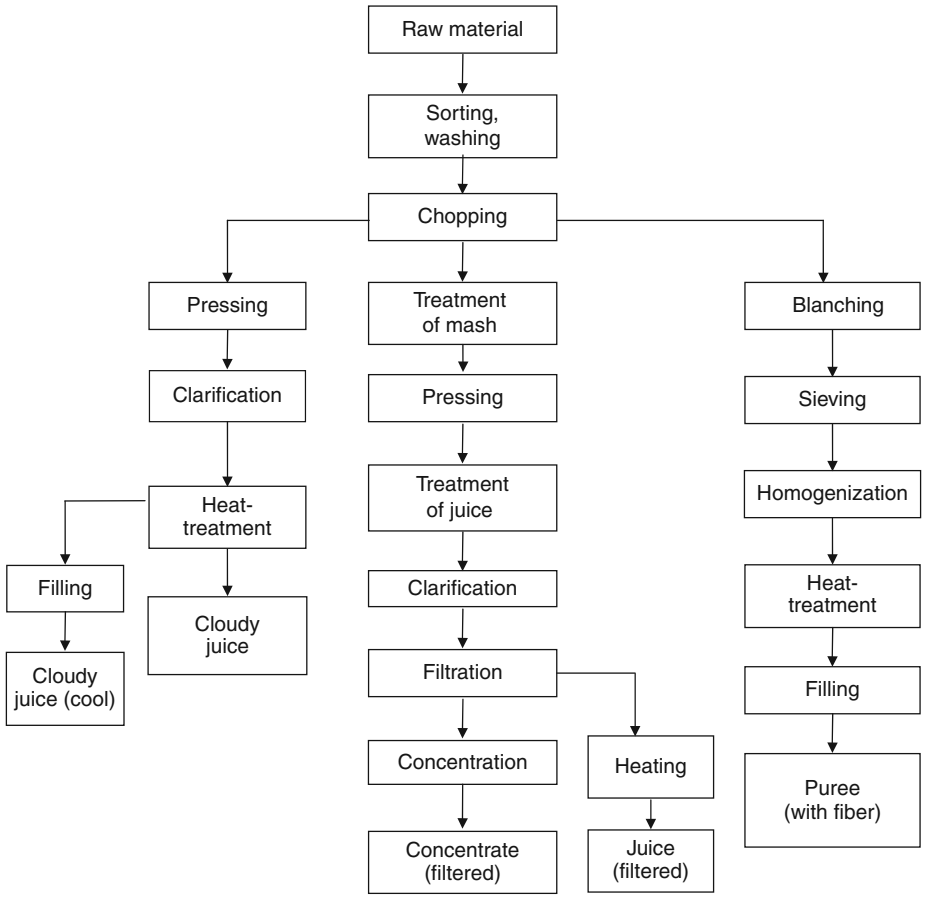

Figure 13.1. Process flow diagram of fruit beverages.

production, and processing technology can often change the composition, resulting in quality problems. The further development of this system led to the publication of the European Economic Commission's Association for Juice and Nectar Production (AIJN), called "Code of Practice." In this publication, RSK values are supplemented with other analytical features that are generally accepted of apple, grapefruit, orange, and grape juices. Besides consumption value, quality, genuineness, raw material, and technological deficiencies, these criteria comprise factors concerning the environmental pollution of the land close to the production unit with arsenic and heavy metals. Technological deficiencies usually result in high concentration of biogenic acids, hydroxymethylfurfural (HMF), ethylalcohol, and patulin; thus, their maximum levels are under regulation (Wiesenberger 1997). Complying with these stringent fruit juice quality criteria is the responsibility of fruit processors, raw material suppliers, and producers. The values determined by the RSK system and the AIJN Code of Practice are primarily used in Europe but significant deviations may endanger the competitiveness of products in the world market.

PRODUCTION OF FILTERED AND CLOUDY FRUIT JUICE

Filtered and cloudy fruit drinks are made of mechanically pressed and cleaned juice directly or from the dilution of concentrated semifinished products. As it can be seen in the flow chart, production technology comprises five main operations (Fig. 13.1).

Juice extraction—the elimination of the juice from fibrous, solid particles—is a basic technological step of fruit juice production. The fruit has to be prepared prior to juice extraction, which is then followed by juice clarification and drink completion. Subsequently, the finished drink is packed and preserved.

Preparation Steps

Raw Material Reception

Only those raw materials are allowed for fruit drink production that meet the following criteria: appropriate ripeness

and flavor, no signs of deterioration, and free from foreign ingredients, pathogenic organisms, and their effect. Moreover, raw materials have to conform to the regulations and standards in force. Because of the change in quality criteria and permitted ingredients of fruit juices, general raw material properties are completed by an increasing number of special requirements. Processing companies expect, for example, that apple intended for juice production possesses the following paramteres: sugar–acid ratio in the 12:1–14:1 range, sugar content above 12 or 13 Brix°, and acid level above 7g/L. Products with proper sensory traits can only be produced from such high-quality raw materials. During reception, attention is paid to the cleanliness of berries in which washing may cause substantial damages (Szenes 1991).

The conformity of each batch should correspond to the methods and examinations of the relevant descriptions. Then, it has to be labeled for further identification and traceability. In addition, conformity to the production technology requirements also has to be checked (crop spraying records).

Washing

The aim of this step is to remove every contamination from the surface of the fruit, i.e., to increase physical, chemical, and microbiological cleanliness.

The surface of raw materials is strongly contaminated by microorganisms; it can attain 10^5–10^9 microorganisms per gram. Even with effective washing, it can be decreased only by 3–5 orders of magnitude. Therefore, washing efficiency has a significant impact on the heat treatment necessary for preservation.

Physical and chemical surface contaminations are eliminated by water soaking, since these substances are water soluble or their adhesion properties decrease in aqueous solution. The efficacy of the dissolving process can be increased with higher water flow. The latter can be achieved by streaming, air injection, and by mechanical means. Because of the water flow, close contacts between fruit particles increase washing efficiency but potentially leading to damages to the fruits. Thus, the texture of the raw material is taken into consideration when choosing washing equipment. Vulnerable juice raw materials or berries are preferably not washed but rinsed with dipping or spraying methods. Fruits, with lower density than water, usually arrive at the processing plant via a floating channel, where surface contamination dissolves in the soaking water. Nozzles, which are positioned at the end of the transportation system, spray clean water onto the fruits and eliminate contaminated water, contamination residues, and other impurities. If destemmer needs to be used, it performs a spray wash of the relatively clean fruits. Other juice raw materials undergo three washing steps. The first phase is soaking, which breaks up surface contamination and eliminates soil particles. In the case of fruits covered with wax layer or oleaginous skin, warm water (50–60°C) is applied. Warm water soaking or a long soaking period may result in substantial loss of valuable fruit components (Barta and Körmendy 2007).

The active phase of washing is intended to remove contamination and is followed by a clean water rinse. Washing means water flows all around the fruit, meanwhile rinsing means water spraying in order to remove washing water residues from the fruit's surface.

Stem Removal

To prepare fruits for juice extraction, in the case of certain fruit species (e.g., cherry, sour cherry, plum, etc.), long green peduncle parts are removed. Otherwise, they will spoil the color and other quality traits of the juice. Mechanized stem elimination can only be carried out in raw materials of homogenous size that do not tend to damage and burst. The most frequently used equipment is the belt-based solution, but in Eastern Europe roller-based machines are still widely used.

Selection

This step, which usually follows washing, separates everything from the raw material that is unsuitable for processing. These can be foreign substances, stem and leaf particles, or moldy, deteriorated fruits. This activity is performed manually and requires close attention. Therefore, the necessary job environments (e.g., proper lighting and reasonably positioned waste containers) must be provided for the workers. The selection table on which this operation is done should be able to roll the fruits, enabling the workers to observe the entire fruit surface. Both the roller-based and belt-based machines comply with this requirement. In order to achieve better efficacy, proper adjustments must be made for single layer fruit flow and optimal belt speed (Parker 2003).

Juice Extraction

Juice extraction from prepared fruits includes more technological steps. It comprises crushing, juice separation from solid fruit flesh particles or juice extraction, juice treatment, and preparation for filling. Crushing prior to pressing can be further divided to chopping and preparation for pressing.

Chopping

The aim of this step is to smash, cut the fruit, increase its surface, and launch cell-fluid elimination. Raw materials with more solid texture (e.g., apples) are chopped by crushing; meanwhile, soft fruits (e.g., red currants) are only cracked. The extent of chopping is determined by the type of the subsequent juice extraction procedure. Pressing preparation should result in crushed fruits that release the juice to relatively low pressure applied. Properly prepared crushed fruits

are not pulpy. It should be the mass of uneven shaped particles of appropriate homogenous size, "roof"-shaped slices and tissue particles that form channels to drain the juice. In case the particle size is too small or it is pulpy, it tends to spread and its structure becomes massive when pressed, so the juice cannot pass through. If diffusion-based juice extraction is performed, fruits have to be chopped in a way that the thickness of slices or strips is the smallest achievable. However the size of these particles should enable the formation of masses where the flow of extraction liquid is ensured.

There are several devices for crushing the fruits. They can be designed for one specific fruit such as different apple mills. However, there are machines that can be generally applied like hammer and barrel crushers. Their common features are the rotation system and the pressing, tearing, pulling, and striking forces applied.

Cracking, crushing, and smashing the tissue structure of fruits can lead to the damage of valuable compounds or initiate enzymatic processes, which result in the formation of nondesired substances. Therefore, crushed fruits have to be processed immediately (Horváth 2007).

Chopped Fruit Preparation

Procedures designed to prepare chopped fruits are to increase juice yield and prevent undesirable changes (chemical, biological, mechanical, etc.) to achieve better aroma, flavor, and color properties. The type of preparation will depend largely on the type of fruit and production technology.

There are several methods for this operation, such as heat treatment, enzymatic, freezing, vibration, ultrasonic, electroplasmolytic, and ion-radiation procedures (Szenes 1991). Heat treatment and enzymatic procedures can lead to 5–10% increase in juice yield.

Heat treatment is mainly performed on berry fruits, such as raspberry and elder berry, prior to pressing. This step means heating the crushed fruit rapidly up to 80–85°C, then cooling it back very quickly. Under this short heat impact, different physical, chemical, and microbiological processes take place. Because of the denaturation of proteins and the hydrolysis of protopectin, enzymes are inactivated, cell walls become permeable, and the diffusion of water-soluble substances accelerates. If heat treatment gets too long, due to improper technology, the tissue becomes soft, it falls apart, the fruit will be difficult to press, and the taste of the juice changes. In case of berries rich in color, this step aims to improve color, besides yield increase.

There are different heat exchangers that can be applied to perform heat treatment depending on the production line.

Enzymatic treatments are also frequently used before pressing, to make the process easier and to increase the yield. Fruit raw materials possess different amounts and types of pectin, depending on the species and the variety. Pectins are complex polysaccharides; chemically they can be described as a polygalacturonic acid chain esterified with methanol. Pectins play a pivotal role in plants' structure and their stability. Pectin can be found between the cell wall layers connecting the solid shells that contain cellulose and hemicellulose. These pectin types are beneficial for pressing, because they ensure the solidity of shaped particles and increase the formation of juice channels. Other pectins are dissolved in tissue fluids, increasing fluid density and sticking properties. These latter pectins hinder juice extraction and increase the risk of plugging in the pressing device. Therefore, the level and the composition of pectin have to be decreased or modified according to the quality criteria of the finished product or the production technology. The change of pectin level is generally achieved by enzyme addition to the crushed fruit.

Enzymes are macromolecular biocatalysts with high activity. These are substances of protein origin that are essential parts of the living world, regulating the building and degradation processes of plant and animal organisms. Their typical features come from their protein origin. One of the most significant traits is their substrate specificity, which means that one enzyme can catalyze only one specific reaction. Another important property is their pH and temperature dependence. Each enzyme has an optimal pH and temperature range, where their catalyzing effect and activity is maximized. Deviations from these optimal values in both directions result in a radical decrease of their activity.

All living organisms synthesize enzymes that regulate biochemical procedures within their body. Therefore, enzymes can be extracted from animal and plant tissues, and microorganisms. However, the most economic way to produce enzymes is fermentation with rapidly multiplying microorganisms under controlled industrial environments. Because of their substrate specificity, enzymes produced by different bacteria, yeast, and mold extracts mainly catalyze the reaction of one specific substrate, for example, pectin. Complex enzyme mixtures are produced by the combination of enzymes coming from different sources. Most commercially available pectinase products consist of at least 20 enzymes with different activity. "Enzyme cocktails" that can successfully treat fruits of different species, varieties, composition, ripeness, and properties are made by this method. Enzyme mixtures are specifically designed for a certain raw material and its processing steps.

Molecular genetics opened new perspectives in the development of enzyme production. Increased efficiency and development of new properties can be attained by better selection of microbial strains. However, the combination of different microorganism species by protoplast fusion or inserting DNA sections into the genome of another cell may lead to significant changes in the features of the enzymes produced by such modified microbes. In case of enzymes applied in fruit juice processing, the most important results of these techniques are efficiency, pH and temperature tolerance, and increased stability (Biacs 2007).

The three most significant pectin-degrading enzymes are pectin lyase or pectin transeliminase, polygalacturonase, and

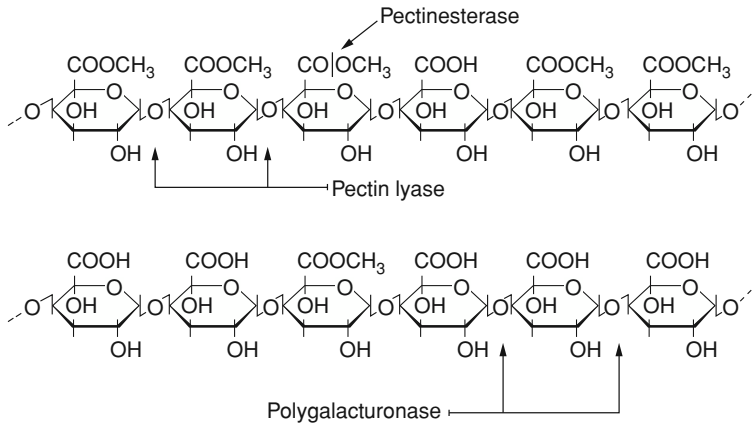

Figure 13.2. Activity points of pectin-degrading enzymes.

pectinesterase. They are effective on different parts of the pectin molecule and are depolymerizing or ester-degrading enzymes (Fig. 13.2).

Pectin lyase and polygalacturonase break down the chains. Polygalacturonase, which belongs to the group of hydrolase enzymes, attacks the pectin molecule where a galacturonic acid is located. Enzymes can break down the chain inside the molecule (endo-polygalacturonases) and can form oligopectins of different size besides water absorption. The nonreducing end of the chain can also be attacked (endo-polygalacturonases), splitting galacturonic acid monomers from the pectin molecule one by one.

Pectin lyase or pectin transeliminase breaks up the chain beside the galacturonic acid that is esterised with a methyl group. The highest efficiency can be achieved in fruits, where the metoxyl value of the pectin chain is high.

Ester-degrading pectinesterase enzymes break down methylester groups found on polygalacturonic acid chains. Besides water absorption, they release methanol molecules (Pilnik et al. 1981). The increase of methanol level may cause problems in fruits that contain highly methylestered pectin (e.g., apples and citrus).

In concentrate production, it can increase the methanol content of the condensed aromas. In case of cloudy juice production, polygalacturonic chain, stripped of its methyl group, reacts with the potassium ions found in the fruit and forms precipitation. This reduces the natural cloudiness of the juice.

The activity of enzymes that depolymerize the pectin molecule and rapidly decrease the viscosity of the mash has a beneficial impact on juice yield. Therefore, it is important to be aware of the pectins' properties found in the fruit to be processed. The optimal enzymes can be selected based upon this information to maximize yield and juice quality.

As written above, the increase of juice yield in fruits containing low level of estered pectins can be achieved by enzyme mixtures rich in endo-polygalacturonase, which break down pectins at the galacturonic acids containing carboxyl group. Meanwhile for the degradation of pectins with high degree of esterification, pectin transeliminase is the most efficient choice, since it breaks down glycoside bonds that are located next to methyl radicals (Reising 1990).

Besides depolymerizing enzymes, mixtures always contain pectin esterases. Cellulases and hemicellulases are also included to break down the cell wall and improve juice elimination.

Enzyme treatment can be carried out under cold and warm circumstances. Cold treatment at 20–25°C takes more hours, which endangers the juice quality (Schmitt 1990). Meanwhile, warm treatment takes place in 0.5–1 hour, at 50–55°C. As enzymes are protein-based molecules, these are heat sensitive and are only active at certain pH values. If the temperature and pH conditions of the mash are not optimal, successful pectin decomposition requires longer time or higher enzyme concentration (Dietrich 1998). The pressing waste of high-pectin fruits (e.g., citrus, apple) is usually used for pectin production. In these cases, enzyme treatment should not be applied.

Enzyme pretreatment is not applied in the production of cloudy concentrates, because their main ingredients are dissolved colloid substances in the liquid phase.

Juice Extraction

In this process, the liquid phase of fruits is expressed from solid particles. There are different methods for this separation: pressing, diffusion, centrifugal procedures, and reverse-osmosis. The type of equipment applied depends on the fruit species, production line, and economy of scale. The most widely used solution is pressing.

Pressing separates a food system into two phases. In this case, fruit tissues are the solid phase, while the liquid between the particles is the liquid phase.

Pressing needs outside forces to create pressure in the system, drain liquid, resulting in shape modification. The equipment hinders the disposal of the solid phase and the liquid gathers in a vessel. The remaining material, with low liquid content, is called marc. The most important parameter of pressing is the liquid yield, which means the percentage of juice extracted, compared to the raw material at the beginning of the process. Juices extracted by pressing are mainly Newtonian fluids. The greater part of dry matter content is present in the form of real solution. Meanwhile large molecule size substances, for example, pectins and starch, form colloid solutions. Juice yield is basically determined by the type of the pressing device, and the quality and preparation of the raw material (Lengyel 1995). Fruit processing industry applies continuous extraction systems such as belt- and screw-based, and intermittent systems, such as the package and basket type pressing machines. In addition, decanters are based on centrifugal forces (Nagel 1992).

There are different techniques for the preliminary extraction of liquids that are easily released. The common feature of these methods is that some part of the juice is drained from the mash by gravity. It can be performed in buffer tank with perforated bottom, in screw conveyor with perforated coating, or in continuous belt press. This latter can be applied as preliminary pressing equipment in case of using basket-type pressing devices. These solutions relieve the pressing machine, thus increasing its capacity (Körmendy and Vukov 2007).

The juice of fruits can also be detached with extraction. It means that semipermeable cell walls are made permeable following a heat treatment, and the cell fluid is then dissolved with water.

This process is featured by the degree of extraction, expressing the amount of extracted valuable substances, compared to the total valuable matter content of the fruit.

The amount of substances diffused is in direct proportion with the diffusion coefficient, the active surface, and the concentration gradient.

In order to increase the diffusion coefficient and the permeability of the cell walls, diffusion fluid extraction is performed at 50–70°C. Active surface can be increased by proper chopping. The concentration gradient is determined by the stream conditions and the solvent–cell fluid ratio. However, the amount of solvent applied is limited by the concentration decrease of the liquid extracted. Diffusion juice extraction is usually carried out in double-screw extractor devices. In this equipment, fruits are extracted in continuous mode with water in counterstream. Chopped fruits, to be extracted, are fed continuously on one end of the device; meanwhile, leached slices continuously exit the other end. Extraction liquid is fed and pumped in counterstream. Therefore, fresh fruit slices get in contact with the solution containing high level of extracted material; on the other end, fresh water first contacts slices that are already extracted. The application of this technology can lead to high extraction efficiency and sufficiently concentrated juice (Körmendy and Vukov 2007). Pressing and extraction can be combined to achieve better extraction of the valuable compounds. In this combined step, soluble residue substances are extracted from the marc by the means of aqueous extraction. Warm condensed water formed from the vapor during the concentration step is usually utilized as extraction fluid. The double pressing method, which is a combination of pressing and extraction, can significantly increase liquid yield. However, this process is time consuming. Moreover, extraction fluid cannot be mixed with the pressed juice; it has to be processed separately.

Juice Clarification

Extracted fruit juices are usually turbid, due to insoluble plant particles (fibers, cellulose, hemicellulose, protopectin, starch, and lipids) and colloid macromolecules (pectin, proteins, soluble-starch fractions, certain polyphenols, and their oxidized or condensed derivatives). Depending on the finished product, these substances must be partially or entirely eliminated to avoid turbidity and precipitation and to improve sensory attributes (taste, flavor, and color). Juice clarification has to be suited to the type of finished product. Filtered (clarified) juices are real solutions that should not contain dissolved colloid substances, so these compounds have to be eliminated. In spite of this, the special turbidity of cloudy juices comes from the fine-size, shaped particles of original ingredients and dissolved colloid substances that are left in the finished product.

Juice clarification can be performed by physical–chemical methods, mechanical procedures, and their combinations.

A physical–chemical clarification is applied when eliminating all substances causing turbidity. In this step, clarification agents are added to form precipitation from insoluble chopped plant particles and macromolecules that can be separated by mechanical methods afterward. As the first part of juice clarification, protective colloids (petcins, starch, and hemicellulose) have to be removed, because they hinder the settlement of floating substances and their gel-forming affinity inhibits concentration. Furthermore, they (starch, araban) can cause subsequent turbidity in concentrates during storage. This process also includes the addition of enzymes. The aim of enzyme treatment is to break down pectin molecules found in the juice. High quality, stable, filtered concentrates can only be produced if pectin decomposition is completed with the break down of starch, hemicellulose, and araban. Therefore, the development and production of combined enzymatic clarification agents, which possess pectinase, amylase, hemicellulase, and arabanase activity, is an important field for enzyme manufacturers. These products are not only specific to fruit species or varieties, but they take ripening stages of raw materials (e.g., apple), which can be processed within a longer period, into consideration as well (Dietrich 1998, Grassin 1990). Modern pectolytic clarifying enzyme products possess specific pectin transeliminase

and endo-pectin lyase activity, which perform pectin decomposition in a transeliminative way without preliminary de-esterification. Compared to traditional enzymes, they do not release methanol groups that esterify the pectic acid molecule. Thus, in subsequent stages of juice clarification, methanol can be eliminated from the fluid as part of the pectin molecule, so it does not pass into the finished beverages or the condensed aroma.

Soluble fractions of araban and starch get dissolved when heated. Thus, they do not cause difficulties during production, but they can result in subsequent turbidity of the finished juice or concentrate. They cannot be removed with clarifying agents either. When the products cool down, they gradually coagulate and cause cloudy, slightly mucous turbidity.

Pectin decomposition is usually completed with starch and protein decomposition, thus enzyme products that are marketed contain other enzyme components as well (Grassin 1990, Dietrich 1998).

Amylase can break down only dissolved starch. Prior to enzyme treatment of unripe fruits or varieties with high starch content, juices have to be heated to around 85°C, then cooled back to 45–55°C, which is optimal for enzymes.

In practice, this heating step is combined with aroma extraction or with the first level of evaporation.

Enzyme mixtures used for juice treatment are added in 10–100 g/1000 L concentration depending on product parameters. The reaction takes place in 1 ± 0.5 hours at 45–55°C. The effectiveness of pectin degradation can be measured with alcohol test; meanwhile, starch break down can be checked with iodine probe.

Physical–chemical techniques are applied following the decomposition of surrounding colloid substances.

Physico–chemical clarification is performed when all substances, responsible for turbidity, have to be eliminated from the juice. This step is carried out with the addition of different clarifying agents.

The effect of mineral clarifying agents is based on their surface activity and electric charge. For the clarification of fruit juices, bentonite and solid silicic acid are used. Bentonite is of volcanic origin belonging to the group of montmorillonites. It possesses big surface and good thickening properties, its negatively charged particles strongly adsorb positively charged proteins. The thickening properties of different bentonite products influence its clarification and stabilizing features.

Silica sol, used for clarification, is the aqueous colloid solution of polymerized silica anhydride that contains negatively charged particles. It is usually combined with gelatin or applied to complete enzymatic treatment. It has good clarification efficacy besides short clarification period.

Gelatine is a protein-based clarifying agent that precipitates negatively charged particles (polyphenols, decomposed pectin). This process is often completed with tannin, which reacts with protein molecules (Rák et al. 2007). Electric discharge triggers flocculation in juices. Thus, coarse particles, responsible for turbidity, are precipitated and form flakes. These precipitates absorb other particles, which cause cloudiness, on their surface. Precipitation thus formed settles and can be eliminated by mechanical methods.

In case of enzymatic pectin degradation, enzyme proteins are protected by the addition of bentonite and silica sol into the juice after the end of the enzymatic activity.

Active carbon has an intensive clarification impact on juices. However, it has a disadvantage, as it adsorbs some aroma besides color pigments and turbid particles. Therefore, it is usually added in low concentration (100–200 mg/1000 L juice).

Brownish coloring agents, which develop during juice production and darken the concentrate, may cause subsequent turbidity. These can be eliminated with synthetic resin treatments. Polyvinylpyrrolidone (PVPP) is a synthetic resin powder insoluble in juices. As clarifying agent, it adsorbs and precipitates polyphenols occurring in the juice. On the other hand, it is indifferent to HMF, which is responsible for nonenzymatic browning. Besides phenolic compounds, HMF is also removed by specific adsorbent polymer resin. PVPP powder is usually mixed into the liquid to be cleaned. Adsorption treatment requires a separate resin station within the processing system.

Mechanical clarification targets the elimination of suspended fibers and precipitation. This process is usually carried out in centrifuges and filtration devices. In this practice, the first filtration phase is performed in settling centrifuges, meanwhile decanters are used to eliminate fibers from cloudy juices (Welter et al. 1991, Nagel 1992).

Filtration is an important step of fruit juice production. Traditional filtration is performed in slurry layer-based devices. First filtration additives (silica, perlite) are added to the liquid to be filtered (Szenes 1991). The fine particle structure of these filtration additives provides the "body" of the filtering layer that lets turbid materials pass through or retains them. However, it ensures the expected flow-through performance. Juices are filtered on bag, frame, and candle filters; rotary vacuum filters are also widely spread.

Ultrafilters (application of membrane technology) play a key role in the clarification of filtered juices (Capannelli et al. 1994, Fábry 1995, Szabó 1995). The advantage of ultrafiltration is that properly selected pore-size membranes selectively retain proteins, starch, pectin fractures, and other large molecules; meanwhile, dissolved sugars, acids, and aroma compounds pass through with the solvent. Filters, which include modules of synthetic polymer-based membrane tubes with 12–20 mm diameter, are widespread in fruit processing industry.

Compared to traditional filtration techniques, ultrafiltered juices are clean, because molecules bigger than the pore size are retained. However, there is no loss of useful substances (e.g., aroma and sugars). Its limitation is that high performance can only be attained in specific pH, temperature, and density ranges.

In these machines, juice clarification and filtration can be performed in one step (Kinna 1990). Although sticky substances found in unclarified colloid suspensions are retained by the pores of the membrane. These compounds accumulate over the membrane and form a dense colloid layer, which hinders dissolved molecules that are passing through. Therefore the active period of membranes is usually extended by performing enzymatic and clarification treatments prior to filtration.

Ultrafiltration membranes used for fruit juice filtration can retain submicron-size colloid particles, microorganisms, and compounds of large molecule size. The cross-flow method is widely used with the following parameters: transmembrane pressure difference 3–8 bar, membrane pore size 0.01–0.1 μm. The cutoff value of ultrafilters is 1–500 kDa. Membranes are usually made of polymers (polysulfone, PAN) or ceramic substances (aluminum oxide, zirconium oxide). They safely filter out compounds, responsible for turbidity and browning, from apple juice. However, its application should be considered in case of dark-colored fruits, since ultrafiltration leads to greater loss of color than traditional filtration. As some of the compounds are filtered out, there is a loss of aroma compounds.

Substances retained by ultrafilters are concentrated in the retentate, which still contains many useful compounds and juice. These are usually separated by rotary vacuum filters.

Further Processing of Filtered, Clarified, or Cloudy Juices

Clarified, filtered, or cloudy juices are ready for consumption and preservation. There are different ways to process these juices to obtain preserved products. They can be natural juices with 100% fruit content, fruit nectars with 25–50% juice content and soft drinks with lower fruit content. If raw material processing is not directly followed by beverage production, juices can be concentrated into semifinished products. These products are finished subsequently, sometimes even at different locations.

Concentrate Production

The aim of concentration is to increase the dry matter content and decrease the water content of juices, in order to extend shelf life and to improve transportation and storage properties. This operation has to be implemented with minimal loss of valuable ingredients and minimal damage to sensory traits. Procedures applied for juice concentration are evaporation, freeze concentration, and reverse osmosis.

Evaporation

This is the most frequently used concentration method. From a physical point of view, it means water evaporation by means of boiling. This operation is carried out in evaporators, and steam ensures the energy necessary for boiling. Evaporators are heat exchangers, where heating steam condensates on one end; on the other end, the solution boils and some of its water content evaporates. Vapors are extracted from the vapor space and then condensed. In order to reduce energy costs, multilevel evaporator systems have been developed which utilize extracted vapors for heating steam in the next concentration element. Some of the solution's water content evaporates during boiling. The vapor thus formed is then driven out from the device and condensed. As the valuable juice components are heat-sensitive, short time, low-temperature condensation is desired. In order to ensure low boiling point, the process is performed under vacuum. Usually, more evaporators are applied in sequence to minimize the energy costs. To utilize the vapor of the previous element as heating steam in the following one, the juice should boil at lower temperature there, thus higher vacuum has to be applied. Such systems of three to four elements are commonly used.

Chemical, rheological, and thermal juice properties play an important role in the condensation process. As these features depend on the raw material, operation parameters may vary with the use of different fruit species. Evaporators should be chosen according to the juice properties. The most widely used devices are the film, tube, plate, and centrifugal-based ones (Szenes 1991).

Evaporator systems are usually combined with aroma-recovery units. These are generally connected to the first part of the evaporator and condense the most volatile aroma compounds. Aromas thus condensed are often remixed into the concentrate to improve its smell and flavor. Otherwise, these can be concentrated and applied as natural aroma extracts for other fruit products. During the clarification, prior to concentration, enzymatic processes may release foreign aroma compounds. Meanwhile surface active clarification agents can bind some of the original aromas. These can adversely change the aroma profile of juices. To avoid this phenomenon, the concentration procedures are divided. Preconcentration combined with aroma extraction is performed on untreated juices, where only large, shaped elements have been mechanically eliminated. This is followed by the treatment of semi-concentrates followed by final concentration. Preconcentration can take place in a separate device that is independent from the concentration system. It can also be performed by dividing the system and detaching the first stage. Thus, aromas are extracted from untreated juice. Heated juice has to be cooled to the temperature of liquid treatment and ultrafiltration.

Concentration by Freezing

This method is used for the concentration of valuable, heat-sensitive fruit juices. During this process, the water content of the juice is frozen with ice-crystal formation. These crystals contain clean water, thus solvent loss occurs in the solution. As the procedure goes on, the fluid gets more and more

concentrated and contains more and more crystals. Then the two phases can be separated mechanically (Fellows 2000).

This type of concentration is a very gentle process, as there is no aroma, color, and vitamin loss due to the low temperatures. Concentrates thus prepared contain almost every valuable ingredient of the original juice. The disadvantages of this type are high energy consumption and lower concentration efficiency compared with the heat treatment procedure (Várszegi 2002).

Reverse Osmosis

To increase the throughput of the freeze concentrating equipment, this membrane-based procedure became widespread in fruit concentrate production (Beaudry and Lampi 1990). The principle of this method is that the membrane is semipermeable and only lets water pass through, retaining all substances dissolved in water. Therefore, it "filters out" some of the water from the solution. One of the biggest advantages of the method is that it does not include heat treatment, thus neither heat damage, nor aroma loss occurs.

Because of the substantial increase of osmotic pressure, the limitation of the technique is that about 30% is the maximum concentration that can be achieved (Hribar and Sulc 1990).

Fruit Concentrate Storage

This method of storage largely depends on the properties of the raw material and the characteristics of the concentrate. From the filtered, clarified juice of less valuable fruit (apple, grape), concentrates containing 70% water-soluble dry-matter can be prepared. These are microbiologically stable enough to be stored in cooled stainless steel containers until further use.

However, colored fruits and berries can be concentrated up to 45–55 Brix percent depending on the fruit species. Moreover, there are concentrates with special composition (chandy) and ones made by freeze concentration that hardly achieve 40–45 Brix. These can only be stored in frozen form or with aseptic technology (Stéger-Máté and Horváth 1997).

PRODUCTION OF FRUIT JUICES WITH FIBERS

These products are made of fruit pulps. They are obtained by passing the raw materials through sieves, thus fruit flesh can be separated from seed and skin particles. Before performing this operation, fruits have to undergo preparation steps. Fruit nectars containing fruit flesh can be made of fruit pulp directly after production or later from the concentrated pulp (Fig. 13.1).

Preparation Steps

This operation includes steps such as raw material reception, washing, stem elimination, and selection, which are described before. However, the last steps are different: coarse chopping and preheating.

Coarse Chopping

Cracking and crushing, applied on pome fruits, chops fruit raw materials to small, irregularly shaped particles. The aim of this operation is to tear the skin and smash the fruit to achieve coarse texture. This step is necessary to ensure the efficiency and evenness of preheating. There are different devices available for chopping fruits with different physical properties. Fruits with more solid tissue structure are chopped in crusher machines; meanwhile, soft species are gently cracked. In cracker–crusher machines, the distance between the crushing drums can be adjusted to suit the size of the fruit.

Special attention has to be paid to the chopping of stone fruits. The distance between the drums have to be adjusted so that they do not break the seed, since broken seed particles could get into the fruit pulp and nondesired compounds can dissolve from the flesh of the broken seeds. The chopping device is usually located above the preheater, since cracked fruits can directly fall into the hopper of the preheating machine.

Preheating

Prior to sieving, most of the raw materials are preheated for two reasons. Heat treatment makes fruit texture soft and lax, improving the efficacy of sieving. It also inactivates the enzymes found in the fruit. It is particularly important in the case of oxidative and pectin-decomposing enzymes, since these can damage the color and texture of the pulp later (Binder 2002). Preheating plays an important role in the stability of colors during the storage of fruit pulps, since heat treatment applied does not inactive the enzyme proteins totally (Vukov 1981). The preheating of the mash should not be followed by significant dilution. Therefore, this process is performed in shell or tube heat exchangers. Some equipments enable direct steam blow to loosen the tissues of stiff flesh fruits. Temperature and duration of preheating is determined by the type of preheating device, raw material properties, and degree of chopping. Preheating is usually considered sufficient if the temperature of the fruit exiting the device attains 80°C. The efficiency of preheating can be determined by guaiacol (peroxidase) test.

Sieving

Sieving is a separation procedure from which pulp, which consists of small fruit particles, is obtained.

The equipment applies centrifugal forces to make tender fruit parts pass through the sieve, while hard skin and seed particles remain on the surface. Nowadays, fruit puree processing lines apply centrifugal and rub sieving equipment. In

high revolution centrifugal sieving devices, centrifugal force applies pressure on the material to be sieved. However, in rub sieving machines, the revolution is lower and fruit parts are passed through by the pressure applied by the batten. Perforation of the sieve determines the size of particles detached. In order to increase sieving efficiency, this separation is performed in more steps with decreasing perforation sieves in line. The perforation of sieves used for fruits is between 0.4 and 6.0 mm (Hidegkuti and Körmendy 2007). In the case of fruits containing seeds, an additional sieve has to be built into the process to detach seeds. This device must be more massive and possess bigger perforations.

Sieving can be carried out under both warm and cold conditions. Soft and vulnerable fruits (raspberry, strawberry) are sieved cold, and the pulp is heated afterwards, in order to inactivate enzymes. Meanwhile, in the case of more solid, heat-resistant fruits (apple, pear, quince, etc.), warm temperatures are used to obtain better juice yield and less sieving waste.

Color Stabilization

Enzymes, mainly oxidase types, which were not inactivated during preheating, are released from chopped tissues after sieving. In contact with air and substrates—diphenols and other easily oxidizing compounds—these enzymes can cause browning. If ascorbic acid is present in the system, it can protect the puree from browning, since it oxidizes quicker than other compounds (Vukov 1981). On the basis of this fact, to preserve the light, fresh color of fruits, ascorbic acid is added to the pulp. The addition of ascorbic acid is recommended in the form of 10% solution after destoning or sieving. In 100–150 mg/kg concentration, ascorbic acid can have sufficient color stabilizing effect.

Homogenization

The aim of homogenization is to ensure homogenous, smooth, creamy pulp texture and to slow down the settlement of shaped particles. Because of the fine chopping of fruit fibers, the amount of aqueous phase bound to their surface will increase. Meanwhile, the quantity of solution flowing between shaped particles will decline. Consequently, the virtual viscosity of the system will increase and fruit puree will be more consistent (Hidegkuti and Körmendy 2007).

The use of homogenizer depends on the further utilization of the pulp. If particle size should not be smaller than 0.5 mm or the subsequent production line includes fine chopping device, homogenization can be omitted.

Deaeration

During sieving and homogenization, significant amount of air can get into the fruit puree. Because of fine chopping, the increased surface can lead to oxidation. Moreover, the air bubbles, released from the pulp during heat treatment, can disturb the effective operation of the pasteurization equipment. Therefore, fruit puree should be deaerated after homogenization. Deaeration is usually performed in a special tank that is under vacuum, where the pulp is entered by spraying. Air is detached by vacuum from the large surface of the drops formed. Departed air contains valuable aroma compounds of low boiling point, which can be recovered in water cooled condenser.

Fruit Puree Processing, Preservation, and Storage

Sieved fruit pulp is a valuable raw material for beverages. However, in its original form, it has no refreshing effect. Purees are mainly used for the production of fruit nectars, baby foods, jams, and syrups. Fruit nectar can be produced directly on the venue of puree manufacturing, or subsequently, even in other areas of the world. Fruit pulps are stored and shipped in natural form or as 26–35% concentrate. Fruit purees are usually preserved by heat treatment. The principle of traditional heat treatment procedures is that the product, which is packed and hermetically sealed in appropriate container, is heated until its product-spoiling microorganisms are safely destroyed. The necessary duration of heat impact largely depends on the size of the batch to be heat treated. Long time, intense heat effect can be detrimental for the product's nutritional and sensory properties. Safe and gentle preservation of fruit puree can be performed by means of aseptic technology, which has been developed from heat preservation.

The Principle of the Method

Heat treatment in aseptic technology is usually performed above 100°C (90–120°C) for a relatively short period (1–2 minutes).

Aseptic heat treatment is performed in units specifically designed for this technology, such as scrapped surface heat exchanger or corrugated tube in tube heat exchanger.

After pasteurization, the pulp is cooled to about 30°C to stop further chemical reactions (Ott 1990). This way of preservation enables to minimize nondesired changes that cannot be avoided, if traditional heat treatment is employed. This can significantly improve fruit pulp quality and almost completely preserve valuable compounds of the raw material.

Filling is done in special filling machines in aseptic atmosphere, where the packaging material and the closing element are sterilized by the machine. Then the puree is led into multilayer aseptic bags via a special filling head under aseptic conditions. Mechanical stability is ensured by outside drums or boxes. Then the filling bags are tightly closed by the machine.

In modern filling devices, filling volume can be adjusted. Therefore, one filling machine can fill various packaging units, such as 220 kg, 120 kg, 50 kg, or even 2–5 kg "bag in box" or "bag in barrel." The advantage of "bag in barrel" packaging is that besides applying sufficiently rigid barrels, it can be transported. Moreover, aseptic bags packed in steel barrels with 216 L volume are generally accepted by international transportation systems (Szenes 1991).

Another aseptic filling technology is linked to storage in large aseptic containers. In this case, sterile pulp is pumped into a previously sterilized stainless steel tank. This technology requires high capacity sterile air developing units to continuously maintain overpressure in the tanks.

The aseptic system is a closed engineering unit, where slight overpressure prevails to avoid microbiological contamination (Buchner 1990). The system is cleaned and disinfected in unopened form by cleaning-in-place procedures. This means programmed washing and disinfection in predetermined periods.

Quality Criteria for Fruit Concentrates and Fruit Pulps

Fruit concentrates and purees are semifinished products, so there are no official regulations and standards for their quality. They are mainly utilized for fruit juice and fruit nectar production. Beverages made of preserved semifinished products can only be successful in the market, if their composition and sensory traits are very close to the ones that are made of fresh fruits and contain no added materials. Therefore, concentrates are always diluted to the average water-soluble dry matter level of the original fruit before evaluation. These products have to possess sensory and analytical properties that are basically identical with the fresh juice extracted from the same fruits. It means that general quality parameters, genuineness, and identity criteria of concentrates are the same as of natural juices. In the international trade of fruit concentrates and pulps, big customers may complete general quality requirements or implement stricter criteria according to their processing needs.

PRODUCTION OF LIQUID FRUIT PRODUCTS AND FRUIT BEVERAGES

The two large groups of fruit beverages are juices and nectars. Furthermore, certain countries produce soft drinks with low fruit content, which contain flavoring and coloring additives as well. There is no international legislation for the composition and quality of such fruit drinks.

The most important property of fruit juices with 100% fruit content is that their composition has to be identical with liquid phase of the original fruit (except losses occurring in production, e.g., vitamins). Therefore, shaped fruit particles have to be separated with physical procedures (pressing, centrifuging, settlement, etc.). In case diffusion process is applied, solvents should not leave residues behind. Water, for example, which contains no dissolved materials, is an ideal solvent. Only those substances can be added that are permitted by international legislation (Table 13.1).

Beverages enriched with different biologically active substances form a separate category. Enrichment and added materials have to be labeled on the packaging.

In case of direct production, filtered and cloudy juices are directly made of clarified juices that were extracted from the fruits mechanically.

Indirect production means that beverages are made from concentrated semifinished products with dilution. If juices are made from concentrates, they are labeled as "made from concentrates." Fruit juices available in the market can be filtered-clarified, cloudy, and contain added fibers.

Fruit nectars are juices or pulps diluted with sugar syrup. In Europe, their minimum fruit content is defined by Council Directive 2001/112/EC for different fruits. Depending on the raw materials, nectars can be filtered or may contain fibers. Filtered nectars are made of filtered juices. Those nectars containing fibers include not only the juice but also the fruit flesh, which is chopped to fine particles and distributed homogenously. Fruit nectars are usually made of fruits that do not possess drink properties in 100% concentrated form (e.g., pulps) or the raw materials are so acidic or have so intense flavor that their sensory traits are not enjoyable (e.g., seabuckthorn, tart cherry, red currant). Other regulations for fruit nectar composition can be found in Table 13.1.

Preparation of Juices with 100% Fruit Content

Raw Material Preparation

In the case of direct juice production, raw material reception, storage and preparation, juice extraction, and clarification are performed as described before.

If the production is indirect, the technology begins with the preparation of semifinished ingredients, the control and evaluation of raw material documentation, compositional features, and sensory properties. The necessity of flavor correction is also done at this stage.

Juice Formulation

If the composition of freshly produced juice corresponds with the criteria determined in the product specification and no flavor correction is needed, it can be directly filled and preserved. In case the product is made of concentrate or more fruits or the composition needs to be modified, ingredients—juice(s), concentrate(s), deionized condensed water—have to be heated up to 50–60°C in a mixing tank.

Taste correction, which means the addition of sugar solution, lemon juice, or lemon concentrate, has to be performed

in this vessel, too. If the product is fortified with vitamins or other substances, accurately measured and dissolved ingredients are added at this stage. Finally, if aroma extraction was performed during direct production, recovered aroma can be readded. If the product is manufactured from semifinished ingredients, aromas, which come from other fruits, but from identical species and varieties, can be used for flavoring. Even distribution of added substances has to be ensured.

After completing the formulation, quality parameters have to be tested. In case the composition is appropriate, the juice is ready for filling.

Production of Fruit Nectars

Raw Material Preparation

Fruit nectars are usually made of semifinished ingredients (juice concentrate, fruit pulp) with dilution. Raw materials can be natural and concentrated fruit purees, but they can be combined with filtered juices or concentrates. They usually contain one fruit, but mixed nectars are also popular.

In case of direct fruit nectar manufacturing, raw material production is done as written in former chapter. If the production is indirect, technology starts with the preparation of preserved semifinished raw materials, the control and evaluation of ingredient documentation, compositional features, and sensory properties. Then, the formula is adjusted according to raw material parameters.

If raw materials have been preserved by heat treatment and stored in closed aseptic bags, preparation means opening the closed bags.. In case the raw material is frozen, the first step is defrosting. This process requires high precision, since improper temperature and duration can be detrimental for product quality.

Formulation of Fruit Nectars

Syrup is cooked from the necessary amount of water and sugar or honey. Then the juice, puree, or concentrate is added in quantities determined by the product specification. The product can be flavored with defined amount of lemon juice or concentrate and can be enriched with vitamins. It can be sweetened with sweetening agents instead of carbohydrates. These substances are added to the product in dissolved form after mixing the syrup and fruit ingredients. Preparation steps of nectars are identical to fruit juices.

A further grinding step is applied in colloid mills to reduce the particle size, which determines the quality and stability of nectars. There are different colloid mill solutions available, but their common feature is the application of hydrodynamic shear forces. The aim of homogenization is to further reduce the particle size of fibers and to create a fine, disperse system. Homogenized liquid has a stable texture and there is little settling of solids during storage.

Fruit Juice, Fruit Nectar Preservation, and Packaging

Finished fruit-based beverages are filled into glass and plastic bottles or carton boxes made of combined layers. According to current legislation, the preservation of fruit juices and nectars is only permitted by heat treatment. This can be performed in the traditional way, so that liquids are heated up to 82–85°C, filled at this temperature, and then pasteurized in water bath. Pasteurization is carried out at 84–88°C for 15–40 minutes depending on the size of the packaging container. After the heat treatment, products are cooled back to room temperature.

Aseptic filling technology offers a better preservation of quality and valuable compounds. Here the liquid is pasteurized in a closed, flow-through system. Then the fluid is cooled under conditions that preclude post-contamination and filled into containers that have been already sterilized. As a result of mixing, applied during the formulation step, and homogenization, significant amount of air gets into the product. In order to remove dissolved gas particles, deaeration is performed under vacuum at the beginning of the preservation technology. Vapors that exit the deaerator are rich in aromas, which are condensed and driven back to the juice. Deaeration is followed by pasteurization at 94–112°C depending on product properties. The duration of this heat treatment is 30–60 seconds. Then the product is cooled to 25–30°C. This heat treatment takes 2 ± 0.5 minutes in total. The cooled liquid is led to the filling machine, where it is filled into presterilized, multilayer boxes, which consist of aluminium, different papers, and plastic foils that are laminated. Products can also be filled into bottles specially developed for aseptic technology. The aseptic filling-closing system is a closed unit under overpressure, which hinders the post-contamination of heat-treated products.

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14
Manufacturing Jams and Jellies

H. S. Vibhakara and A. S. Bawa

Abstract: Jams and jellies constitute an important segment of fruit products and the range of these products is undergoing extension due to the increase in the types of various fruits being used for manufacturing of jams and jellies. The fruits include apple, pear, sapota, apricot, loquat, peach, papaya, plum, mango, grapes, muskmelon, etc. The chapter describes mechanism of gelling and various gelling agents used in the manufacture of jams and jellies. Similarly, other ingredients such as sweetening agents, acidulants, colorants, and flavoring agents are described. Various recipes are also described along with the manufacturing methods and packaging materials used in the manufacture of the products. The importance of low-calorie jams has been given due importance as the products are in greater demand in the recent past. Industrial practices involved in jam and jelly manufacture is highlighted for the benefit of small-scale and cottage-scale industries. The chapter as such encompasses the basics of gelling, fruit pulps to manufacture the products along with the critical aspects of the process to ensure adequate quality and safety of the products.

INTRODUCTION

Commercial scale jam and jelly production developed from home-prepared preserves and desserts made during fruit season and are still practiced in one form or other as cottage industry. The method to preserve fruits in this way although evolved mostly from an art is older than canning and freezing (Peckham 1964, Thakur et al. 1997). Jam and jelly products were prepared with a high concentration of dissolved solids so fermentation was avoided. The earliest published record of jelly making appeared in the later part of the 18th century. Jams in their various forms were probably the easiest by-products of citrus fruits. As sugar became more affordable, the popularity and availability of these fruit products increased (Anon 1983).

Commercially made jams and jellies are required to conform to certain specifications and legal standards. The consistency of jams and jellies depends upon the type of pectin, and lack of knowledge about the requirements necessary for the pectin gel formation frequently contributes to products of undesirable consistency. As the knowledge of pectin chemistry increased, jelly and jam production grew and to some extent replaced home-prepared products. However, only pectin and sugar are not sufficient for the formation of the products. Equally important is the acidity of the fruit, resulting in a definite equilibrium in the "pectin–acid–sugar" system (Breverman 1963). Hence, commercial jam manufacture is based on proper use of pectin and formation of pectin–sugar–acid gel.

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INGREDIENTS FOR JAMS AND JELLIES

Definition and standards of identity for various fruit preserves and jellies have been issued by the U.S. Food and Drug Administration (FDA) under the Food, Drug, and Cosmetic Act. A brief outline of these standards has been presented here. The U.S. standards for grades were established by the production and marketing administration (Anon 1974, 1975).

Jellies are viscous or semisolid foods made from a mixture of not less than 45 parts by weight of fruit juice ingredients and 55 parts by weight of saccharine ingredients. The mixture is concentrated by heat to such a point that the soluble solids content of the finished jelly is not less than 65%. Spices, sodium citrate, sodium potassium tartrate, sodium benzoate, benzoic acid, mint flavor, and harmless artificial green coloring may be optional ingredients. Optimal saccharine ingredients are corn sugar, invert sugar syrup, sucrose, honey, or combinations of these. Pectin and designated organic acids can be added to compensate for deficiencies of these substances in fruit juice. Inducement for adding pectin or acid in quantities greater than required to supply the natural deficiency of the fruit juice is eliminated by fixing the minimum fruit juice content. The name of the fruit or fruits present as well as spices, chemical preservatives, honey, or corn syrup used must be indicated on the label.

Standards for jams and preserves are similar to those for jelly except that fruits are used rather than fruit juice ingredients, and mint flavor and green coloring are not optional ingredients. The fruit mixture is concentrated by heat to such an extent that the total soluble solids content is not less than 65% for certain specified fruits and 68% for others.

It is extremely difficult to account for the behavior of gels formation. Gels are a form of matter intermediate between a solid and a liquid. They consist of polymeric molecules crosslinked to form a tangled, interconnected molecular network (Fig. 14.1) immersed in a liquid medium (Oakenfull 1991). The water, as a solvent, influences the nature and magnitude of the intermolecular forces that maintain the integrity of the polymer network; the polymer network holds the water, preventing it from flowing away in acid medium; pectin with sugar affects the pectin water equilibrium and forms a network of fibers throughout the jelly (Rees 1969, Mitchell and Blanchard 1979, Thakur et al. 1997). This structure is capable of supporting liquids. Figure 14.2 shows the factors affecting the strength of the network.

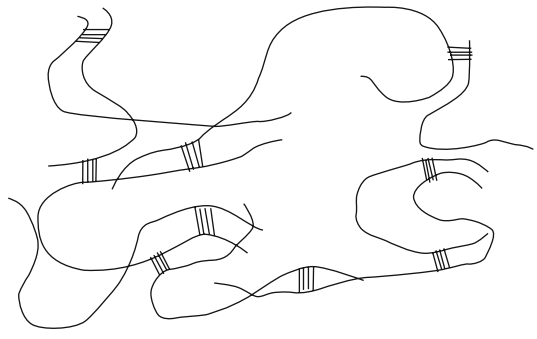

Figure 14.1. Gel network in jams and jellies (the hatched areas represent junction zones).

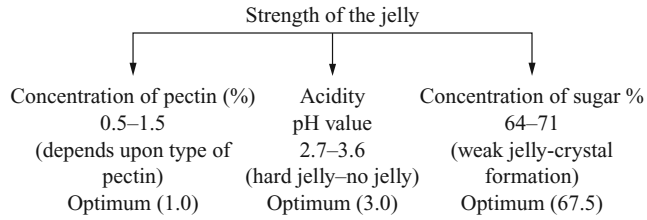

Figure 14.2. Factors affecting the jelly strength.

Fresh, frozen, or canned fruits may be used in the preparation of jams. The cut slices are cooked and mixed as 55 parts of sugar and 45 parts of smashed fruit slices. The exact level depends on the pectin content. Citric acid at the rate of 5 g/kg of mashed fruit slices may be added to improve the sugar/acid blend of the product, to effect proper inversion of the sugar, and to avoid undesirable crystallization in the final product during storage. The mixture is then cooked with continuous stirring until it attains a thick consistency with soluble solids to an extent of 65–68°C. Jam is filled hot into clean, sterilized dry containers, sealed air tight, cooled, and stored.

The ingredients for the preparation of jam must be added carefully. For an ideal jam formation, it should be with the composition of 1% pectin, 65% sugar, and adequate acid concentration to yield a pH value of 3.1. Too much of pectin will make the spread too hard and too much sugar will make it too sticky. The fruits for the preparation of the jam are inspected for quality using color, ripeness, and taste as guidelines. The mixtures are usually cooked and cooled three times. In addition, if flavoring is to be included, it is added at the end. When the mixture reaches the predetermined thickness and sweetness, it can be filled in the bottles.

The right amount of acid is critical to gel formation, with too little acid the gel will never set and too much acid will cause the gel to lose liquid (weeping). If fruits are low in acid, addition of lemon juice or other acid ingredients will be helpful to ensure gelling.

Sugar helps preserve sweet spread and contributes in flavor promotion. Granulated white sugar is most often used to make jams and jellies. We can replace part of the sugar with corn syrup or honey, but it may mask the fruit flavor and changes the gel structure. If we reduce the amount of sugar, gel would not form and yeast and mold may grow in the spread.

The proportion of sugar and fruit varies according to the type of fruit and its ripeness, but roughly is equal weights of each. When the mixture reaches the temperature 104°C, the acid and pectin in the fruit reacts with sugar and jam will set on cooling. In open pan method of preparation, it gives traditional flavor with some caramelization of sugars. Commercial method involves the use of vacuum vessel where jam is placed under vacuum, which has an effect of reducing its boiling temperature between 65°C and 80°C depending upon recipe and the end result desired. It has added benefit of retaining fruit flavors, preventing condensations of sugars, and reducing the overall energy required to make the product. A jam setting depends on the pectin content of the fruit. Most citrus fruits, apples, and black currants set very well. Other fruits such as strawberries and ripe black berries often need to have pectin added.

TYPES AND VARIETIES OF FRUITS

A jam manufacturer can choose a fruit from among the following five categories:

1. Fresh fruit
2. Frozen, chilled, or cold stored fruit
3. Fruit or fruit pulp preserved by heat
4. Sulfited fruit or fruit pulp, i.e., fruit preserved with sulfur dioxide
5. Dried dehydrated fruits

Fresh fruits generally give the best jams. As pectin is the main ingredient in the fruit that gives a set to the jam, it is preferable to use a slightly under-ripe fruit that is rich in pectin along with the ripe fruit to secure the desirable gelling effect in the jam. Apple, pear, sapota, apricot, loquat, peach, papaya, karonda, plum, strawberry, mango, tomato, grapes, and muskmelon have been used for preparation of jams. It can be prepared from a single fruit or a mixture of two or more.

In jelly making, pectin is the most essential constituent. Although there is difference of opinion about the exact nature of pectin, it is generally accepted that pectin forms jellies, when mixed and boiled with proper amounts of sugar, acid, and water. All these constituents must be present in a particular proportion for making a good jelly (Kratz 1993, 1995).

Guava, sour apple, plum, grapes, karonda, wood apple, loquat, papaya, and gooseberry are generally used for preparation of jelly. Apricot, pineapple, strawberry, raspberry, etc. can be used but only after addition of pectin powder, because these fruits have low pectin content. Fruits can be divided into four groups on the basis of their pectin and acid contents (NIIR Board 2002).

1. Rich in pectin and acid: sour and crab apple, grape, sour guava, lemon, orange (sour), plum (sour), jamun.
2. Rich in pectin but low in acid: apple (low acid varieties), unripe banana, sour cherry, fig (unripe), pear, ripe guava, peel or orange, and grapefruit.
3. Low in pectin but rich in acid: apricot (sour), sweet cherry, sour peach, pineapple, and strawberry.
4. Low in pectin and acid: ripe apricot, peach (ripe), pomegranate, raspberry, and any other overripe fruit.

Types and varieties of fruits selected should be used without undue delay for making jam and jelly because if kept for a long time, degradation of pectin proceeds rapidly.

Peels

Besides sorting and removal of leaves, stalks, and undesirable portions of the fruit, which can only be done by hand, most fruits require treatment of some kind before they enter the boiling pan. For example, strawberries require light crushing, plums require heating with minimum of water until soft. When it is required, cherries are similarly treated. Currants are passed through machines that remove the stalks; gooseberries are whirled in machine.

Sour and bitter oranges are utilized by hand or machine and the peel cut of any desirable size or shape by special machines. Sometimes, admixture of certain proportion of grapefruit or lemons is used, peel of which constitutes only a quarter to a half if utilized in proportion to the total weight of fruit. These slices need to be softened either by prolonged boiling, or more rapidly by heating. The slices may be covered with water and cooked until tender, the water being changed at least twice during cooking. It can be done in autoclaves under pressure of 1 atm. More rapid softening is attained by boiling the peel in a solution of carbonate of soda or ammonium hydroxide, which removes from the cell wall that render the peel tough after boiling with sugar. Ammonia is less drastic in its action than the soda and is preferred for use as there is less danger of the peel breaking up into small fragments (soda dissolves hemicelluloses and pectic substances, whereas the former are said to be insoluble in ammonia). However, more research is required to determine the precise causes of the softening.

The time required to soften peel in an autoclave depends on the size of the slices and on the pressure and temperature employed. Some discoloration may occur if too high pressure is used. After having been cooked in ammonium hydroxide or soda, the peels may be re-cooked for a short time with a weak solution of citric acid to remove any traces of the hydroxide.

GELLING AGENTS

Gelling agents are used in the food industry in a wide range of products, both traditional and novel, and this use is increasing rapidly with the increase of convenience foods. An ideal gelling agent should not interfere with the odor, flavor, or

taste of the product to which it is added (Fishman and Jen 1986). Improvements to existing and development of new ones require basic understanding of the processes of gelatin and the properties of gels at the molecular level (Doublier and Thibault 1984).

Gels are a form of matter intermediate between a solid and a liquid. They consist of polymeric molecules cross-linked to form a tangled, interconnected molecular network immersed in a liquid medium (Flory 1953). The polymer network holds the water, preventing it from flowing away (Meyer 1960, Oakenfull 1987). In gels, the molecules are held together by a combination of weak intermolecular forces such as hydrogen bonds, electrostatic forces, Vanderwaals forces, and hydrophobic interactions. The cross-linkages are not point interactions but involve extensive segments from two or more polymer molecules, usually in well-defined structures called junction zones (Rees 1969). The gelation process is essentially the formation of these junction zones (Fig. 14.1).

The physical characterizations of gel are the consequence of the formation of a continuous three-dimensional network of cross-linked polymer molecules on a molecular level; an aqueous gel consists of three elements (Jarvis 1984):

1. Junction zones where polymer molecules are joined together.
2. Interjunction segments of polymers those are relatively mobile.
3. Water entrapped in the polymer network.

Gels are always formed in an aqueous environment. Thus, the interactions of protein and polysaccharides with water are by themselves important factors in the gelation process. Both types of polymers are strongly hydrated in aqueous solution, so that some water molecules are so tightly bound that they fail to freeze even at temperatures as low as –60°C (Eagland 1975). Although the formation of a stable intermolecular junction is a critical requirement for gelation, some limitation on the interchain association is also necessary to give a hydrated network rather than an insoluble precipitate (Axelos and Thibault 1991).

It is important to know the condition for the onset of gelation in technological processes involving gelling food products. Several methods are used to characterize this change in consistency (Doesburg and Grevers 1960, Walter and Sherman 1981, Beveridge and Timber 1989, Dhame 1992, Rao 1992, Rao and Cooley 1993). Physically, the critical stage of gelation may be monitored from the loss of fluidity or from the rise of the elastic property of the growing network (Shomer 1991). Table 14.1 gives different types of jelling agents used in the manufacture of jellies.

Gelatin is a water-soluble protein formed by initial degradation of collagen from animal skin and bones. Gelatin jellies have a rather soft or rubbery texture. For these, it is normal to use an additional gelling agent such as thin boiling starch. This involves the texture incidentally. Gelatin gels forms reversibly on cooling a gelatin solution. It is now well established that the protein molecules are cross-linked to form a network by junction zones, where the protein chain have partly refolded in the collagen triple helix structure (Veis 1964).

Agar/alginates are the major structural polysaccharides of algae. Agar jellies have a very soft texture. Straight agar jellies have a characteristic "shortness" that may be modified by the addition of gelatin, gum arabic, pectin, starch, etc. Alginates with a high ratio of poly-β-D-mannuronic acid (M) and poly-α-L-guluronic acid (G) form weak, forbid gels, whereas low M/G alginates give transparent, stiff, brittle gels, and the gel strength depends on the nature of the divalent cation (Smidsred 1974).

Gum arabic is the most water soluble of the natural gums (up to 50%) and their solutions are of relatively low viscosity. Other advantages of gum arabic are its absence of odor, color, and taste. Hard jellies can be produced with gum arabic.

Unmodified starches, produced by wet milling of field corn, supply the major amount of thickening material.

Table 14.1. Different Types of Jelling Agents Used in the Manufacture of Jellies

Type of Gelling Agent	Origin	Use
Gelatin	A protein of animal origin extracted from bones and purified	Generally, must not be boiled. To be added to warm syrup for setting on cooling
Agar/alginates	Extracted from various sea weeds	Various products such as neutral jellies are weakened by boiling in acid solution
Gum arabic/acacia	Exudates from trees	Used to produce hard gums, and as an extender and thickener in products, e.g., marshmallow
Starch/modified starch	Seeds and various roots	These have been completely and partly replaced by other jelling agents in gums—Turkish delight Glazer
Pectin	Fruit residues particularly citrus and apple pomace	Used largely in acid fruit jellies but with low melting point is used in neutral jellies

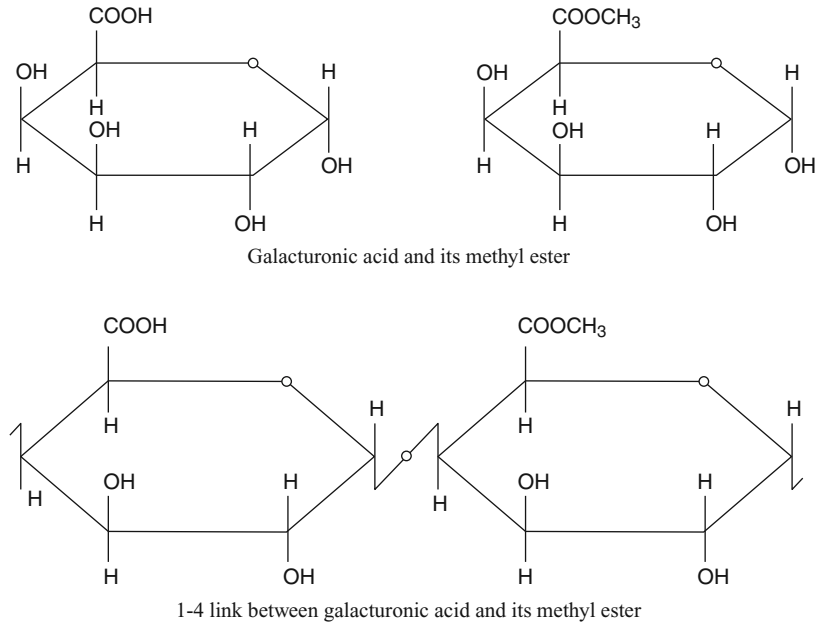

Figure 14.3. Chemical structure of galacturonic acid and its methyl ester.

Modified starch is starch that has undergone one of the varieties of treatment to alter its physical property and/or functionality (Furcsik and Mauro 1991, Mauro et al. 1991). They are used to extend the bodying or gelling effect of normal starches, to modify gelling tendencies, and to improve texture. Starch is an essentially linear polymer of α-(1→4) linked D-glucose (Wolfram and EI Khadem 1965). Starch gels consequently have a composite structure of open, porous amylopectin molecules threaded by an amylose matrix. Thus, actual gel-forming polymer in starch is amylose. The molecular weight distribution of amylose depends on the plant source and molecular weights of several millions with broad distribution have been reported (Rao et al. 1993).

Pectin is the most frequently used hydrocolloids in processed fruits. Jams and jellies are the major food type using larger amounts of pectin. Pectin is a class of complex hetero polysaccharides found in the cell walls of higher plants, where they function as a hydrating agent and cementing material for the cellulosic network (Muralikrishna and Taranathan 1994).

When pectin-rich plant materials are heated with acidified water, the protopectin is liberated and is hydrolyzed into pectin that is readily soluble in water. It happens in plant tissues during ripening of fruits with the aid of an enzyme protopectinase. As the ripening of fruit proceeds, more and more of the insoluble protopectin is converted into soluble pectin (Woodmansee et al. 1959). Their composition varies with the source and conditions of extraction, location, and other environment factors (Chang et al. 1994). Pectic substances in the primary cell wall have a relatively higher proportion of oligosaccharides chain on their backbone, and the side chains are much longer than those of the pectin of the middle lamella (Sakai et al. 1993).

Pectins are primarily a polymer of D-galacturonic acid (homopolymer of [1→4]-α-D-galacto-pyranosyluronic acid units with varying degrees of carboxyl groups methylated esterified) and rhamnogalacturonan (hetero polymer of repeating [1→2]-α-L-rhamnosyl [1-L]-α-D-galactosyluronic acid disaccharide units), making it an α-D-galacturonan (Lau et al. 1985). The molecule is formed by L-1,4-glycosidic linkages between the pyranose rings of D-galacturonic acid units. As both hydroxyl groups of D-galacturonic acid at carbon atoms 1 and 4 are on the axial position, the polymer formed is 1,4-polysaccharide (Oakenfull 1991, Sakai et al. 1993).

The chemical structure of galacturonic acid and its methyl ester are shown in Figure 14.3, and the linkages between different galacturonic acids and their methyl esters in pectic and pectinic acid are shown in Figure 14.4 (Swaminathan 1987).

Pectic acid is composed mostly of colloidal polygalacturonic acid molecules and is essentially free from methyl ester groups. The salts of pectic acids are either normal or acid pectates, whereas pectinic acid ones are colloidal polygalacturonic acids containing more than a negligible portion of methyl ester groups. Pectinic acid under suitable conditions is capable of forming gels with sugar and acid or, if suitably low in methoxyl content, with certain metallic ions. The salts of pectinic acids are either normal or acid pectinates.

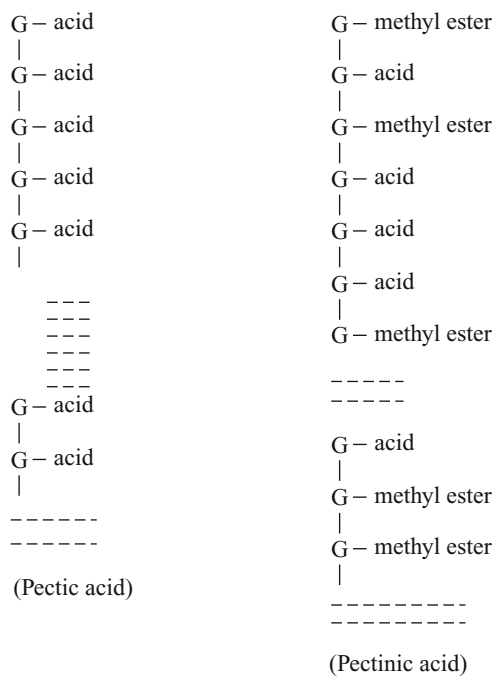

Figure 14.4. Pectic acid and pectinic acid (G represents galacturonic acid).

Studies of esterified residue in pectin indicate that they are randomly (De Vries et al. 1986, Garnier et al. 1993) or non-randomly distributed (Mort et al. 1993). However, ion exchange chromatography showed a random distribution of change in citrus pectin that had undergone acid-catalyzed de-esterification (Garnier et al. 1993). Such disparate findings may, in part, be due to the length of galacturonate residues being examined or due to differences in pectin source (Baker et al. 1996).

Polygalacturonic acid could be considered as a rod in solution, whereas pectins are segmented rods with flexibility at the rhamnose tees (Fry 1986). The size, charge density, charge distribution, and degree of substitution of pectin molecules can be changed biologically or chemically (Kerstez 1951, Kratz 1993).

The most unique and outstanding property of pectin is their ability to form gel in the presence of Ca^{2+} ions in sugar and acid solution (Gordon et al. 2000). Degree of esterification, attached chain of neutral sugars, acetylation, and cross-linking of pectin molecules also affect the texture of pectin gels (Guichard et al. 1991). Pectin chains carry negative charge and the charge density is higher at higher pH and lower degree of methoxylation (DM; Gross et al. 1980). Conformation of the pectin molecules is not affected by the branching, but side-branching in pectin can result in significant entanglement in concentrated solutions (Ring and Oxford 1985, Hwang and Kokini 1992).

Depending on the DM, pectins are classified into (1) low methoxy (LM; 25–50%) and (2) high methoxy (HM; 50–80%) pectins, and form gels of two types with occasional intermediates. They are called acid and calcium gels and formed from HM and LM pectins, respectively. In HM pectins, the effect of sugars depends specially upon molecular geometry of the sugar and the interactions with neighboring water molecules (Oakenfull and Scott 1984). Noncovalent forces (i.e., hydrogen bonding and hydrophobic interactions) are believed to be responsible for gel formation in HM pectins (Walkinshaw and Arnott 1981, Da Silva et al. 1992). In LM pectins, gel is formed in the presence of Ca^{2+}, which acts as a bridge between pairs of carboxyl groups of pectin molecules. The two kinds of pectins are relatively stable at the low pH levels existing in jams and jellies (Pilgrim et al. 1991). HM pectin is used to form gels in acid media of high sugar content, and LM pectins are used in products of lower sugar content (Axelos and Thibault 1991). Pectins can be further divided into rapid-set, medium-set, and low-set pectin depending upon the time the gel takes to set.

The functionality of pectin molecules is determined by a number of factors, including DM and molecular size (Doublier et al. 1992). Pectins of 100–500 grades are available in the market. Their application as a food hydrocolloid is mainly based on their gelling properties (Voragen et al. 1986). Selection of pectin for a particular food depends on many factors, including the texture required, pH, processing temperature, presence of ions, proteins, and the expected shelf life of the product (Hoefler 1991).

Combinations of gelling agents are often used because a combination gives a desirable texture. For this reason, mixed systems are of great technological importance (Christensen and Trudsoe 1980, Hughes et al. 1980). The physical chemistry of mixed system is obviously very complex. However, there has been significant progress in developing a suitable theoretical framework, at least for two component systems (Morris 1986).

Advances in the chemistry of pectin and its gels have made it possible to control the consistency of the jam and jellies under commercial methods of production. Pectin substances are complex carbohydrates and are found primarily in cell walls functioning as the cementing material that holds the cell together. Chemically, pectin substances consists of galacturonic acid and its methyl esters chains of undetermined length. They are linked by a 1-4-glycosidic linkage. The number of methoxylated galacturonic acid in the chain is known as the degree of esterification (DE). It has got great effect on the property of a pectin substance. Pectin substances always associated with certain monosaccharides, especially arabinose, galactose, and xylose as side chains.

Pectin substances are most abundant in the albedo of citrus fruits. Albedo is often used as a commercial source for pectin. There are three general categories of pectin substances. Pectic acid is the long-chain polygalacturonic acid containing no methyl esters, whereas pectinic acid contains some methyl

esters. Both are capable of forming gels in low Brix concentration and are often found as insoluble salts of divalent cations. The second category consists of pectin or pectins that contain water-soluble pectinic acid with higher degree of methylation. Protopectin constitutes the third category. This term is applied to the parent water-insoluble pectinics of plant material. Upon hydrolysis, it can form pectins or pectinic acids. Pectic substances influence the firmness of the products and impart characteristic mouth feel due to increased colloidal suspension of particles.

All fruits contain varying extents of pectin. Apple, gooseberry, crab apple, and some plums and grapes contain enough natural pectin to form a gel. They must be mixed with other fruits that contain less pectin for proper gel to form. Fully ripened fruit contain less pectin, so one need to combine it with 1/4th under-ripe fruit in order to form spread without added pectin. Commercially frozen and canned juices are low in natural pectins and cause soft texture in sweet spreads. When jams are made from a mixture of fruits, they are usually called preserves, especially when they contain citrus fruits, nuts, raisins, or coconut.

Many sub-tropical fruits such as apples, apricots, plums, and strawberries as well as some tropical fruits such as bananas, guavas, mangoes, and papayas are commercially processed into jams. Jam and jelly making is a rapidly expanding industry and has become an important source of export revenue in India, China, and Malaysia. Banana, mango, pineapple, lychee, and papaya products are particularly important tropical items with commercial significance in the international trade. With the advance of modern industrial techniques, most traditional processing methods have shifted to industrial production to meet market demands.

Sweetening Agents

Sweeteners are used in fruit processing for many functional reasons as well as to impart sweetness. They add flavor, body, bulk, and control viscosity that contribute to texture and prevent spoilage. Sweeteners bind moisture in fruits that is required by detrimental microorganism. Too little sugar prevents gelling and may allow yeast and mold growth. Sugar serves as a preserving agent and aids in jelling.

Sucrose, commonly known as table sugar (or refined sugar), is the standard against which all sweeteners are measured in terms of quality, taste, and taste profile. However, glucose syrups have been widely used as a part of sugar source in recent years. An invert sugar component is necessary to prevent sucrose crystallization in high solids jellies and jams during storage. Such crystallization is rare in products containing less than 68% solids. If the concentration of sugar is high, the jelly retains less water, resulting in a stiff jelly, probably because of dehydration (Giridhari Lal et al. 1986).

The optimum percentage of invert sugar is between 35% and 40% of the total sugar in the jam. During the process of inversion, molecular water is taken into the sugars; that is the reason why 95 parts of sucrose yield 100 parts of invert sugar. The rate of inversion is influenced by three factors:

1. Hydrogen ion concentration (pH) of the product
2. Boiling temperature
3. Boiling time.

During boiling, sucrose undergoes a chemical change. Cane and beet sugars are nonreducing sugars. However, when boiled with acid or treated with some enzymes, sucrose is converted into two reducing sugars, namely dextrose and fructose in equal parts. Sucrose has a molecular weight of 342, invert sugar 360, the difference of 18 being the molecular weight of water molecule added during inversion (Rauch 1965).

Invert sugar syrup can be produced from sucrose by the action of an acid. After the process is completed, a suitable amount of sodium bicarbonate is added in order to neutralize the acid, as it is frequently undesirable to use strong acid in a food containing sugar. Methods using hydrochloric, tartaric, or citric acid are satisfactory when pure white sugar is used. Lower grade of sugar may require larger amount of acid.

The addition of sugar in LM pectin gels can increase gel strength and reduce syneresis (Axelos and Thibault 1991). For HM pectin gels, a number of other sugars, alcohols, and polyols will permit gelation. From a practical point of view, it may be advantageous to substitute other sugars for sucrose, either because of cost or to reduce the likelihood of crystallization, or for flavor modification (Ahmed 1981). Partial replacement of sucrose with other sugars such as maltose, glucose, syrups, or high fructose corn syrup altered the setting times and certain rheological properties of model gels (May and Stainsby 1986). For example, addition of maltose reduced the setting time and extended the pH range of gelation, while fructose delayed setting time. Partial or complete replacement of sucrose with other sugars alters the water activity of the system and can modify the hydrophobic interactions contributing to gelation.

HM pectin gel forms only under acidic conditions and when the sugar content is at least 55% (Oakenfull and Scott 1984). Low pH suppresses dissociation of free carboxylic acid groups, reducing their electrostatic repulsion (Watase and Nishinari 1993), while sugars stabilize hydrophobic interactions between the methyl ester groups (Oakenfull and Scott 1984, Brosio et al. 1993, Rao et al. 1993). Junction zone size and the standard free energy of gelation increase as the DE increases, being proportional to the square of the DE. As pectin ester content is lowered to 50%, jelly strength increases, but only at progressively lower pH values (Smit and Bryant 1968).

Esterification levels of pectins can also have an effect on the flavor perception of the jellies. For a substance to be tasted, it must contact the taste buds. Therefore, if a gel delays diffusion of the substance to the taste bud surface, perception may be controlled by diffusion and not by the taste reaction.

Guichard et al. (1991) found that at similar gel consistencies, HM pectin reduces taste intensity more than LM ones.

Acidulants

Acidulants are acids that either occur naturally in fruits and vegetables or are used as additives in food processing. Acidulants perform a variety of functions in fruit processing, the primary being acidifier, pH regulator, preservative and curing agent, flavoring agent, chelating agent, buffering agent, gelling/coagulating agent, and antioxidant synergist.

The choice of an acid for any specific food application is dependent upon a number of factors. Since each acid has its own unique combination of physical and chemical properties, the choice should be made on the basis of the qualities required (Watase and Nishinari 1993). The simplest possible use of a food acid involves decreasing the pH only. As an example, it might be desired simply to acidify a solution where pH adjustments are required. In many cases, the selection is based upon the ability of the acid to bring out and enhance flavor. For such purposes, compatibility and blending are important factors in the choice of acid. Each acid behaves somewhat independently of pH. Thus, citric acid is preferred in most fruits, tartaric acid for grape, and malic acid for apple. Since taste stability cannot always be predicted, the product should be examined both before and after storage, when blending or substituting the acids used.

Gel formation occurs only within a certain range of hydrogen ion concentration; the optimum acidity for jams and jellies being around pH 3. The gel strength fouls slowly on decreasing and rapidly on increasing the pH. Beyond pH 4, no jelly formation occurs in the usual soluble solid range. The pH value is also critical in determining the temperature at which jellies set. Insufficient acidity is one of the common causes of jelly failure. The pH value of jelly should be taken when the jelly is concentrated sufficiently to pour. Different juices will require different amounts of additional acid depending upon the original acidity of the juice and buffering capacity of the juice. The pH may be adjusted to attain optimum flavor to control or modify the rate of setting and to modify the degree of sugar inversion (Smit and Bryant 1968).

Control of pH is critical to successful gel formation with pectin, particularly in the case of HM pectins. Low pH increases the percentage of unionized carboxyl groups, thus reducing electrostatic repulsion between adjacent pectin chains. Rapid-set pectins with high DE will gel at higher pH than the one with lower degree esterifications; however, in slow-set pectin, this difference is minor, with the optimum pH for slow-set pectins being about 3.1 and for rapid-set pectins being 3.4 (Crandall and Wicker 1986). Substitution of other sugars for sucrose, by modifying hydrophobic interactions between chains, allows gels to be formed at somewhat higher pH (May and Stainsby 1986). Since they rely on calcium bonding to effect gelation, LM pectin can form gels at higher pH than HM pectins. Gels can be made at pH values near neutrality (Chang and Miyamoto 1992, Garnier et al. 1993), which is advantageous in producing dairy-based products (Baker et al. 1996).

Coloring and Flavoring Agents

The color of jam is a factor of considerable importance (Abers and Wrolstad 1979). A good jam should appeal to the eye as well as to the palate. No coloring is required for jams produced from fresh fruit, provided the boiling time is short and the heat not excessive. The natural color of the fruit is, however, always affected by presentation with SO_2 and in some cases by the process of boiling, necessitating the addition of artificial color. The aim should be to restore the original natural appearance. Only permitted edible food colors should be used.

It is essential that the colors should be intensive, readily soluble, and stand up to high concentration in solution. As a rule, acid colors are of higher stability than basic ones. Color should be acid proof; many are affected by acids and particularly by sulfur dioxide. They must also be light proof and have certain stability to heat. All colors suffer from prolonged and excessive heat and should therefore be added at the last stage of the boiling process (Rauch 1965).

Traditionally, permitted artificial colors have been used to color jams and marmalades, particularly those prepared from sulfited fruit. Use of natural colors, such as anthocyanins from grape skins, is increasing as artificial additives become less acceptable to consumers (Encyclopedia Food Science 1993). Colors available in powder form should be prepared just before the time of addition, since many colors have a tendency to precipitate on standing. When dissolving, the color is made into a paste with a little cold water and then required amount of boiling water is added and stirred well.

Ordinarily, jams do not require the addition of flavors. If desired, they may be added when jam boiling is nearing completion. Citrus oils and fruit volatile compounds (recovered in the concentration of fruit juices) can be added toward the end of the process to improve product aroma.

Product Type and Recipes

According to the U.S. federal standard, a jam should have a minimum of 45 parts of prepared fruit and 55 parts of sugar, concentrated to 65% or higher solids, resulting in a semisolid product. Jellies are similar to jams with 45 parts of clarified fruit juice and 55 parts of sugar, resulting in a minimum of 65% solids. Both categories can utilize a maximum of 25% corn syrup as sweetener as well as pectin and acid to achieve the gelling texture required (Baker et al. 1996).

On the basis of specification and the allowance for soluble solids such as acids and pectin, it will be seen that the finished jam or jelly, no matter what the grade, will contain approximately the quantity of sugar necessary to give the maximum strength to the pectin–sugar–acid gel. Typically, about 3–5%

of the total weight of the jam is represented by sugar derived from the fruit; hence, about 63–65% would be added sugar. However, this figure would be based on the nature of the jam or jelly being produced. If the fruit that is being used is deficient in pectin or acid or both, or if the quantity of fruit in the recipe is less, it may be necessary to add pectin or acid, so that a gel with sufficient firmness can be obtained.

Typical recipes used in large-scale manufacture of jams are described (Giridhari Lal et al. 1986).

To prepare jam, the requirement of pulp (fresh or canned) is 75 kg, with sugar 75 kg, citric acid 35 g, pectin 150 grade 565 g, and pineapple essence 75 mL.

To prepare orange jam, 50 kg of lye-peeled segments, 50 kg sugar, citric acid 250 g, pectin 150 grade 375 g, and sweet orange essence 50 mL.

To prepare mango jam, 40 kg mango pulp, sugar 40 kg, pectin 150 grade 500 g, citric acid 400 g, and mango essence 70 mL.

To prepare apple jam, 40 kg apple pulp, sugar 44 kg, pectin 150 grade 400 g, citric acid 500 g, and apple essence 60 mL.

To prepare mixed fruit jam, blends of mango, pineapple, orange, apricots, papaya, guava, etc., and equal weight of sugar to that of blended pulp taken, and citric acid to the extent of about 0.75–1.0% by weight of blended pulp containing pectin to the extent of 0.5–1.0% by weight of blended pulp are required depending upon the fruits used. A blend of predominantly red food grade colors may be added along with an appropriate essence to the desired extent.

Jams from cherry, mulberry, strawberry, muskmelon, jack fruit, cashew apple, etc. also can be made as above. It may, however, be necessary to vary the fruit sugar ratio and the percentage of acid added. In some cases, it may be useful to supplement the flavor of the jam by adding extra fruit flavor.

To prepare jelly from guava, ripe fruits are washed well and cut into thin slices and covered with an equal weight of water containing 2 g of citric acid for every kg of guava taken. The mixture is heated gently for about 30 minutes to extract pectin from the slices. The extract is drained and to the residue, water equal to one-fourth of the weight of slices is added and a second extract is taken. The two extracts are combined and strained through a piece of thick cloth to remove the coarse particles. The strained extract is allowed to settle overnight in a tall vessel. The clear supernatant liquid is tested for its pectin content. The required quantity of sugar (generally an equal quantity) is added to the extract and the mixture boiled down to the desired consistency. The finished jelly is packed in glass jars or in cans. By adopting the procedures described for guava jelly, jellies can be prepared from fruits such as apple, grape, jamun, jack fruit, etc.

Uncooked jam and jelly recipes are a newer method of preserving fruit produce to keep fresh from the wine flavor. These are also called freezer jams, since they need to be stored in the freezer to preserve them. In these recipes, the uncooked fruit is just mixed with sugar, lemon juice, and pectin, and stirred. Powdered pectin is usually dissolved in water first and then added to the fruit. Care is taken to stir well to dissolve as much sugar as possible, so that it would not have a sugary or gritty jam or jelly. The jam is then usually poured into covered plastic freezer container or can or freezer jars and allowed to set at room temperature. It may take 24 hours for the product to jell properly. Recipes for uncooked freezer jams and jellies come with all the pectin products available and the methods of preparation vary slightly for each (Peckham 1964).

METHOD OF MANUFACTURE

Manufacture of jams and jellies may be considered rather simple; however, unless scientific principles discussed before are adhered to, the finished product will not be acceptable. The basic steps with respect to fruit preparation, boiling, filling, and packaging is discussed below.

Fruit Preparation

Fruits for jam making should be fully mature, possess a rich flavor, and be of the most desirable texture. Fruits are washed thoroughly with water to remove any adhering dirt. If the fruit has been sprayed with lead or arsenic sprays, it should be washed in a warm solution of 1% hydrochloric acid and then rinsed with water (Giridhari Lal et al. 1986).

All berries must be carefully sorted and washed. Strawberries must be stemmed; peaches, pears, apples, and other fruits with heavy skin must be peeled, while apricots, plums, and fresh prunes can be pitted by machine. Stone fruits such as plum and apricots require a very heavy pulping screen because of abrasive action of the pits. Berries should not be softened by boiling before the addition of sugar, but need only to be crushed (Cruess 1948).

The proportion of sugar to fruit varies with the variety of the fruit, its ripeness, and the effect desired, although the most common ratio of sugar to fruit is 1:1. This is usually a suitable ratio for berries, currants, plums, apricots, pineapple, and other fruits. Sweet fruits with low acidity such as ripe peaches, sweet prunes, and sweet varieties of grapes normally require less than an equal weight of sugar.

Jams may be made from practically all varieties of fruits. Various combinations of different varieties of fruits can often be made to advantage, pineapple being one of the best for blending purposes because of its pronounced flavor and acidity.

Fruits for Jelly

Fruits required for jelly making should contain sufficient acid and pectin to yield good jelly without the addition of these substances, although often in commercial practice, this ideal condition is not attained. Some fruits contain enough of both

pectin and acid for the purpose, while others are deficient in either one or both the substances (Smith 1972).

In the case of fruits deficient in pectin but rich in acid, fruits rich in either pectin or commercial pectin should be added. Both these methods have their own merits. Combining fruits rich in acids with those rich in pectin is expensive than using acid or commercial pectin to supplement the deficiency, but the drawback is that the flavor of the jelly is affected. Therefore, special care is necessary to ensure that the fruits are mixed in proper proportions; on the other hand, commercial pectin does not have any deleterious effect on the final flavor of the jelly made from any particular fruit.

Of the fruits rich in pectin and acid, table varieties of apples, sour blackberries, currants, lemons, limes, grapefruits, sour oranges, sour guavas, and sour varieties of grapes, plums, and cherries are good examples. Of the fruits low in acid but rich in pectin are sweet cherries, unripe figs, ripe melon, and unripe bananas. Fruits that are rich in acid but low in pectin are apricots and most varieties of strawberries. Fruits that may be classified as containing a moderate concentration of both acid and pectin are ripe varieties of grapes, ripe blackberries, ripe apples, and loquats. Fruits low in both acid and pectin are represented by pomegranates, ripe peaches, ripe figs, and ripe pears (Cruess 1948).

Boiling

Boiling is one of the most important steps in the jelly making process, as it dissolves the sugar and causes union of the sugar, acid, and pectin to form a jelly. It usually causes a coagulation of certain organic compounds that can be skimmed from the surface during boiling, and their removal renders the jelly clearer. The principal purpose of boiling is to increase the concentration of the sugar to the point where jelling occurs (Ashish Kumar 1988).

The boiling operation, while normally being a necessary step in jelly making, should be as short as possible. Prolonged boiling results in loss of flavor, change in color, and hydrolysis of the pectin; consequently, it is a frequent cause of jelly failure (Lesschaeve et al. 1991). In jam making, the fruits resistant to boiling are desirable to concentrate the product by evaporation of excess moisture. Boiling in commercial practice is usually conducted in open steam jacketed stainless steel kettles. During boiling, the juice or pulp should be skimmed, if necessary, to remove coagulated material and should be stirred to cause thorough mixing. The boiling is continued until cooling, and on cooling, the product will form a jam or jelly of the desired consistency. The concentration of the mixture when this point is reached will depend upon several factors, viz, the concentration of pectin, the concentration of acid, the ratio of sugar to pectin and acid, and the texture desired.

The most common method of determining the end point is by allowing the liquid to sheet from a wooden paddle or a large spoon. If the drips form as thin syrup, the process is not complete. If it partly solidifies and breaks from the spoon in sheets, or forms jelly-like sheets on the side of the spoon, the boiling is considered to be complete.

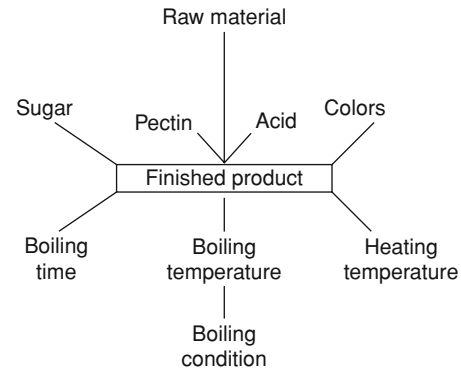

Figure 14.5. Factors controlling process of jam manufacture

Boiling of sugar solution in presence of the fruit acid results in the inversion of sugar, hence, a jelly that is boiled for a long period is less likely to develop crystals of sucrose than a jelly boiled for a short time. Prolonged boiling may result in loss of flavor through evaporation, hydrolysis, or other forms of decomposition.

Sometimes, jam is boiled in a vacuum pan at a lower temperature in the range of 65–76°C. The vacuum boiling or cooking minimizes the undesirable changes in color and prevents loss of vitamin C. However, the jam mixture has to be boiled for a long time to soften the fruit pieces, resulting in some loss of flavor, which can, however, be restored by recovering the volatile esters and putting them back into the jam (Lal et al. 1986). Proper control of boiling is necessary to avoid over concentration of soluble solids, over inversion of sugar, and hydrolysis of pectin. Figure 14.5 gives a scientific approach to different factors involved in jam production.

Filling

The finishing of jams comprises three main steps: (1) precooling prior to filling, (2) filling, and (3) cooling after filling. Prolonged heating affects the appearance as well as the keeping quality of the finished product. As the inversion of sugar is greatly influenced by the temperature, it is obvious that an efficient cooling system is necessary to manage this process. Difficulties are also experienced in filling, as some fruit varieties show a tendency to float, the most susceptible being strawberry, cherry, black currant, and stone fruit jams. These jams should be cooled until they are near setting point, but great care must be taken not to exceed the limit, otherwise the set will break and the jam curdles, more so in the case of jellies (Rauch 1965).

The efficient method in trade is filling on a roller conveyor. The empty jars are packed into trays, each one holding a certain number. The trays are then moved on roller conveyer to the filling operators. The trays containing filled jars are moved to cooling room after the preliminary setting has taken place. This prevents discoloration due to caramelization of the sugar.

After being filled, jam in jars must not be cooled too quickly. As far as canned jam is concerned, the procedure is simple enough, the cans being passed through a water bath. Glass jars and large containers have to be cooled by air. This can be done by passing them slowly through a tunnel fitted with an air blast or keeping them in a cooling room constructed on the same principle until the jam is well set. Automatic filling machines that measure a definite volume of jelly into each container are in general used in large factories. They greatly reduce the cost of filling as compared to that of hand filling and give more uniform net contents.

Packaging Materials

Packaging is the final stage of the process. A wide variety of sizes and shapes of containers are used for jellies. Glass is the usual material, although enamel-lined tin cans and special containers are also used.

Jelly should be hermetically sealed in glass containers. A paraffin seal is not adequate to prevent spoilage of the product. Container filled scalding hot (in excess of 83°C) need not be pasteurized, as the hot-filled jelly itself will sterilize the container. The jar should be filled to at least 90% full, leaving not more than 1.25 cm head space. The scalded lids should be loosely placed on the containers immediately following filling, and then tightened firmly within 2–3 min. This allows time for exhausting of air from the head space. The steam in the head space condenses when the jelly cools, creating a vacuum seal. Capping with superheated steam injection is often used to attain a hermetic seal. Where the product is not filled sufficiently hot to ensure head space sterilization, or where superheated steam injection is not used, a post-capping sterilization treatment is employed.

Some jellies would form bubbles on the surface of which should be quickly skimmed so only clear jelly is filled into the jars. If jelly is to be poured into glass jars, the sides of the jar should be smooth so that the jelly can be turned out without breaking its shape or structure. Before pouring the jelly, glass containers should be warmed to prevent breakage. After filling, the jars should be cooled rapidly to about 21°C. Pectin jellies set more quickly at this temperature than at lower temperatures. If the jelly fails to set or is weak, it is placed in a drier to evaporate the excess of water in it and promote setting (Giridhari Lal et al. 1986).

Deterioration in storage is now largely prevented by hermetically sealing the jars, while still hot, in sterile manner using metal caps fitted with rubber gaskets. Many patented caps of this kind have been devised, which can be placed in position, sterilized by steam jets in a steam box and, finally, held firmly by creating a partial vacuum in the head space of the jars, either in a specially constructed vacuumizing chamber or merely by screwing them up tightly while still hot. Jars sterilized and sealed in this way form an ideally hygienic package and are to a very large extent independent of storage conditions.

Two types of vacuum-sealed jars are in common use. In one of these, the seal between the glass and jar cover is made with a rubber composition ring attached to the cap. This composition melts during pasteurization, and after cooling of the jar and contents, it solidifies to form an air-tight seal. The lid must be held in place with a clamp during pasteurization. The second type of jar is sealed with a rubber gasket similar to a fruit jar rubber, but this rubber is pressed against the side of the jar rather than the top. It is held in place by friction and the cap is rolled in much the same manner as an ordinary sanitary can top. The cap needs no clamp to hold it in place during pasteurization. A similar lid is pressed into position but is not rolled (Cruess 1948).

Small enamel-linked jam cans and gallon cans are sometimes used for jelly. Wooden tubes or buckets are often used for cheap jellies for baker's use, the product usually being preserved with sodium benzoate. The inside of cans used for jellies made from fruits of red color should be heavily lacquered to prevent bleaching of the color by tin salts. Glass containers are almost universally used for jams and jellies. For jams, the processes of filling and sealing are done by automatic machinery as described for jellies.

NOVEL VALUE-ADDED JAMS AND JELLIES

Response surface methodology was used to develop low-calorie jellies and to evaluate three factors, viz, sweetener, LM pectin, and calcium contents at three levels each on the overall acceptability of a tropical mixed fruits of pineapple, banana, and passion fruit jellies. A statistical model was used to optimize the three factors for highest acceptability and to obtain a jelly that provided less than 12 calories per serving, allowing the products to be labeled as "low calorie" (Acosta et al. 2008).

Seabuckthorn fruits are rich sources of vitamin C, carotenoids, and other ingredients. Despite being acidic, seabuckthorn berries have potential for being used in a wide variety of processed foods such as fruit juices, squashes, syrup, jam, and jellies (Chauhan et al. 2003). The seabuckthorn berries grow wild in the cold desert of Himalayas. Nutritive composition of seabuckthorn berries was compared with that of apples and guavas. Jam and jellies were produced from seabuckthorn berries and various combinations of apple and guava. Out of six combinations of jam prepared using seabuckthorn pulp at the minimum level of 25 % with 75 %

guava had the best overall acceptability. Jellies were prepared from seabuckthorn berries alone or by combination of guava extract in 40:60, 50:50, and 60:40 ratios. Pure seabuckthorn jelly did not set completely and had a semisolid consistency. Setting was improved by addition of pectin. The jelly prepared with 50:50 guava:seabuckthorn was highly acceptable due to proper setting and good scores for flavor, taste, and color (Kotoch et al. 2006).

Seabuckthorn mixed fruit jellies are prepared by blending seabuckthorn juice with papaya, watermelon, or grapes in varying proportions, maintaining a constant level of TSS and acidity in the final product. Among the blends, seabuckthorn plus grape juice exhibited good sensory properties and high sensory scores. The shelf stability of jellies was evaluated at ambient and 37°C for a period of 6 months. Seabuckthorn in combination with grape was acceptable under ambient temperature conditions and stored in PET bottles. The microbial load of stored jelly under above conditions was found to be within acceptable limits (Muthukumaran et al. 2003, 2007).

A process has been developed to prepare low-calorie apricot jam by using different hydrocolloids and sweetener. Because of the combination of proper gelling agents, a desirable texture was obtained in the product (Vibhakara et al. 2004).

Strawberry represents the main source of ellagic acid derivative in the Brazilian diet. They are also good source of flavonoids, mainly anthocyanins besides phenolic acids to which many beneficial effects have been attributed. Five different commercially available strawberry jams were characterized in relation to the abovementioned parameters. It was observed that total phenolics varied from 58–136 mg/100g (f.w.b.) and the antioxidant capacity from 0.55–0.76 μmol BHT equivalents/g (fresh weight basis). The data indicated that jam can be a source of antioxidant compounds (da Silva et al. 2007).

HIGH-PRESSURE PROCESSING IN JAM MANUFACTURING

There are jams obtained by subjecting a mixture of raw materials to high hydrostatic pressure treatment without heating. Accordingly, under predetermined conditions, permeation of a solution of sugar into fruits as well as sterilization and jam setting can be conducted simultaneously, and it is not necessary to carry out the conventional heat treatment at all. Thus, novel jams maintaining color and taste of fresh fruits can be obtained using high hydrostatic pressures. High pressure offers a potential nonthermal preservation method for pasteurization of food products. It can also result in microbial destruction and product stabilization without affecting sensory qualities (Basak and Ramaswamy 1988). Pectin levels, texture, and color properties of strawberry jam were studied using high-pressure processing. The data indicated that the optimal pectin concentration for color retention and textural properties are 2.5–5% (w/w). Current research is directed towards investigations on the parameters that affect the quality of high-pressure processed jam with the aim of producing high-pressure jam with superior organoleptic qualities (Panagiota et al. 2001).

SPECIFICATIONS/STANDARDS

Jams and jellies are widely used in nearly every part of the world. Large numbers of units are manufacturing jams and jellies to cater the demand of domestic and export market. The domestic market comprises of defence and institutional sector, railways, airlines, consumer stores, and bakeries. Each year many new types of jams and jellies appear on retail shelves and represent competition for the traditional ones. Improvements in processing techniques, more basic knowledge about fruit characteristics, and competitive situations have resulted in a great increase in the overall quality of the products. Precautionary steps to maintain quality assurance and quality control in manufacturing jams and jellies are described in Table 14.2.

The U.S. FDA published standards of identity in 21 CFR 150 and treats jam and preserves as synonymous, but distinguish jelly from jams and preserves (Table 14.3). The FPO specification for jams and jellies recommended standards of FAO/WHO Codex Alimentarius Commission are quoted under jams (fruit preserves) and jellies CAC/RS 79/80-1976 regarding their composition, formation, soluble solids of the finished products, and quality criteria (Ranganna 1986; Table 14.4).

The codex Alimentarius standards aim at protecting consumer's health and ensuring fair practices in the food trade. Their publication is intended to promote the standardization of jams and jellies in various parts of the world to facilitate harmonization of standards and in doing so to further the development of international food trade.

In European Union, the jam directive (council directive 79/693/EEC, July 24, 1979) set minimum standards for the amount of "fruit" in jams. Specifications were made for vegetables that are sometimes made into jams, such as carrots,

Table 14.2. Precautionary Steps to Maintain Quality Assurance and Quality Control in Manufacturing Jams and Jellies

1. Use HACCP throughout the production process.
2. Verify raw material quality.
3. Meet proper specifications of pH, Brix, and pectin contents.
4. Maintain hygienic conditions before and after usage.
5. Testing of post-processing to ensure finished product quality.
6. Regulate internal and external audit to ensure quality procedure.

Table 14.3. Codex Standard for Jams (Fruit Preserves) and Jellies and Description as Per Codex STAN 79-1981

Sl. No.	Description for Product Specification
1.	"Jam" or "preserve" or "conserve" is the product prepared from a suitable fruit ingredient
a.	Which may be whole fruit, pieces of fruit, fruit pulp, or fruit puree
b.	With or without fruit juice or concentrated fruit juice as optional ingredient (S)
c.	Mixed with a carbohydrate sweetener, with or without water
d.	Processed to a suitable consistency
2.	"Jelly" is the product prepared from a suitable fruit ingredient
a.	Which is practically free from suspected fruit particles
b.	Mixed with a carbohydrate sweetener, with or without water
c.	Processed to a semisolid consistency

sweet potatoes, cucumbers, and pumpkins. This definition continues to apply in the new directive, council directive 2001/113/EC (Dec 20, 2001).

There are large numbers of jams and jellies now produced that do not meet the FDA standards with respect to fruit (or juice) sugar ratio or optimal ingredients. These are sold as "imitation" jams or jellies. Many of them are now made by use of corn syrup and imitation flavors. Since no standards have been set up for such products, any of the edible food acids can be used in their formula. However, it needs to be highlighted on the label. Malic acid, fumaric acid, adipic acid, or succinic acid, when used in whole or part, offers some interesting flavor properties. Since these products do not meet the federal standards for fruit jams and jellies, they should be labeled "IMITATION" on the label of the product along with its ingredients used (Tresser and Woodroof 1976). Some codes of practice aim to set out the characteristics of good manufacturing practice (GMP) to achieve quality during processing. As with codex standards, these recommendations are sent to national governments with a clear suggestion that the recommendations should be followed.

Table 14.4. FPO Specifications of Jams and Jellies

Determination	Specification
Fruit content	Not less than 45%
Total soluble solids	Exception: raspberry and strawberry
	Jams—not less than 25%
	Jams—not less than 68% w/w
	Jelly—not less than 65% w/w
Preservatives	
Sulfur dioxide	Not more than 40 ppm
Benzoic acid	Not more than 200 ppm
Synthetic sweetening agents	Not permitted
Added color	Permitted colors
Mold growth	Absent
Fermented test	Negative pressure at sea level
	Retain flavor of original fruit
	Free from burnt or other objectionable flavors
Crystallization	Absent

FUTURE RESEARCH NEEDS

Jam and jelly production relies on the native pectins of incorporated fruit for gel formation. Modern manufacturing requirements of uniform gel strength and appearance preclude reliance on fruit maturity and variety. In spite of the current availability of other gelling agents, pectin remains the universal choice for jams and jellies, in part because of its presence as a natural fruit ingredient and also because of the characteristic consistency that pectin imparts to a gel. The joint FAO/WHO committee on food additives recommended pectin as a safe additive with no limit on acceptable daily intake, except as dictated by GMP.

In recent years, pectin has been used as a fat or sugar replacer in low-calorie foods. It is estimated that 80–90% of commercial pectin production, which totals 6–7 million kg, is used in the production of jellies and jams (Crandall and Wicker 1986). In spite of its availability in a large number of plant species, commercial sources of pectin are very limited. There is a need to explore other sources of pectin or modify the existing sources to obtain pectin of desired quality attributes. Current knowledge of the molecular basis of gelation in pectin has helped us to understand some aspects of this complex phenomenon. There are still some areas where our knowledge is scanty. So a systematic study of these observations will help in understanding the reaction processes in pectin gel formation, resulting in better control of processes and products.

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15
Fresh-Cut Fruits

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Abstract: Fresh-cut fruits appeared in the market as a response to growing demand for fresh-like quality products and an increase in popularity of ready-to-eat products. The fresh-cut produce requires new preservation techniques capable of maintaining the safety and quality of commodities long enough to make distribution feasible and achievable. In the developed countries, those commodities are provided by the food industry while in the rest of countries these products are prepared under uncontrolled conditions which is a big risk for consumers. Conscientious of the growing interest on this kind of products by consumers, researchers are increasing efforts in offering adequate technologies and practices to processors in order to assure products safety while keeping the most nutritional and sensory properties of the fresh fruit or vegetable.

This chapter aims to introduce the main factors of minimal processing, which affect the handling of raw material, processing, packaging, and distribution of fresh-cut fruit. Requirements for extending microbiological, sensory, and nutritional shelf life of fresh-cut fruits are analyzed in each step of the production chain. This chapter covers some recent advances for the maintenance of fresh-cut fruit-quality with respect to washing and sanitizing raw materials for minimally processed fruit products, the use of chemical compounds, including plant natural antimicrobials and antioxidants, as well as calcium salts for maintaining texture. It also includes advances in modified atmosphere packaging (MAP) systems, distribution and commercial storage of fresh-cut fruit commodities. Edible coatings are presented as a good alternative or complementary to MAP packaging. Better technology for the entire processing chain would permit processors to achieve more stable products and to meet the highest hygienic standards, thus reinforcing the consumers trust on fresh-cut fruit.

INTRODUCTION

Fresh-cut fruits appeared in the market as a response to growing demand for fresh-like quality products and an increase in popularity of ready-to-eat products. The fresh-cut produce requires new preservation techniques capable of maintaining the safety and quality of commodities long enough to make distribution feasible and achievable. These products were first introduced in the markets of countries such as the United States, which have efficient commercial distribution systems.

Fresh-cut fruits and vegetables are also called lightly processed, ready-to-eat, and minimally processed fruits and vegetables. These products are usually defined as those processed by appropriate unit operations, such as washing, peeling, slicing, and packaging, including chemical treatments, which may have synergistic effect (Wiley 1994). The processing of fresh-cut produce includes packaging in modified atmosphere (MA) as well as storage at 2–4°C during the shelf life of about 7–10 days (Fig. 15.1).

For processors, achieving microbiologically safe products with fresh-like sensory quality and nutritional values can be a challenge despite the amount of research on this topic

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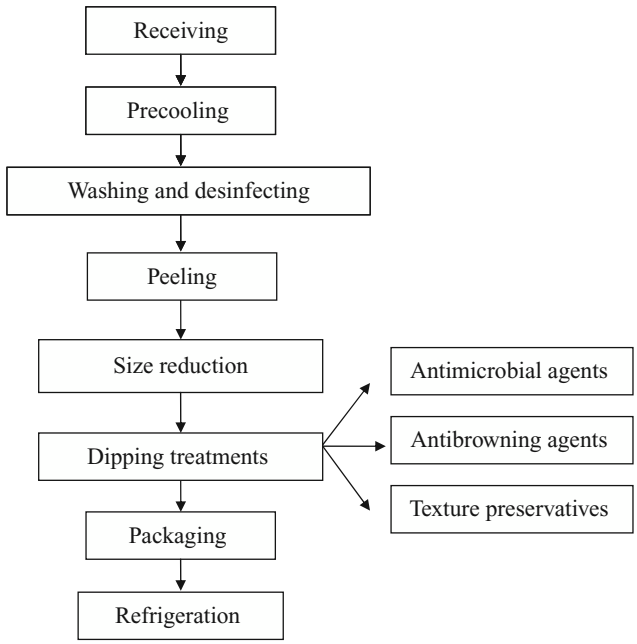

Figure 15.1. Flow diagram of fresh-cut produce.

(Bett et al. 2001, Rojas-Graü and Martín-Belloso 2008). As a result of peeling, cutting, and preparation of ready-to-eat fruits, a large number of physiological phenomena, such as biochemical changes and microbial spoilage, take place and may result in degradation of color, texture, and flavor. As the acceptance of fresh-cut fruits by consumers is mainly based on fresh-like appearance as well as flavor and texture, these attributes will determine the commercial viability of fresh-cut produce.

Physiological factors such as cultivar, growing and harvesting practices, postharvest treatments, and/or maturity at processing would influence the feasibility of processing into a fresh-cut product (Rocha et al. 1998, Soliva-Fortuny et al. 2002a).

This chapter aims to introduce the main factors of minimal processing, which affect the handling of raw material, processing, packaging, and distribution of fruits. The requirements for extending microbiological, sensory, and nutritional shelf life of fresh-cut fruits are analyzed in each step of the production chain.

HYGIENIC REQUIREMENTS FOR FRESH-CUT FRUIT PROCESSING FACILITIES

During peeling and cutting operation, the natural barrier of skin is removed and damage is inflicted to the fruit tissue. This requires that fresh-cut fruits be processed under strict sanitary conditions. Unlike whole fruits, fresh-cut products can be spoiled by hazardous human pathogens (FDA 2001). Therefore, microbiological risks have to be controlled and reduced from the orchard to the consumer.

The appropriate handling of whole fruits during harvest and postharvest can significantly reduce the risk of contamination prior to processing. If fruits were contaminated with pathogenic microorganisms during these steps, sanitation with chlorine or other disinfectants would not assure the product safety. Cleaning operations of field bins, drenchers, storage chambers, and other possible sources of cross-contamination must be carefully controlled to ensure proper sanitation.

The risk of product contamination does not stop at this point. Adherence to good manufacturing practices and the implementation of hazard analysis critical control points (HACCP) are important in a processing plant for such commodities. Within the processing plant, hygienic conditions should be maintained. All workers, maintenance personnel, and visitors should be required to wear gloves, caps and appropriate smocks, and footwear. Hygiene training should insist on the importance of hand washing with bactericidal soap and water before entering the plant. Gloves should also be renewed several times a working shift. General advice should be followed regarding conditions during processing. Proper sanitation of the processing facilities must be conducted to ensure exclusion of harmful bacteria. In addition, low temperatures are helpful to inhibit microbial growth and to minimize the respiration of the cut fruit in response to mechanical bruises (Toivonen and DeEll 2002). Refrigeration temperatures below 8–10°C are important. Also, cooling of dipping solutions or transport water is an effective way of controlling microbial spoilage although some microorganisms, even pathogenic, such as *Listeria monocytogenes* can grow under those conditions (Zagory 1999).

Use of field bins is not suggested; plastic washable boxes or pallet boxes are more appropriate for maintaining the sanitation. Compartmentalization of each step of the process, especially the first, may help to prevent cross-contamination of the product throughout processing. Before the cutting operations, a rinse in chlorinated water may reduce the initial loads of naturally occurring microorganisms. Design of hygienic equipment for these processes is required. Some of the equipment available in the market has evolved from machinery used by fruit preserve producers. Mechanical peelers that remove skin, seeds, and debris, with isolation of the parts in contact with the product from other components of the machine, are a must. It is important to ensure that the cutting blades are kept clean and sharp. An alternative to blade peeling technologies could be the use of water jet cutting systems, which would substantially improve the risk of cross-contamination during this step. However, the high cost of water jet systems limits their use in the fruit industry.

The next processing steps are generally conducted to extend the fresh-cut fruit shelf life, although little can be done

to reduce much of the contamination. Dips to stabilize the cut surfaces are often blends of antioxidants and/or antisoftening agents (Rosen and Kader 1989, Gorny et al. 1998a). Since it is not possible to replace these solutions after a single batch, because of the high cost of the products used, they represent a high risk of cross-contamination through the plant process. New methods are to be developed to sanitize these solutions, given that chlorine, ozone, ultraviolet (UV) light, and other possible methods of decontamination, such as thermal treatments, are not compatible with most antioxidant treatments (FDA 2001).

QUALITY OF RAW MATERIAL

Once detached from the plant, fruits undergo a physiological response such as transpiration, respiration, and ripening. Transpiration leads to loss of water and the consumption of substrates during respiration converts the stored energy into usable energy to sustain life. Thus, the higher the transpiration and respiration, the shorter the shelf life. Such processes are mainly responsible for wilting, shrinking, and loss of firmness among other phenomena, which adversely affect sensory quality of produce (Amiot et al. 1995, Kader 2002, Soliva-Fortuny et al. 2004).

The quality of fresh-cut fruits depends directly on the quality of the raw material and other factors related to processing, storage, and distribution (Gorny et al. 1998b). These factors include the condition of the raw materials such as firmness, size, variety, and ripeness at processing. These significantly affect the shelf life and quality of produce.

The ripening process is induced by the plant hormone ethylene and related factors characterized by physical, chemical, physiological, and metabolic changes. Ripening has an important influence on sensory features related to color, flavor, and texture of fruits. Ethylene may be responsible for the synthesis of enzymes that lead to ripening and subsequent senescence and degradation (Perera and Baldwin 2001). In fact, these adverse effects of ethylene on quality tend to be enhanced in climacteric fruits, since ripening implies a larger evolution of ethylene and abrupt rise in respiration rates when ripeness is about to take place. Generally, climacteric immature fruits are more likely to shrivel and undergo physiological alterations during processing. Overripe fruits may produce less ethylene but are more sensitive to mechanical damage and fungal development. Softness, mealiness, and insipid flavor are some sensory characteristics related to excessive maturity at processing (Kader 2002). Ethylene production observed during the first weeks of storage under passive packaging conditions can double that of ripe fruits, compared to fresh-cut apple and pear slices processed in a partially ripe state (Fig. 15.2). Therefore, the ripeness stage of fruit at processing clearly determines the shelf life of fresh-cut fruits (Soliva-Fortuny et al. 2002a).

The quality of fresh-cut produce is related to an appropriate selection of cultivars. In pears, the shelf life based on flesh firmness and cut surface discoloration can be affected by cultivar. Barlett pears showed the longest shelf life among cultivars such as Bosc, Anjou, and Red Anjou (Gorny et al. 2000). Additionally, the most important factors that determine the shelf life of fresh-cut peach and nectarine slices (Gorny et al. 1999) are

- Selection of cultivars,
- Maturity at harvest (18-31 N flesh firmness), and
- Proper storage temperature (0°C) and relative humidity (RH; 90–95%).

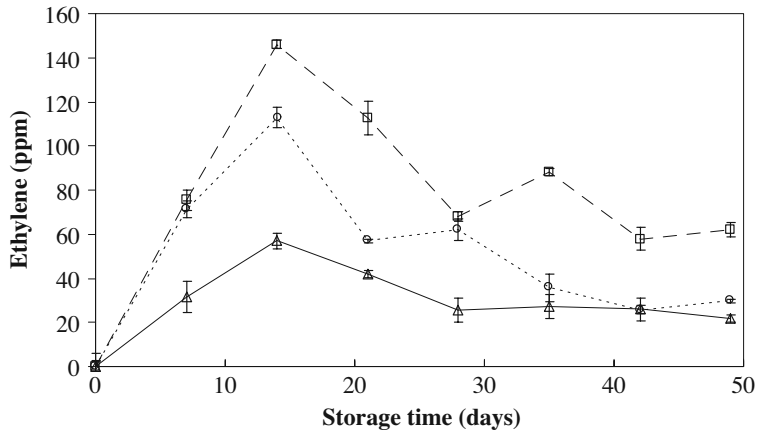

Figure 15.2. Ethylene concentrations in the package headspace of fresh-cut pears processed at different maturity states: Circles, mature-green pears; squares, partially ripe pears; triangles, ripe pears.

PROCESSING

Washing and Sanitizing Raw Materials for Fresh-cut Fruit Produce

Washing and sanitizing of raw fruits is required to remove pesticide residues, plant debris, and other possible contamination as well as microorganisms responsible for quality loss and decay. Fruit products undergo fermentative spoilage by lactic acid bacteria or yeasts, resulting in the production of acids, alcohol, and CO_2. Fermentative species of yeasts such as *Kloeckera* and *Hanseniaspora* occur naturally on the surfaces of fruits and are capable of causing fermentative spoilage (Barnett et al. 2000).

Raw material is generally immersed in tap water, whereas sanitizing agents are added to process water to effectively reduce the microbial loads on the fruit surface. The use of chlorine at a concentration no greater than 200 ppm has been widely reported as an effective sanitation treatment of both whole and fresh-cut fruits (Lanciotti et al. 1999, Dong et al. 2000, Gorny et al. 2000, Bett et al. 2001, Soliva-Fortuny et al. 2002b). In melon and watermelon, sanitation of the whole fruit is usually achieved by using dips ranging from 50 to 1000 ppm of sodium hypochlorite (NaOCl; Qi et al. 1999, Portela and Cantwell 2001). The effectiveness of NaOCl on microbicidal activity is related to the concentration of sanitizer as well as pH and temperature. On the other hand, chlorine efficacy may be influenced by the type of produce and diversity of microorganisms that fruits contain (Beuchat 2003).

New sanitizing agents have been introduced in the past few years because of concerns about the products obtained when chlorine is decomposed by organic matter, resulting in the formation of potentially harmful substances, such as chloroform or other trihalomethanes, which are known or suspected of being carcinogenic. Therefore, the use of chlorine in the fresh-cut industries has been forbidden in some European countries such as Germany, The Netherlands, Denmark, Switzerland, and Belgium (Carlin and Nguyen-the 1999, Betts and Everis 2005). As a consequence, several innovative approaches have been explored for the decontamination of minimally processed fruits and vegetables.

Other sanitizers such as hydrogen peroxide (H_2O_2), chlorine dioxide, peroxyacetic acid, and organic acids have been used for washing produce. Hydrogen peroxide demonstrates a broad-spectrum efficacy against virus, bacteria, yeasts, and bacterial spores, although it is less active against fungi than against bacteria (Block 1991). Its bacteriocidal effect is based on the production of hydroxyl free radicals (·OH), which attack essential cell components, including lipids, proteins, and DNA (McDonnell and Russell 1999). The efficacy of H_2O_2 washing has been demonstrated to be similar to that of NaOCl for extending the shelf life and reducing the native microbial and pathogen populations, including *Escherichia coli*, of whole grapes, prunes, apples, oranges, melons, tomatoes, and fresh-cut melons (Artés et al. 2007). Sapers (1996) also showed that hydrogen peroxide vapor treatments were highly effective in reducing loads of microorganisms on whole prunes and table grapes. Hydrogen peroxide solutions used alone or combined with commercial sanitizing agents achieved more effectiveness in decontaminating apples, which contained nonpathogenic strains of *E. coli*, than by using chlorine or other commercial sanitizing agents for fruits or vegetables (Sapers et al. 1999). However, exposure to H_2O_2 vapor caused bleaching of anthocyanins in strawberries and raspberries. This treatment could also be unfit for pome fruits due to the presence of residual contents in the product (Sapers and Simmons 1998). Although H_2O_2 is permitted for other uses in food processing and packaging because it leaves no potentially harmful residues, it is not yet approved by the Food and Drug Administration (FDA) as a sanitizing agent for fresh produce (Artés et al. 2007).

Chlorine dioxide (ClO_2) is more effective than free chlorine against many classes of microorganisms at lower concentrations. Its major advantages over NaOCl include reduced reactivity with organic matter and greater activity at neutral pH. Chlorine dioxide has been shown to produce lower amounts of potentially carcinogenic chlorinated reaction products than chlorine (Tsai et al. 1995). There are very few reports about the use of ClO_2 in fresh-cut products. It has shown, though, that for apple, lettuce, strawberry, and cantaloupe, concentrations of 3–5 mg/L are effective for inhibiting the main epiphytic microbiota as well as some inoculated foodborne bacteria such as *E. coli* and *L. monocytogenes* (Rodgers et al. 2004, López-Gálvez et al. 2010). A main drawback is that it has to be generated on-site by reacting sodium chlorite and acid or chlorine. Currently, new technology allows for an easier production by systems where the reactants are packed together. ClO_2 is unstable and can be explosive when concentrations reach 10% or more in air (Betts and Everis 2005).

Several published studies have assessed the efficacy of different sanitizers against *E. coli* O157:H7 on inoculated apples. Apples washed with 80 ppm of peroxyacetic acid reduced the microbial loads by about 2 logs, and a 5% acetic acid wash reduced the load by about 3 logs when compared to water wash (Wright et al. 2000). On the other hand, 80 μg/mL of chlorine dioxide, 16 times the recommended concentration, was needed to reduce the population of *E. coli* O157:H7 by 2.5 logs (Wisniewsky et al. 2000). A dip containing 68 ppm of peroxyacetic acid reduced psychrotrophic counts on fresh-cut Galia melon by 2 log units and mesophilic counts by 1 log units in comparison with a 150 ppm NaOCl dip, which allowed to extend shelf life to 10 days at 5°C (Silveira et al. 2007).

Ozone, UV light, and pulsed light could be other alternatives to traditional sanitizing agents as these sanitizing processes are not only effective in destroying microorganisms, but they could also improve the safety of fruits because

of the lack of residues on produce. Fungal deterioration of blackberries and grapes was decreased by ozonation of the fruits (Beuchat 1992). Recent studies supported this work; ozone exposure at 0.3 ppm inhibited the normal aerial growth of the mycelia and prevented sporulation on peach wounds inoculated with *Monilinia fructicola*, *Botrytis cinerea*, *Mucor piriformis*, and *Penicillium expansum* and stored for 4 weeks at 5°C and 90% RH. Under 0.3 ppm ozone, gray mold, caused by *B. cinerea,* spread from the decayed fruit to adjacent healthy fruit among table grapes was also completely inhibited, when fruits were stored for 7 weeks at 5°C (Palou et al. 2002). In citrus fruit, the exposure to ozone did not reduce final incidence of postharvest green mold, caused by *Penicillium digitatum*, and postharvest blue mold, caused by *Penicillium italicum Wehmer*, although infections developed more slowly on fruits stored in an ozonated atmosphere than on fruits stored in an ambient air atmosphere (Palou et al. 2001).

UV light could be effective as a minimal processing alternative for extending the shelf life of fresh-cut fruits. The effect of UV light (UV-C, $\lambda = 254$ nm) may be based on its direct effect on pathogens because of DNA damage as well as its ability to simulate biological stress in plants and, consequently, by inducing resistance mechanisms in different fruits against pathogens. Actually, the exposure of melon slices to UV light decreased the concentrations of most of the aliphatic esters by over 60% of the amounts present in fresh-cut fruit and resulted in the production of terpenoid compounds in response to biological stress, particularly β-ionone, which is capable of inhibiting the microbial growth in the fruit tissue (Lamikanra et al. 2002). UV at a wavelength of 253.7 nm was applied to apples inoculated with *E. coli* O157:H7, achieving a log reduction of approximately 3.3 logs at 24 mW/cm^2 (Yaun et al. 2004).

Intense light pulses are an interesting decontamination method for food surfaces approved by the U.S. FDA that could be suitable for disinfecting fresh-cut fruit. Different microorganisms, including *Alternaria alternate*, *A. niger*, *B. cinerea*, *Fusarium oxysporum*, *Fusarium roseum*, *Monilinia fructicola*, *Penicillium expansum*, *Penicillium digitatum*, and *Rhizopus stolonifer*, were completely or partially killed after exposure of fruit surfaces to PL (248 nm) treatments (Lagunas-Solar et al. 2006). These authors observed that the energy threshold that causes injury in fruits such as apples, oranges, lemons, peaches, raspberries, and table grapes was below 2 J/cm^2. Maximum 4.3 and 2.9 log CFU/mL reductions for *Salmonella* and *E. coli* O157:H7, respectively, were achieved after treating blueberries with a PL treatment of 22.6 J/cm^2 for 60 (Bialka and Demirci 2007). On raspberries and strawberries, maximum 3.9 and 2.1 log reductions of *E. coli* O157:H7 were obtained after treatments of 72 and 25.7 J/cm^2, respectively, while 3.4 and 2.8 log reductions of *Salmonella* were observed at 59.2 and 34.2 J/cm^2 (Bialka and Demirci 2008).

Mechanical Operations

Mechanical operations during minimal processing damages fruit tissues, which in turn limits the shelf life of products. Operations including peeling, coring, cutting, and/or slicing are responsible for such phenomena as microbial spoilage, desiccation, discoloration or browning, textural changes, and development of off-flavor or off-odor. During the preparatory steps of minimal processing, the natural protection of fruit (the peel) is generally removed, and hence, they become highly susceptible to microbial spoilage. During processing, the leakage of juices and sugars from damaged tissues allow the growth and fermentation of some species of yeasts such as *S. cerevisiae* and *S. exiguous* (Heard 2002).

Damage on plant tissues may make them more susceptible to attack by pathogenic microorganisms and contamination with human pathogen. Cross-contamination may occur during cutting and shredding operations because sanitation in raw fruits may have not been carried out properly (Garg et al. 1990). The whole fresh fruits with bacterial soft rot and fungal rot were shown to have a high incidence of contamination with *Salmonella* spp. (Wells and Butterfield 1997, 1999).

Although food safety is the most important consideration, color, texture, flavor, and nutritional values of the produce are equally important for acceptability by consumer. Therefore, the influence of cutting operations on quality should be taken into account. It is clear that turgor-pressure has a great incidence on the textural response, as it has been reported for minimal processed melon by Rojas et al. (2001). In bananas, less ethylene production and lowest respiration rate were observed when 1-cm thick transverse cutting section was chosen (Abe et al. 1998). In apples or pears, the core and adjacent tissues should be removed during cutting operation because these parts of the fruit are susceptible to browning (Soliva-Fortuny et al. 2001).

Enzymatic browning is regarded as one of the most important problems related to color deterioration in fresh-cut fruit produce. Such phenomenon is caused by the discoloration of fruit by the action of enzyme polyphenol oxidase (PPO). This enzymatic reaction consists of the oxidation of phenolic substrates, found naturally in many fruits, to *o*-quinones, which are highly reactive compounds and will react with (Whitaker and Lee 1995)

- Other quinone molecules
- Other phenolic compounds
- Amino groups of proteins, peptides, and amino acids
- Aromatic amines, thiol compounds, ascorbic acid (AA), etc.

Browning phenomena are caused when, after mechanical operations during processing, enzymes, which are liberated from the tissues, come in contact with phenolic compounds. However, several factors may contribute to the development of brown pigments due to enzymatic browning. The tendency

toward browning may be influenced by high concentration or types of phenolic compounds in fruits as well as high PPO activity (Garcia and Barrett 2002), ripeness stage, activity of oxidative enzymes, oxygen availability, and compartmentalization of enzymes and substrates (Nicoli et al. 1994, Rocha et al. 1998). According to Soliva-Fortuny et al. (2002b), in mature apples, the chloroplast begins to disintegrate, causing a solubilization of PPO, which would increase the oversensitivity of browning. In pears, browning is related to phenolic and PPO compositions, whose contents may vary according to cultivar, stage of maturity, and postharvest storage conditions (Amiot et al. 1992). It was found that, in pear fruits of different varieties, the susceptibility to browning and the phenolic content were not greatly different, although a significant decrease in the phenolic content occurred with delayed harvest times (Amiot et al. 1995). Reduced rates of enzymatic browning in pears may be related to low levels of PPO (Soliva-Fortuny et al. 2002b).

It has been shown that pectinolytic and proteolytic enzymes may be responsible for softening when they are exuding from bruised cells during slicing operations. These enzymatic mechanisms not only play a significant role in the softening process but also affect morphology, cell wall-middle lamella structure, cell turgor, water content, and biochemical components (Harker et al. 1997). Peeling and cutting also results in high rates of moisture loss from cut surfaces as it was reported in pears by Gorny et al. (2000). Increased rates of water loss lead to wilting and/or shriveling, limiting factors of quality in fresh-cut produce (Toivonen and DeEllm 2002).

Low temperatures minimize the effects of mechanical injuries because they are able to reduce enzymatic activity, metabolic reactions, and microbial growth. Processing is performed at around 10–15°C, and washing water is generally refrigerated (Ahvenainen 1996). Rinsing the peeled and/or cut product in cold water is suggested to keep products in a suitable range of temperature or for removing cellular exudates released during mechanical operations.

Dipping Treatments

Dipping treatments after peeling and/or cutting reduce microbial loads and rinse tissue fluids, thus reducing enzymatic oxidation during storage and the growth of microorganisms.

Because of low pH values of most fruits, the main typical flora consists of molds and yeasts. Both fungi and yeasts are responsible for the production of a wide range of enzymes. Among these, pectic enzymes should to be taken into account because of their role in the degradation process of plant polymers. *B. cinerea and Aspergillus niger* were found to be important fungi on fruits as well as yeasts such as *Canidia*, *Cryptococcu*s, *Fabospora*, *Kluyveromyces*, *Pichia*, *Saccharomyces,* and *Zygosaccharomyces* (Chen 2002). Also, the ability of lactic acid bacteria to alter food flavor might contribute to the relatively rapid flavor loss in fresh-cut fruits. In fact, the deterioration of fresh-cut cantaloupe stored at 20°C was related to gram-positive bacteria and an increased production of lactic acid (Lamikanra et al. 2000). During the spoilage of fruits, gram-negative bacteria such as pseudomonads are believed to degrade the fruit tissues through the production of pectic enzymes.

Consumption of fresh-cut fruits are associated with foodborne disease due to some pathogenic bacteria such as *Cyclospora cayetanensis* in raspberries, *Salmonella* spp. in precut watermelons, and *Shigella* spp. in fruit salad, among others (Heard 2002). In general, pathogens may often be able to grow on some fruit surfaces such as melon, watermelon, papaya, or avocado because of the high pH value of the fruits. For example, *Shigella* species can survive on sliced fruits, including watermelon and raw papaya (Escartín et al. 1989). A recent study suggests that, after contamination, *Campylobacter jejuni*, a common cause of foodborne bacterial gastroenteritis in developed countries worldwide, may continue to survive on cantaloupe pieces and strawberries (Kärenlampi and Hänninen 2004). *E. coli* O157:H7 can grow within damaged or wounded apple tissues (Dingman 2000). The ability of *E. coli* O157:H7 to grow in the moderate pH of a bruise will likely predispose the bacterium for survival in a fresh-cut fruit. Therefore, the use of damaged fruits will increase the risk for contamination of fresh-cut products.

Proliferation of microorganisms on the surface of fresh-cut fruit is currently retarded or inhibited by using low storage temperature, MA packaging, and antimicrobial substances (Rojas-Graü and Martín-Belloso 2008). Either spraying of antimicrobial agents throughout the cut surface or dipping into antimicrobial solutions is widely practiced to prevent microbial growth (Oms-Oliu et al. 2010). Organic acids are usually applied as a dip. Citric acid has been widely used as an effective preservative because it is able to reduce the pH of cut fruits such as orange (Pao and Petracek 1997), apple (Rocha et al. 1998), peach, apricot, kiwifruit (Senesi and Pastine 1996), avocado (Dorantes et al. 1998), and bananas (Moline et al. 1999). However, there is a growing demand for natural food, where the use of chemical additives is reduced or eliminated. Hence, the use of antimicrobial agents from plants and plant products can represent a natural alternative to food additives. These substances, generally regarded as safe (GRAS), are able to inhibit microorganisms (Utama et al. 2002). Some natural constituents, such as hexanal, hexanol, 2-(*E*)-hexenal, and 3-(*Z*)-hexenol, responsible for the aroma of some fruits and vegetables provide protective action towards microbial proliferation in wounded areas (Gardini et al. 2002). The effectiveness of hexanal in improving quality of minimally processed apples is based on its antimicrobial activity, its ability to delay color deterioration of slices, and its interconversion to volatile compounds, giving an enhancement of aromatic properties. The formation of volatile compounds such as hexanol and hexyl acetate may be beneficial as they are regarded as inhibitors of the PPO (Valero et al. 1990). Hexanal inhibited mesophilic bacteria at 4°C and considerably prolonged

the lag phase of psychrotrophic bacteria. Its presence also significantly inhibited, at abuse temperatures, the growth of molds, yeasts, mesophilic, and psychrotrophic bacteria (Lanciotti et al. 1999). Hexanal, 2-(*E*)-hexenal, as well as hexyl acetate are also capable of inhibiting some pathogenic bacteria. In fresh apple slices, their addition at levels of 150, 150, and 20 ppm for hexanal, hexyl acetate, and 2-(*E*)-hexenal, respectively, may have a bactericidal effect on *L. monocytogenes* and caused a significant extension of lag phases of *E. coli* and *S. enteritidis* inoculated at levels of 10^4–10^5 cfu/g (Lanciotti et al. 2003). In addition, the antimicrobial activities of hexanal, 2-(*E*)-hexenal, and hexyl acetate are positively affected by a rise in temperature, since their action is dependent on vapor pressure (Lanciotti et al. 1999). The antimicrobial action of essential oil (EO) constituents seems to be related to their solubility in the microbial membrane (Karatzas et al. 2000), their partition in the cytoplasmatic microbial membranes (Juven et al. 1994), or the perturbation of membrane permeability (Tassou et al. 2000). While in vitro antimicrobial activity has been well demonstrated, there are a limited number of studies reporting the use of EOs to inhibit microbial growth on foods. The difficulties of the application to foods underlies in their limited solubility and the impact of these substances on the organoleptic food properties, variability of their composition, and their variable activity in foods due to interactions with food components (Gutierrez et al. 2008). Citrus EOs may be compatible with the organoleptic characteristics of minimally processed fruits. Lanciotti et al. (2004) also reported that the addition of 0.02% (v/v) citrus, mandarin, cider, lemon, and lime EOs to a minimally processed fruit mix inhibited the proliferation of the naturally occurring microbiota and reduced the growth rate of inoculated *S. cerevisiae* populations, thus extending the shelf life of the fruit salad without affecting its sensory properties. In this way, Ngarmsak et al. (2006) applied a vanillin dip (0.12% w/v) to delay the development of total aerobic bacteria and yeast and mold populations of fresh-cut mangoes stored at 5°C and 10°C for up to 14 and 7 days, respectively. A dip of vanillin (0.18% w/v) inhibited 37% and 66% of the microbial growth on "Empire" and "Crispin" apple slices, respectively, after 19 days of storage (Rupasinghe et al. 2006).

The addition of chemical agents is the most common way to control browning phenomenon. They can either affect the enzyme or their substrates. AA has been generally used as anti-browning agent. This reducing agent indirectly inactivates the PPO enzyme by degrading the free radical of the histidine molecule at the active site and by reducing the cofactor Cu^{++} to Cu^{+}, thereby causing the cuprous ion to dissociate more readily from the enzyme (Osuga and Whitaker 1995). AA is able to prevent the browning caused by PPO reducing quinones back to phenolic compounds before they undergo further reaction to form brown-colored pigments. The anti-browning effects of AA have been widely demonstrated in several fresh-cut fruits under a wide range of conditions (Dorantes et al. 1998, Rocha et al. 1998, Agar et al. 1999, Buta et al. 1999, Gorny et al. 1999, Senesi et al. 1999, Soliva-Fortuny et al. 2001, Soliva-Fortuny et al. 2002a). However, this treatment may not be completely effective to control enzymatic browning of fresh-cut fruits, since once the AA is completely oxidized to dehydroascorbic acid, *o*-quinones are no longer reduced and darkening occurs (Nicolas et al. 1994). In addition, recent works have demonstrated that AA may cause important oxidative damage in fresh-cut "Fuji" apples (Larrigaudière et al. 2008).

Other anti-browning agents include thiol-containing compounds such as cysteine, glutathione, and *N*-acetylcysteine, which are thought to form colorless thiol-conjugated *o*-quinones (He and Luo 2007). Dips in aqueous solutions containing sulfur-containing amino acids such as *N*-acetylcysteine and/or glutathione at concentrations around 0.75% have been shown to inhibit browning of fresh-cut pears and apples (Oms-Oliu et al. 2006, Rojas-Graü et al. 2006).

Acidulants, such as citric acid, are effective in preventing the fresh-cut produce from browning due to its dual effect on PPO enzyme by chelating copper and its action as an acidulant (Sapers 1993). Optimum PPO activity is observed at pH 6.0–6.5, while little activity is detected below pH 4.5 (Whitaker 1994). However, acidulants are not often used alone because it is difficult to achieve efficient browning inhibition. Nevertheless, the acid combination with a chemical reductant may show a major effect. According to Pizzocaro et al. (1993), above 90% inhibition of PPO in apple cubes was reported by using a mixture of 1%AA + 0.2% citric acid or 1%AA + 0.5% sodium chloride. Effects of citric acid and/or AA dips were not effective in controlling the browning of pear slices but there was an improvement in color by adding 1% $CaCl_2$ and storage at 2.5°C for 1 week (Rosen and Kader 1989). Other carboxylic acids such as oxalic and oxalacetic acid showed higher anti-browning activity than citric acid on fresh-cut apples (Son et al. 2001). Immersion of banana and apple slices in oxalic acid solutions was effective against browning (Son et al. 2001, Yoruk et al. 2004).

Among several resorcinol derivatives, 4-hexylresorcinol (4-HR) has proved to be effective in controlling browning on fresh-cut apples and pears (Monsalve-González et al. 1993, Dong et al. 2000, Son et al. 2001, Rojas-Graü et al. 2006). These latter authors stated that 4-HR concentrations lower than 0.5% were effective in preventing browning of fresh-cut Fuji apples for 14 days at 4°C. The inhibitory action of 4-HR is based on its interaction with PPO, which compromises the ability of the enzyme to catalyze the reaction. Its applicability on fresh-cut fruit has been proven, especially when used in combination with reducing agents (Monsalve-González et al. 1993, Luo and Barbosa-Canovas 1997, Dong et al. 2000, Arias et al. 2008).

Some blends of additives have proved to extend the storage life of fresh-cut produce. A mixture of 0.001 M 4-HR + 0.5 M isoascorbic acid + 0.05 M calcium propionate + 0.025 M homocysteine maintained the freshness of apple slices

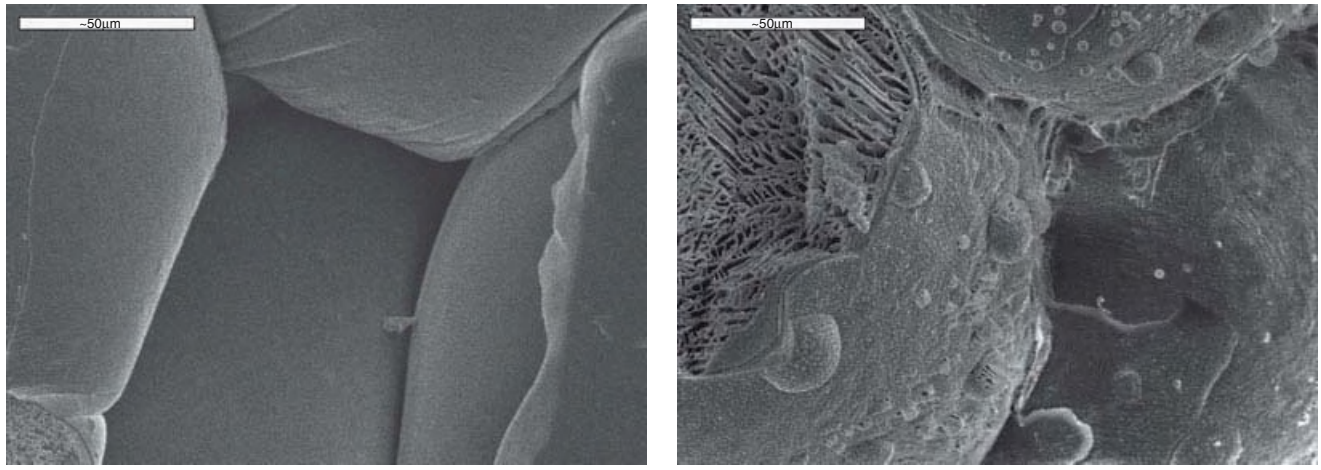

Figure 15.3. Cryo-SEM observations of fresh-cut apple cells and intercellular spaces. (**A**) Detail of smooth cell walls and intercellular space in a conjunction of cells of a newly processed tissue. (**B**) Detail of exudate droplets on the external surface of the cell walls with partial flooding of the extracellular gaps after 45 days storage at 4°C under a 2.5 kPa O_2 + 7 kPa CO_2 (balance N_2) packaging atmosphere (from Soliva-Fortuny et al. 2003).

for 4 weeks at 5°C (Buta et al. 1999). Other combinations have been suggested to be effective in preventing fresh-cut pears from browning. For instance, 4-HR in combination with sodium erythorbate had a significant effect on maintaining the color of fresh-cut Anjou pears (Sapers and Miller 1998). A dip in 0.01 4-HR + 0.5% AA + 1–0% calcium lactate solutions also provided color stability during 30 days refrigerated storage (Dong et al. 2000). Arias et al. (2008) showed the effectiveness of a treatment dip in 2% AA + 0.01% 4-HR + 1% calcium chloride solution against pear browning (Arias et al. 2008). Gorny et al. (2002) reported minor changes in the surface color of Barlett pear slices treated with 2% AA + 1% calcium lactate + 0.5% cysteine provided that the latter chemical was added at pH 7, otherwise pinkish-red colored compounds may appear (Richard-Forget et al. 1992). In fresh-cut apples and pears, *N*-acetylcysteine combined with glutathione in concentrations higher than 0.60% were effective against browning (Oms-Oliu et al. 2006, Rojas-Graü et al. 2006). In banana slices, among the antioxidants tested by Moline et al. (1999), citric acid + *N*-acetylcysteine provided the best results in browning inhibition during 1 week storage.

Softening is a major factor limiting the shelf life of fresh-cut produce. It is generally regarded that pectinase enzymes such as pectinmethylesterase (PME) and polygalacturonase (PG) are responsible for texture losses in plant tissues. PME demethylates pectin, resulting in the production of methanol and a pectin molecule with a lower degree of methylation. This allows depolymerization by PG, which breaks down α-1,4 glycosidic bonds, leading to cell wall degradation (Alandes et al. 2006). However, calcium can interact with the free carboxyl groups liberated by the de-esterification of pectin by PME to form insoluble calcium pectates, which strengthen the structure of the cell wall (Fig. 15.3). Calcium salts such as chloride, lactate, ascorbate, and propionate may be added to maintain such a structural integrity. This benefit is related to the high affinity of pectin acid to form calcium bridges.

The effect of calcium dips at concentrations ranging from 0.1% to 1% (Rosen and Kader 1989, Sapers and Miller 1998, Bett et al. 2001, Soliva-Fortuny et al. 2002c, 2002d) has been widely reported in texture preservation. A concentration of 2.5% of $CaCl_2$ has been regarded as optimal to preserve the texture of minimally processed melon (Luna-Guzmán et al. 1999). In kiwifruit slices, there were little differences between 1% and 2% $CaCl_2$ treatments. In addition, a retention of AA was observed in the slices (Agar et al. 1999). The major drawback to use of calcium salt is that it may provide bitterness to the processed product (Luna-Guzmán and Barrett 2000, Perera and Baldwin 2001, Lamikanra and Watson 2003, Saftner et al. 2003, Hernández-Muñoz et al. 2006). An integrated sensory approach involving instrumental/sensory correlations has been reported to evaluate the use of different calcium salts in fresh-cut apples by Varela et al. (2007). Their results show that dipping fresh-cut "Fuji" apples in 1% $CaCl_2$ for 3 minutes maintained the overall acceptability of the samples for at least 8 days of storage. An astringent aftertaste in treated samples was detected by a trained panel but did not affect the apple taste liking score in a consumer test.

In recent years, calcium lactate has been used as an alternative source of calcium, since it does not impart any residual taste to the product, it prevents browning, and acts as an acidity regulator (Manganaris et al. 2005). In this way, calcium

lactate stabilizes the food's pH when acids or bases are added. This effect is important for the food industry as pH of foods can affect the effectiveness of other additives such as preservatives and flavorings, which only act in a narrow pH range. Dong et al. (2000) and Gorny et al. (2002) extended the shelf life of fresh-cut pears treated with calcium lactate by substantially preventing firmness decay during storage. Alandes et al. (2006) preserved the texture of fresh-cut "Fuji" apples by treating them with calcium lactate. Peaches treated with calcium lactate were also found to be firmer than untreated samples (Manganaris et al. 2007).

Calcium propionate and calcium ascorbate have been also proposed as firming agents for fresh-cut fruit are calcium propionate and calcium ascorbate. A Cryo-SEM (scanning electron microscopy) and light microscopy study of fresh-cut "Fuji" apples treated with calcium propionate demonstrated that calcium consolidated the structure and preserved the integrity of the apple parenchyma for at least 2 weeks of storage at 4°C (Quiles et al. 2007). A dip with calcium ascorbate reduced firmness loss of fresh-cut Gala apples by roughly 13% after 3 weeks at 10°C (Fan et al. 2005). Treating fresh-cut Golden Delicious apples with calcium ascorbate and electrolyzed water reduced softening for 21 days at 4°C (Wang et al. 2007).

Drainage

Prior to packaging, the cut fruit should be submitted to a drainage step. The excess water or juice is undesirable because it may be an excellent medium for the growth of microorganisms. Moreover, some enzymatic reactions can be accelerated leading to a rapid degradation of the fruit flavor and/or appearance. A good drainage is also important between steps of the same process to avoid cross-contamination throughout the processing line. When the mechanical integrity of the fruit allows it, spinning could be an alternative to drainage, but at much lower speeds than those currently used for leaf vegetables (Rosen and Kader 1989, Bett et al. 2001, Gorny et al. 2002).

Packaging

Packaging plays an increasingly important role in the food chain. Food packaging has developed strongly during recent decades, mainly due to increased demands with regard to product safety and quality, shelf life extension, cost efficiency, environmental issues, and convenience. In order to improve the performance of packaging, innovative modified atmosphere packaging (MAP) and active and intelligent packaging systems are being developed.

MAP of fruits generally consists of the use of low oxygen (O_2) and/or high carbon dioxide (CO_2) atmospheres to slow the degradation processes that occur throughout storage. It also provides a moisture barrier that maintains a high RH in the environment, thus avoiding dehydration of the cut surfaces.

Because tissue respiration is substantially increased after processing, it can often account for the atmosphere modification that is needed to reach a desired equilibrium of gas concentrations. With this aim, plastic materials with high enough O_2 transmission rates have been developed to prevent excessive modification of the package headspace atmosphere. Too low O_2 levels and/or excessive amounts of CO_2 in the package headspace are often detrimental to the fruit shelf life because anaerobic respiration is induced, leading to fermentative processes and the subsequent production of undesirable metabolites and physiological disorders (Zagory and Kader 1988, Soliva-Fortuny et al. 2002a). Sometimes, the modification is not achieved soon enough to avoid browning and other undesirable reactions of quality loss, and the package needs to be initially flushed with an appropriate gas mixture. The package area and the ratio of product/gas are also important to reach an adequate O_2/CO_2 balance.

Actually, the most difficult task in manufacturing high-quality fresh-cut fruit and vegetable products relies on the fact that only a few of the available packaging materials are permeable enough to match the respiration of these products. Packaging films usually do not have sufficient O_2 and CO_2 transmission rates, especially for produce exhibiting a high respiratory activity and, as a consequence, too low O_2 levels and/or excessive amounts of CO_2 reached in the package headspace may eventually be detrimental to the product. In addition, packaged fruits and vegetables are usually exposed to oscillating surrounding temperatures during handling and retail display. Most MAP systems are designed for a specific temperature, and films with adequate O_2 permeability, adequate response to temperature variations, or both, are rare. Thus, changes in the environmental temperature create a specific problem in MAP systems because the film permeability used to obtained certain MA conditions do not allow the temperature variation occurring during the commercial shelf life of produce. Temperature variation can only be minimized by an integral temperature control throughout the whole logistic chain from packaging to consumption (Oms-Oliu et al. 2009).

Low O_2 atmospheres have been extensively used to extend the shelf life of cut fruits, although the limitations posed by most packaging materials available make that passive atmosphere as most used commercially. Thus, in many cases, the modification of the package headspace atmosphere is left to the respiration of the cut produce.

The use of superatmospheric O_2 concentrations ($\geq$60 kPa O_2) to maintain freshness of fresh-cut fruits has also been proposed as alternative to low O_2 atmospheres to inhibit the growth of naturally occurring spoilage microorganisms, prevent undesired anoxic respiration processes, and maintain the fresh-like quality of fresh-cut produce. Recommended gas concentrations for different fruits are displayed in Table 15.1.

Table 15.1. Recommended modified atmosphere concentrations for different fresh-cut fruits.

Commodity	Atmosphere	Bibliographic Source
Apple	<1 kPa O_2	Gil et al. (1998) Soliva-Fortuny et al. (2002b)
Pear	0.5 kPa O_2 2 kPa O_2	Rosen and Kader (1989) Gorny et al. (2000) Soliva-Fortuny et al. (2004)
Peach	2 kPa O_2 + 12 kPa CO_2 0.25 kPa O_2 + 10 kPa CO_2	Palmer-Wright and Kader (1997) Gorny et al. (1999)
Kiwifruit	2 kPa O_2 + 5 kPa CO_2	Agar et al. (1999)
Cantaloupe melon	4 kPa O_2 + 10 kPa CO_2	Bai et al. (2001)
Honeydew melon	2 kPa O_2 + 10 kPa CO_2 5 kPa O_2	Qi et al. (1999) Ayhan et al. (1998)
"Piel de sapo" melon	70 kPa O_2	Oms-Oliu et al. (2008c)
Watermelon	3 kPa O_2 + 15 kPa CO_2	Cartaxo et al. (1997)
Mango	2 kPa O_2 + 10 kPa CO_2	Nithiya et al. (2001)
Persimmon	2 kPa O_2 + 12 kPa CO_2 60 kPa O_2	Palmer-Wright and Kader (1997) Poubol and Izumi (2005)
Strawberries	1–2 kPa O_2 + 10 kPa CO_2 >70 kPa O_2	Watada et al. (1996) Van der Steen et al. (2002)
Raspberries	>70 kPa O_2	Jacxsens et al. (2003)
Citrus	Air	Palma et al. (2003)
Jackfruit	3 kPa O_2 + 5 kPa CO_2	Saxena et al. (2008)

The benefits of reducing the amounts of O_2 surrounding media are well reported in literature. Depleted O_2 levels help to reduce respiration of the cut fruits and thus limiting the consumption of sugar, starch, and other energy storage products that are responsible for texture and flavor changes. Also, a large number of enzymatic processes in which O_2 is involved can be limited, especially those related to browning. Together with elevated CO_2 concentrations, appropriate amounts of O_2 may also control ethylene production by injured tissues, probably because O_2 is necessary for the conversion of 1-amino-cyclopropane-1-carboxylic acid to ethylene (Yang 1981). Rosen and Kader (1989) reported a substantial decrease in browning of sliced pears and in texture loss of strawberry slices throughout MAP storage. Senesi et al. (1999) reported that fresh-cut pears could be preserved during 15 days under passive packaging conditions. These results are in agreement with those of Soliva-Fortuny et al. (2002a, 2004) in apples and pears, although oxygen concentrations facilitated a dramatic increase in ethylene evolution. Gorny et al. (1999) suggested the use of 0.25 kPa O_2 + 10 kPa CO_2 atmospheres to extend the shelf life of fresh-cut peach and nectarine slices to control ethylene production and respiration rates. Higher CO_2 concentrations (20 kPa) were discarded because off-flavor formation was detected in the product. Because O_2 is needed for browning reactions, low O_2 concentrations (0.25–5 kPa) in combination with increased levels of CO_2 (10–20 kPa) have been used to maintain the visual appearance of several fresh-cut fruits, such as peach (Gorny et al. 1999), kiwifruit (Agar et al. 1999), and mango (Rattanapanone et al. 2001). However, low O_2 atmospheres have been also related to the development of translucency in MAP-packaged fresh-cut melon (Bai et al. 2001, 2003) and tomatoes (Gil et al. 2002).

The application of high O_2 atmospheres has been suggested as an alternative to low O_2 and moderate CO_2 concentrations to improve quality and shelf life. This MAP technique has been suggested to be particularly effective in inhibiting enzymatic browning, preventing anaerobic fermentation reactions, and inhibiting both aerobic and anaerobic microbial growth in fresh produce (Kader and Ben-Yehoshua 2000). However, the results achieved with high O_2 atmospheres are often controversial. The inhibitory effect of high O_2 levels on in vitro PPO activity was shown by Gómez et al. (2006). However, high O_2 concentrations alone could not effectively prevent browning of fresh-cut pears (Gorny et al. 2002, Oms-Oliu et al. 2008a). The results achieved in this field are sometimes contradictory and rely on numerous factors, but it is agreed that MAP alone is not enough to prevent fresh-cut fruit from senescence.

Atmosphere modification is also very important to control microbial spoilage of fresh-cut fruits. The proliferation of aerobic microorganisms can be substantially

delayed with reduced O_2 levels. Gram-negative aerobes such as *Pseudomonas* are especially inhibited compared to gram-positive microaerophilic species such as *Lactobacillus* . CO_2 inhibits most aerobic microorganisms, specifically gram-negative bacteria and molds (Al-Ati and Hotchkiss 2002). Anaerobic conditions inhibit the growth of aerobic spoilage microorganisms, which usually warn consumers of spoilage. On the contrary, the growth of anaerobic pathogenic microorganisms may be favored by these conditions. Maintenance of refrigeration conditions is also crucial. In low acidic fruits, such as melon, presence of *Clostridium botulinum* toxin has been reported after 9 days storage at 15°C (Larson and Johnson 1999). High O_2 concentrations have been found to cause damage to microorganisms by intracellular generation of reactive oxygen species that damage cell components and reduce cell viability when oxidative stresses overwhelm the cellular protection system (Jacxsens et al. 2001). Wszelaki and Mitcham (2000) found that 80–100 kPa O_2 inhibited the growth of *Botrytis cinerea* on strawberries. Consistently, an initial atmosphere of $\geq$ 70 kPa O_2 has been reported to retard the growth of molds (Van der Steen et al. 2002) and yeasts (Jacxsens et al. 2003) on strawberries and raspberries. In fresh-cut pears, *Candida parapsilosis* survived on inoculated samples stored under 70 kPa O_2, whereas *Rhodotorula mucilaginosa* was shown to be sensitive to superatmospheric O_2 concentrations (Oms-Oliu et al. 2008b). *Rhodotorula* yeast genera found in fresh-cut melon and mango cubes were also inhibited when exposed to high O_2 concentrations (Poubol and Izumi 2005, Oms-Oliu et al. 2008c).

Active packaging systems, including antimicrobial packaging, temperature-sensitive switches, absorbent packaging, and cook-in packaging, are being developed in order to make MAP more active in protecting and maintaining the quality of fresh-cut fruits and vegetables (Toivonen et al. 2009). In addition, methods for achieving high-permeable packaging structures that better match the respiration characteristics of fruits and vegetables are particularly active areas of development. Combination of treatments in a hurdle approach could induce synergistic effects on quality maintenance of fresh-cut fruits and vegetables. In this regard, edible coatings can be applied to improve the shelf life of fresh-cut produce packaged under MAP by reducing moisture and solute migration, gas exchange, respiration, and oxidation processes, as well as by suppressing physiological disorders.

Edible Coatings

Edible coatings may be a good alternative or complementary to MAP packaging. Edible coatings can serve as a barrier to moisture migration, preventing diffusion of gases and control of microbial growth. They can also enhance quality and appearance of fresh produce by preventing flavor and aroma migration and by providing structural integrity. Quality, stability, safety, and functionality of fresh-cut commodities can be improved by incorporating antioxidants, antimicrobials, and active ingredients into edible coatings. In fact, the application of edible coatings to deliver active substances is, so far, one of the most promising technologies to increase the shelf life of fresh-cut produce (Rojas-Graü et al. 2009). Edible coatings can be composed of one or more ingredients of protein, lipid, or polysaccharide nature. Mechanical structure of the film and the affinity between the coating material and the food are important factors to be controlled. For fully taking advantage of edible coating applications, the coating must adhere to the food surface (Lin and Zhao 2007). For improving surface adhesion of coatings, surfactants are typically added into coating formulations to improve wettability and adhesion (Choi et al. 2002, Lin and Krochta 2005). Alone, most coatings bases are unlikely to be effective for fresh-cut fruits. Polysaccharides and proteins are normally hydrophilic and do not behave well as moisture barriers (Nisperos-Carriedo 1994). Lipid coatings, on the contrary, have good barrier properties for water vapor but may be incompatible for fresh-cut fruits from the point of view of flavor (Hernández 1994). Combined or emulsified, some coatings may improve the quality of some precut fruits. The integration of proteins, polysaccharides, and/or lipids in a single coating can substantially improve its functionality (Lin and Zhao 2007). Bilayer coatings made of polysaccharides and lipids significantly reduced water loss and respiration processes in fresh-cut apples (Wong et al. 1994). Browning of fresh-cut apples has been reported to be reduced with the incorporation of antioxidants into coatings such as cellulose (Baldwin et al. 1996), chitosan/lauric acid (Pennisi 1992), alginic acid/casein/lipid (Wong et al. 1994), and whey protein concentrate (Sonti et al. 2003). In addition, antioxidants can be added into the coating matrix to protect the cut surface against oxidative rancidity, degradation, and enzymatic browning. Olivas et al. (2003) preserved fresh-cut pear wedges from surface browning by applying a methylcellulose-based coating containing ascorbic and citric acids. Rojas-Graü et al. (2007a) and Tapia et al. (2005) applied alginate- and gellan-based coatings with the addition of cysteine, glutathione, and AA to fresh-cut apples and papayas, these coatings were good carriers of antioxidant agents. Perez-Gago et al. (2006) reduced browning of cut apples by using a whey protein concentrate-beeswax coating containing AA, cysteine, or 4-HR.

The use of edible coatings with antimicrobial properties or with incorporation of antimicrobial compounds is another potential alternative to enhance the safety of fresh-cut produce. The incorporation of antimicrobial agents into edible coatings provides more inhibitory effects against spoilage and pathogenic bacteria by maintaining effective concentrations of the active compounds on the food surface (Gennadios and Kurth 1997). Nevertheless, not much literature is available on the use of edible coatings as carriers of antimicrobials to prevent microbial growth on fresh-cut fruits. Alginate and/or gellan edible coatings incorporating EOs with antimicrobial properties have prolonged shelf life of fresh-cut apples and melon (Rojas-Graü et al. 2007b, Raybaudi-Massilia et al.

2008a, 2008b). Chitosan, a polysaccharide coating, has been shown to extend shelf life of fresh fruits (El-Ghaouth et al. 1991, Kittur et al. 2001) and has a great potential to be used in fresh-cut products because of its natural preservative effect against many pathogenic bacteria and fungi (Romanazzi et al. 2002). Chien et al. (2007) reported the effectiveness of chitosan in maintaining quality and extending shelf life of sliced mango. Assis and Pessoa (2004) and Han et al. (2005) also proposed chitosan for extending the shelf life of sliced apples and fresh strawberries respectively.

A new generation of edible coatings is being currently developed, allowing the incorporation and/or controlled release of active compounds using nanotechnology, which can be potentially used to incorporate functional ingredients and antimicrobials into edible coatings for fruits by micro- and nanoencapsulation (Rojas-Graü et al. 2009). Micro- and nanoencapsulation is defined as a technology for packaging solids, liquids, or gaseous substances in miniature (micro- and nanoscale) sealed capsules that can release their contents at controlled rates under specific conditions. Release can be solvent-activated or signaled by changes in pH, temperature, irradiation, or osmotic shock (Vargas et al. 2008).

Distribution and Commercial Storage of Fresh-cut Fruit Commodities

The commercial shelf life of fresh-cut fruits is mostly determined by storage temperature. Because fresh-cut products continue to respire and are highly susceptible to spoilage by microorganisms, the chill chain (temperatures ranging from 0°C to 4°C) must be kept throughout every stage to achieve optimum freshness, quality, and safety. Consumers should also be aware of the storage requirements of this produce and therefore information about handling at home should be provided by producers and retailers. Special attention must be dedicated to the temperature of display cases. Overfilled shelves, blocked return airflow, or even the position of the product in the shelf may impact the product temperature significantly. In addition, optimal temperatures are rarely achieved. Refrigeration may account for more than 50% of the annual electric energy costs of a supermarket (RTTC 2004). Therefore, small temperature changes are commercially significant because supermarkets operate on a narrow profit margin and increased energy costs impact their competitiveness.

There are few researches that take into account temperature fluctuations throughout storage and the subsequent limitation of the product shelf life. Gorny et al. (1998b) reported that the shelf life of fresh-cut "Flavorcrest" peach and "Zee Grand" nectarine processed at optimal maturity and stored at 0°C under a continuous flow of humidified air was reduced by one half, if the storage temperature was increased up to 10°C. This degradation was attributed to an increase in respiration rates and ethylene production at high temperatures. As well, Odriozola-Serrano et al. (2008) reported a better preservation of the microbiological quality of fresh-cut tomatoes stored under refrigeration (5°C), although some antioxidant characteristics of the fruit, for example, lycopene and total phenolic compounds, significantly increased under abusive temperatures (>10°C) due to the wounding stress caused by damaging MAP conditions.

REGULATIONS FOR FRESH-CUT PRODUCE

As indicated above, concerns about safety issues need to be strengthened for fresh-cut produce. This is being translated into higher requirements for processors and distributors but information about storage and handling should also reach consumers. Nevertheless, the development of HACCP-specific plans for the fresh-cut product industry is not yet mandatory. A poor storage and handling protocol of these produce, especially during the primary stages, may entail a high risk of contamination with pathogenic microorganisms and the possibility of foodborne illnesses. The HACCP system is recognized as having significant advantages over alternative approaches based on inspectional procedures, because of the inherent weaknesses in microbiological sampling and testing. The adoption of HACCP by the fresh-cut produce sector has been growing slowly but steadily and nowadays, most processors and organizations, such as the International Fresh-cut Produce Association, recognize the importance of HACCP and have own guidelines for designing specific HACCP plans for fresh-cut produce.

Regulatory rules specific for fresh-cut products may greatly vary upon countries. Fresh-cut fruits and vegetables are subjected to the food law of the country where they are grown, harvested, processed, transported, and sold. Many national regulations in Western countries limit the counts of aerobic microorganisms to 10^6 cfu/g at expiration date. Pathogenic microorganisms are not allowed (*Salmonella*) or greatly restricted (*E. coli*, *L. monocytogenes*) in ready-to-eat meals prepared from raw vegetable products.

On September 2001, U.S. FDA together with the Institute of Food Technologists issued a document entitled "Analysis and Evaluation of Preventive Control Measures for the Control and Reduction/Elimination of Microbial Hazards on Fresh and Fresh-Cut Produce" (FDA 2001). This document presents a comprehensive guide about potential microbial risks in fresh-cut produce and how to handle them throughout production, processing, and distribution.

The European Commission has set food safety criteria for *Salmonella* in fresh-cut fruits and vegetables and for *L. monocytogenes* in three ready-to-eat foods (EC Regulation 2005). Further, process hygiene criteria have been set for *E. coli* in relation to ready-to-eat fruits and vegetables.

The Codex Alimentarius Commission has developed nonbinding rules and standards for hygienic practice for precut fruits and vegetables in order to ensure consumer health

protection and adequate trade practices in this field (CAC 2003). The Code recommendations represent a valuable tool for the standardization of this market all over the world.

Another important issue is regarding the safety of the chemical substances involved in fresh-cut fruit processing. GRAS-listed additives (generally recognized as safe by the U.S. FDA) should be used. The list of additives and their specifications of the Codex Alimentarius Commission is a world reference in this subject.

FINAL REMARKS

The fresh-cut fruit industry is expected to continue growing during the forthcoming years. However, there are still some research goals to be achieved to allow the continued growth of the fresh-cut fruit market.

Future challenges include the development of procedures that ensure high quality and safety standards for fresh-cut fruit production. Special attention should be dedicated to investigate new treatments and technologies to improve quality and to extend the microbiological shelf life to prevent the growth of pathogenic microorganisms. The effect of nontraditional sanitizers and new compounds from natural sources that appear to be healthier for consumers needs further research. Furthermore, it would be important to study the influence of traditional and new packaging systems on safety, specifically with a proper regard for the growth of human foodborne pathogens. Last but not least, it is necessary to continue to develop better technology for the entire processing chain, from the growing fields to consumers. This will permit processors to achieve more stable products and to meet the highest hygienic standards, thus reinforcing the consumers trust on lightly processed commodities.

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16
Fruit and Fruit Products as Ingredients

Györgyi Pátkai

Abstract: This chapter provides a review of the fruit products and semiprepared fruit products used in different sectors of the food industry making dairy, confectionary, distillery, frozen, baked or canned products, frozen or heat treated ready meals, and fruit-filled pastas. The chapter describes chemistry and processing technology behind the applied fruit products: purees, pulps, jams, marmalades, juices, jellies, concentrates, desiccated, frozen, sweetened and candied fruits. Attention is given to the quality requirements of the fruit components applied to produce high-class finished products.

INTRODUCTION

Fruits can be sources of plant-based nutritives, flavorful, and value-added ingredients in many food applications. They can find use not only in fresh or frozen, diced, or sliced forms but also as processed fruit preparations, fruit fillings, jams, marmalades, jellies, juices, concentrates, sweetened-dried fruits, dried fruits, fruit powders and extracts, fruit fibers, etc. As highlighted in other chapters of this handbook, fruits are regional and seasonal commodities requiring specific pre- and postharvest processes to extend their use. This chapter deals with production, characteristics, and quality requirements of preserved fruit preparations and semiprepared fruit components that can be used as food ingredients.

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FRUIT PRODUCTS AND SEMIPREPARED PRODUCTS AS FOOD INGREDIENTS

Fruit Purees

Fruit puree is the edible part of the fruit, pulped, homogenized, or manufactured by a similar process (Anon 1996). It is a semiprepared product; it contains the fruit in a sieved, homogenous form, and contains no recognizable fruit pieces. Fruit puree is not suitable for direct consumption by most people except infants, elderly, and individuals under medical care. However, it is the raw material for production of jams, marmalades, fruit juices, and bakery fillings, and it is used as an ingredient in many food products. Industrially processed fruit purees can be preserved by preservatives, by cooling, freezing, heating, concentration, and addition of sugar. The best way to preserve it is with aseptic technology. Properly ripen and good-quality fruit is suitable for puree production. Exceptions can be made in the case of fruits containing a high concentration of pectin (e.g., apple, gooseberry, etc.).

The typical fruit puree processing steps would include preparatory steps of fruit selection, washing, sorting for defects, dicing, etc. Blanching is usually necessary prior to pulping to decrease losses, energy requirement, and mechanical stress on the sieve. Crushing of the blanched fruit is performed gradually by passing through a crusher, a coarse sieve, a fine sieve followed by homogenization. The homogenized fruit puree can be preserved by adding preservatives such as SO_2 (max. 2 g/kg), benzoic acid (max. 1.5 g/kg), sorbic acid (max. 1.0 g/kg), or by pasteurization of puree (filled in 5-liter jars with hermetic seal) at 94–96°C.

In the modern fruit processing industry, fruit purees are preserved by aseptic technology. In this case, a continuous, so-called "scratched-wall" heat exchanger (type α-Laval, Crepaco, Manzini, APV, etc.) is used for inactivating yeasts and molds. The sterile product is filled under aseptic conditions into sterile packaging (laminated foil bags, bag-in-box, barrels, containers, etc.), hermetically closed, and stored until further usage (Körmendy and Török 1990, Potter and Hotchkiss 2001).

Single-strength apple puree can be concentrated to 20°–25°Brix in a multistage vacuum evaporator or film evaporator with scraper. These evaporators are suitable for production of a concentrate of 40°Brix. Concentrated fruit purees not only enrich the product with valuable extracts, characteristic taste, flavor, and color, but they also contribute to the product's functional properties because of their high pectin and fiber content (Hegenbart 1994).

In great demand for fruit preparations are berries and cherries because of their high vitamin and mineral content, and attractive taste and color. The vitamin content of fruits can be protected by use of mild processing parameters. In this case, the processing of fruits with high vitamin content (elderberries, rosehip, sea buckthorn, etc.) results in fruit preparations with valuable composition; and when used as ingredients, increases the nutritive value of the combined product (Lampe 1999, Barta et al. 2002).

The above-mentioned berries and red-grape-vine are processed to give anthocyanin extracts and concentrates as well, which are used as natural food colorings. The stability and intensity of elderberry anthocyanins are increased by the fact, that the high anthocyanin content is coupled with high vitamin C content of the fruit (Stéger-Máté et al. 2001).

A similar synergic effect between anthocyanins and vitamin C was proved in case of blackberries as well (Stéger-Máté et al. 2002). The antioxidative effect of the anthocyanins helps to protect the vitamin C content (Gardner et al. 2000).

Selected Fruit Purees

1. Banana puree
   Banana puree is by far the most important processed product from the pulp of ripe bananas. The puree has a creamy white to golden yellow color, free from musty or off-flavors. Banana puree is an important infant food. Puree canned in drums by an aseptic canning process, it is a good ingredient for bakery products and ice creams. The puree can be successfully canned by the addition of ascorbic acid to prevent discoloration and used as an ingredient for dairy desserts, bakery items, drinks, processed foods, and sauces and as a part of special diets in hospitals and nursing homes. In canned banana puree, it is important to lower the pH approximately to 4.2 with citric acid. Sugar is added to balance the sugar/acid ratio.
2. Mango puree
   Mango puree is the most common semiprocessed product of this fruit. Mango puree, prepared from ripe fruits is particularly relished for its succulence and exotic flavor. It can be used for making jams, jellies, beverages, and various dairy and bakery products that contain mango as an ingredient. Mango puree in fresh, processed, or chemically preserved form appears promising because of the ease of handling and the low cost of production. The puree requires a heat treatment sufficient for inactivation of enzymes. A plate heat exchanger is usually used to heat the product to 108–112°C for 2 minutes, and then the puree is cooled rapidly. Sucrose and corn syrup are acceptable sweeteners in the preparation of mango puree. The puree can be stored under suitable conditions (freezing or chemical preservation) for 6–8 months.
3. Peach puree
   Fruits are washed, trimmed, and cooked, and the pulp passed through a continuous rotary unit with perforation, followed by the addition of ascorbic acid (0.14%). Clingstone peaches are preferable for the preparation of baby food because of the yellow color of the puree, better storage ability, nonmelting flesh, and thicker consistency. The peach pulp is blended with sugar syrup,

sterilized at 110°C and deaerated. It can either be canned or preserved in jars. The peach baby food has soluble solids of 21%–22%, a pH of 3.0–4.1 and 0.35%–0.45% acidity as citric acid.

4. Some other fruit purees
   Subtropical fruit puree such as kiwifruit puree, plum puree, and some tropical fruit purees such as guava and papaya purees are available on the market.

- Guava puree, also known as guava pulp, is a relatively liquid product. Guava puree is an excellent source of ascorbic acid, niacin, thiamine, riboflavin, calcium, iron, phosphorus, and dietary fiber. The ascorbic acid contents range in guavas from 100 to 1000 mg/100 g fruit. It is commonly used for the preparation of nectars, various juice-drink blends, ice-cream toppings, jams, and jellies.
- Kiwifruit puree is used as a fruit topping and in yogurts. The product has a fresh green color and high natural flavor.
- Papaya puree is a liquid product with a light yellow color and sweet flavor, which is prepared by the maceration of papaya flesh into a semifluid-like product. Much papaya products, such as juices, nectars, jams, jellies, syrups, toppings, and dried fruit rolls can be made from papaya puree.
- Avocado puree is often used as a filling for several kinds of sushi, including California rolls. It is also popular in chicken dishes and as a spread on toast. In Australia and New Zealand, it is commonly served in sandwiches, on toast, or with chicken.
  A puree of the fruit was used to thicken and flavor the liqueur Advocaat in its original recipe, made by the Dutch population of Suriname and Recife, with the name deriving from the same source. The fruit has a markedly higher fat content than most other fruits, mostly monounsaturated fat, and as such serves as an important staple in the diet of various groups. About 75% of an Avocado's calories come from fat, most of which is monounsaturated fat. Avocados also have 60% more potassium than bananas. They are rich in B vitamins, as well as vitamins E and K. They have high fiber content among fruits including 75% insoluble and 25% soluble fiber (Naveh et al. 2002).
- Plum puree is used in ice-cream mixes, confectionery products, and meat sauces. The product has a light yellow color and tart–sweet flavor (Anon 1999).

Fruit Pulps

Pulp is the edible part of the fruit, possibly without the skin, shell, stones, etc., sliced or crushed, but not sieved (Anon 1996). It is a semiprepared product, containing crushed fruit flesh with recognizable pieces, processed of washed and selected raw material. It is not suitable for direct consumption. Fruit-processing industry is producing jams from fruit pulp and fresh fruit as well.

Fruit pulps differ from the previously mentioned fruit purees. "Pulping" means to crush washed and selected fruit flesh after separation of the peel, shell, stones, and stalks as needed, by a cog-crusher, fruit-milling machine, or hammer grinder, without crushing it by a sieve. These machines crush the fruit flesh to coarse ground, recognizable pieces. The provisional preservation of the cleaned and crushed fruit flesh can be performed by preservatives, heat, cooling, or freezing. In the case of chemical preservation, the pulp is mixed with a given preservative (e.g., 0.03% SO_2, 0.15% benzoic acid, 0.1% sorbic acid, or with their Na or K salts). The chemical preservatives are effective below pH 3.5. If the pH value is higher, a combination of acid and preservatives is used. This step requires careful mixing of the pulp in a mixer of moderate revolution per minute and continuous injection of preservatives. Attention is given not to crush fruit pieces.

The advantage of the heat-preserved fruit preparation is that it does not contain preservative; however, a considerable demand on package materials is a disadvantage, as the pasteurization of the pulp is often performed in 5-liter jars. The slow rate of cooling following pasteurization can affect color, flavor, and nutrients. In case of pulps, use of aseptic technology is difficult because of the lumpy character of the product. The cleaned and crushed fruit flesh is blanched in water (added water cannot be more than the water quantity evaporated during the blanching) before pasteurization in a duplicator kettle or continuous blancher. The acidity of the blanched product can be adjusted to about 1% by adding citric acid, and the hot pulp is filled in glass jars and pasteurized without delay. The temperature at the center should be 86–90°C for effective pasteurization.

Pulps of Exotic Fruits

1. As an example for the processing of fruit pulp of exotic fruits, see later, the pulping process of the fruit of the multipurpose tree from Nepal known as Lapsi. It is a potential agro-forestry tree species for income generation and nutrient supplementation in the hills of Nepal. Farmers normally process the fruits for their household needs as pickles and chutney by crushing and boiling the fruits, whereas entrepreneurs purchase the fruits from growers and produce varieties of edible pulp cake indigenously called Titaura for selling in the market of Nepal as well as neighboring countries. This practice has been instrumental in raising the socioeconomic status of rural communities in Nepal (Chhetry and Gauchan 2007)
2. Baobab dried fruit pulp is derived from the fruits of the Baobab tree (*Adansonia digitata*), also known as the "upside down tree." On pollination by fruit bats, this tree produces large green or brownish fruits. The baobab tree is found primarily in South Africa, Botswana, Namibia, Mozambique, and Zimbabwe.

In July 2008, "*Phytotrade Africa*" was granted authorization to market Baobab dried fruit pulp in the EU by Commission Decision of the Advisory Committee on Novel Foods and Processes according 2008/575/EC [(ACNFP), Anon 1996]. There is a proposal to market baobab dried fruit pulp as a novel food ingredient for use in a range of food products, namely, smoothies, cereal bars, and other similar food products. The level of baobab dried fruit pulp would be between 5% and 15%. Marketing of a depectinized baobab fruit pulp as a novel food ingredient for use in biscuits, confectionery, and related food products is also envisaged.

Desiccated Fruits

Dehydration of food is one of the most ancient ways of preservation, and it is based on the limit of water activity (a_w) for microbial growth. A a_w of 0.65 and below is effective in controlling microbial spoilage.

Only healthy and ripen fruits are desirable for drying. Quality requirements for fruits as raw material for drying include: solid fruit flesh, easy separation of pits and skin, and small pits. Washed and cleaned fruit flesh is treated with SO_2, if necessary to prevent enzymatic browning. This treatment gives some protection against microbial deterioration, pests, and nonenzymatic browning (Maillard reaction).

Withdrawal of water from the prepared fruit flesh can be performed in two different ways:

- Under tropical climate, people take advantage of the sunshine, and dry fruits in thin layer by slow, natural drying (figs, bananas, peaches, and apricots).
- Dehydration means treatment in tunnel or band dryers by blowing through warm air of 60–70°C (apples and plums).

Residual water content of dehydrated fruits is about 18%–24%, and when adequately packaged they are long lasting without any damage because of their high-sugar content and low ($a_w = 0.72$–0.75) water activity.

Quality requirements related to the dried product are the following:

- Solid, plastic, and creamy but not sticky consistency and leather-like surface of dried prunes and apricots.
- Bright color of dried apple rings, light color of peaches, and other fruits.
- High-sugar content, harmonic sugar/acid ratio, easy disconnection of the stones.
- Bigger size, thin skin, and a pleasant, pliable consistency (dried figs).

Dried grapes are taken in trade as "raisins," "sultanas," and "korinths." Raisins have a brown color, and do not contain any pits. Sultanas have a light color without pits; korinths are smaller than raisins and sultanas, and are dark colored.

Dehydrated cherries and dehydrated apple products are widely used in foods such as pastry, confectionery products, ice cream, frozen desserts, sweets, fruit salads, cheese, and yogurt (Somogyi et al. 1996).

Dried plums are available in many forms suitable for bakery use. Diced and extruded dried plum bits can be used to enhance fruit breads, pastries, muffins, and cakes. Gaining in popularity are the extruded bits, which are guaranteed pit free. These bits can also be modified by adding other flavors, fruits, and colors to extend the use of more expensive fruits.

The relatively low cost of dried plum paste makes it an ideal base to create various fruit-filling flavors for Danish pastry and bar cookies. The flavor of dried plums is compatible with other fruits, spices, and chocolate. In fact, dried plums act in a manner similar to vanilla to round out and enhance other flavors. Thus, dried plums can be used to reduce the cost and improve the quality of fillings. For example, strawberries can be used as the characterizing fruit in a high-quality filling using dried plum paste as the base fruit. The high pectin content in dried plums provides added stability to heat processes, and can eliminate the need for added stabilizers.

Dried plum purees are available which contain approximately 45%-dried plums, pureed with added water and/or corn syrup. Dried plum puree has the advantage of being soft and easily incorporated into batters and doughs. As will be illustrated later, it has been found to be an excellent fat replacer in bakery products (Scott 1993).

Sweetened and Candied Fruits

Sweetened fruits, soughs, candied fruits, and dehydrated-sweetened fruits belong to the above-mentioned product family. The sugar content of these products is increased to a degree, which prevents the growth of microorganisms. The important point here for preservation is to achieve a low water activity with the addition of sugars. The significant increase of sugar content of the fruit preparation can be performed by soaking in sucrose or glucose solution of gradually increasing concentration, under atmospheric pressure or in vacuum. The concentration difference between the sugar syrup and fruit cells will be equalized in consequence of the difference in osmotic pressure. The saccharose content of 70%–80% of the fruit flesh can be achieved by soaking in concentrated sugar syrups. Its water content is decreased to 12%–21% by careful drying. Cherries and sour cherries, pineapples, pears, quinces, peaches, apricots, plums, figs, green almonds and nuts, chestnuts, gooseberries, strawberries, and raspberries can be processed to candied fruits of good quality.

The surface of sweetened fruits is coated with sugar glazing or with a thin layer of crystallized sugar for confectionery use. The first-mentioned procedure is called glazing and the second is candying. A special group of this type of fruit preparations is produced by treating the blanched peel of citrus fruits with sugar syrup, by glazing and drying it carefully. Preparatory steps of the technology are similar in the case of all types of sweetened products, but they are adapted to the characteristics of the raw material (e.g., washing, cleaning, pitting,

peeling, separation of the stems if needed, crushing, and blanching). Ready-made fruit preparations (sweetened fruits, soughs, candied fruits, and dehydrated-sweetened fruits) differ from each other in finishing and final appearance. The raw material of all those products is the so-called "egute"—the cleaned, blanched fruit, soaked in syrup of starch or saccharose or in high-fructose corn syrup.

In case of fruits with high-fructose content (pears, quinces, melons, etc.) fruit preparations of low caloric content can be prepared. In this case, concentrated syrup of Jerusalem artichoke juice with high-fructose content (75%–80%) can be used as a sweetener (Barta 1993, Bray et al. 2004).

The aim of soaking in syrup is to saturate the cells opened during blanching with sugar. The form and consistency of the fruits can be stabilized as a consequence of this treatment. Following the above-mentioned preparative steps the fruit pieces should be fed in a flat vessel and filled with hot sugar syrup of 28°–30°Brix. The product being filled with the syrup stays in the syrup for 2–3 days, after that the syrup will be poured off, heated, and sweetened with sugar to a concentration value of 35°Brix. This procedure is repeated five to six times, gradually increasing the concentration of the syrup to 60°Brix. After having achieved this value the hot, sweetened fruit pieces are dripped, filled in 5-liter jars, and filled up with high-fructose corn syrup or starch at a concentration of 68°–70°Brix and hermetically packed. This semiprepared product (egute) can be stored and used.

Candied Fruits

Definition. Fruits preserved by soaking and heating in sugar syrup. The fruit is usually boiled in the syrup, and then can be left in syrup for 4–14 days. During the candying process, the naturally occurring water in the fruit is replaced by sugar, resulting in fruits with firm textures, sweet flavors, and extended keeping qualities. Fruits that are already firm, such as pineapple, apricots, cherries, and apples, are best for candying. Soft fruits, such as most berries, will not survive the extended soaking process. The fruit is first poached in water and then sugar is added to the mixture. During the prolonged soaking period, the sugar syrup is gradually concentrated by adding more sugar periodically. Finally, the candied fruit is left to dry outside of the syrup for several days. It can be finished by being sugared or glacéd, or can be used as is for dipping in chocolate or incorporated in other recipes:

- Candied apples are whole apples covered in a hard candy coating. The topping varies from place to place.
- Toffee apples are popular in the United Kingdom. These products are coated with a hot toffee.
- Caramel apples or taffy apples are created by dipping or rolling the apples in hot caramel, sometimes then rolling them in nuts or other small savories or confections, and allowing them to cool. They are always served with a stick of sorts in the middle, making them easier to eat.

Sweetened Fruit Products

Sweetened fruit products are made from egute after being dripped, dried in a warm current of air, rolled in crystalline sugar, and packed in cellophane. Sweetened berry preparations are manufactured also by blending whole, sliced, or crushed fruits with sugar in ratios such as 4:1, 3:1, or 7:1 (berries:sugar). A usual procedure is to "cap" or sprinkle sugar onto the surface of the berries, after they have been filled into pails or drums. In the United States, the quality of the berries is US Department of Agriculture (USDA) Grade A or B. These products are typically used in ice cream, yogurt, bakery preparations, or fillings (Somogyi et al. 1996).

The sough (glazed egute covered with a shining fondant layer) is manufactured by soaking the semiprepared product in a hot, oversaturated sugar solution, finally put on a grating and dried in a hot room. A bright fondant layer crystallizes on the surface of the fruit pieces, which makes the product attractive and protects its fresh, plastic consistency. This procedure is called "glazing." Dripped, dried egute is also used to manufacture candied fruit (fruit pieces, coated with a thin layer of crystallized sugar). The semiprepared product will be soaked in cool sugar syrup of 59°–60°Brix. The surface of the fruit pieces is covered with a thin layer of granulated sugar. After the sweetening treatment, the syrup will be racked from the vessel, which is equipped with an outlet and a grating on the bottom. The fruit layer remains on the grating, and can drip and dry. The sugar layer on the surface of the fruit pieces, consisting of closely united crystals, protects the product from drying out quickly. An attractive packaging is improving the protecting effect of the sugar layer and also the marketability of the product. To manufacture sweetened-dehydrated fruits, the raw material is prepared in a similar way to the procedure used in the technology of canned or bottled fruit processing: washing, cleaning, peeling, and pitting, destemming, halving, or slicing, treatment of the surface in the case of light colored fruits with diluted solution of citric acid or H_2SO_3. The prepared raw material should be soaked 10–20 minutes under vacuum in a sugar solution of 15°–20°Brix and 60°C. Duration of the treatment depends on fruit ripeness. After the well-made sweetening treatment the fruits become transparent. Because of the vacuum effect, the intercellular capillaries will be deaerated, and sugar solution will penetrate into the air space. The less the aroma the fruit contains, the lower sugar concentration has to be adjusted (apples, pears: 30°Brix; apricots and peaches: 35°Brix; quinces: 40°Brix).

Sweetened fruits should be carefully placed on a sieve, slowly dried to a water content of 15%–17%, at the beginning at a temperature of 70–75°C, and at the end at 65°C. To decrease hygroscopicity, the sweetened-dried fruits should be rolled in sugar powder. The sugar surplus can be removed

by sieving, and the product can be packed in cellophane or in ornamental boxes (Mathlouthi 2003, Szenes 1995).

Fruit Jams, Sweetened Fruit Purees, Jellies, and Marmalades

These products are according to Codex Alimentarius (Anon 1996) fruit preparations of jelly-like consistency, produced from fruit purees, pulps, juices, or extracts of one or more sorts of fruits, by adding sugar.

Sweetened fruit purees are fruit preparations, manufactured of fruit purees (pulped and homogenized fruit flesh, fresh or preserved) or of fruit juices by adding sugar, citric acid, pectin, and food colorings possibly. They have a spreadable, bounded, jelly-like consistency. They are generally made of one sort of fruit, except "mixed sweetened fruit puree," which contains several fruits. It has a harder consistency and it is sliceable with a knife. Concentrated plum puree of good quality can also be made without added sugar. Soluble solid content of the sweetened fruit purees is about 56°Brix; 10%–12% of this value originates from the fruit; the rest is added in form of beet sugar. The Department of Canning Technology of the Corvinus University of Budapest successfully used high-fructose Jerusalem artichoke concentrate for sweetening fruit preparations (Barta 1993, Barta and Pátkai 2006). In limited amounts, fructose tolerance by diabetics is accepted in Europe, but those products are sweetened, in addition to fructose as a natural sweetener, by simultaneous addition of artificial sweeteners and gellying additives, because in the absence of saccharose, pectin has no gellying effect (Pátkai and Barta 2000, Bassoli 2003).

In the course of putting together a batch of sweetened fruit puree the pectin is added in the form of a colloidal solution, which is prepared by mixing the pectin with cold or warm water. The sweetened fruit preparation is cooked in a vacuum evaporator. At first fruit puree and 1/3 of the sugar quantity needed is fed into the machine. The excess water is evaporated under vacuum that can take about 25–40 minutes. Before the end of the evaporation additional sugar-pectin solution is added to the puree. After having added the rest of sugar and the pectin solution, the evaporation is continued for about 5 minutes under vacuum, finally, vacuum is stopped, and the product is heated to 80–90°C. The pH value of the sweetened, evaporated puree is adjusted to a value of 2.8–3.2 by adding citric acid. After having controlled the soluble solid content of the product, it can be filled into specified packages; the filled packages are than closed and pasteurized. If the volume of the package is smaller than 5 liters, a processing period of 10 minutes at 94–96°C is adequate for pasteurization.

Jams are Solid Gels Made of Fruit Pulp or Juice, Sugar, and Added Pectin

They can be processed from one single kind of fruit or from a combination of fruits. The fruit content should be at least 40%. In mixed fruit jams, the amount of the first-named fruit should achieve at least 50% of the total fruit quantity (based on UK legislation) (Anon 2009).

The semiprocessed product (pulp), preserved by adding SO_2 should be fed into the vacuum cooking kettle, and at first SO_2 has to be removed by boiling under vacuum. If the semiprepared product has been preserved by addition of sorbic acid or by heat treatment, the above-mentioned pretreatment is not necessary. A measured quantity of pulp can be fed directly into the evaporator and the batch can be prepared. The solid content of the jam is composed of the solid content of the fruit, sugar, pectin, and citric acid. Its recommended value is 68°Brix. "Fruit rate" (rate of the solid content originating from the pulp) should be between 20% and 50%, and it is always an actual quality prescription. Added pectin and citric acid quantities should be established by cooking test, on the basis of quality prescriptions as well. The pectin quantity has to guarantee the jelly like, suitably bounded consistency. The pH value of the jam should be adjusted to a value of 2.8–3.2 by adding citric acid. The quantity of pectin and citric acid to be added is generally about 0.3%–0.5%, depending on the original pectin and acid content of the fruit. The sugar quantity needed can be calculated on the basis of these data. Both pectin and citric acid are used in the form of solutions, and similar to the case of sweetened fruit purees they are added only at the end of cooking. Cooking time for jams is 5–15 minutes, depending on the fruit type.

Cooking apparatus used are open, double-wall, steam-heated, tiltable stainless steel kettles, provided with stirrer, or closed, pressure-tight vacuum kettles.

The cooked jam is cooled to 90°C or 60–70°C, respectively, and depending on the on the pectin quality and depending on the type of packaging material, filled into packages with a screw or piston loader. Jams filled into jars should be heated at 95–100°C for a short time. In the case of wooden or plastic packages, the product must be preserved by preservatives (0.15% benzoic acid, 0.1% sorbic acid, or their Na or K salts, respectively) (Körmendy and Török 1990, Smith 2003).

Fruit Jellies are One of the Oldest and the Most Popular Fruit By-Products

The jelly is bright and transparent. A good jelly gelatinizes on cooling and is firm enough to hold the shape of the container when removed from the container. It must be soft enough to quiver upon shaking, but must not flow. It must be clear and transparent and should retain the flavor of the fruits. Jelly is strictly defined in the United States as a semisolid food, made from not less than 45 parts by weight of fruit juice ingredient and 55 parts by weight of sugar. This mixture is concentrated to not less than 65% soluble solids. Three substances are essential for the preparation of normal fruit jelly: pectin, acid, and sugar. Fruit gives jelly products its characteristic flavor and furnishes at least part of the pectin and acid required

Table 16.1. Chemical Composition of Jams, Marmalades, and Jellies, Frequently Used as Food Components

Name	Product	Soluble Solids (%)	Soluble Carbohydrates (%)	Red. Sugars (%)	Saccharose (%)	Pectin (%)	Acids (Total) (%)	Sugar/Acid Ratio
Apples	Jelly	65.0	64.87	–	–	–	–	–
Apricots	Jam	66.2	62.0	33.1	28.2	0.50	0.71	86.34
Raspberries	Jam	67.8	61.3	35.7	24.7	0.37	0.88	68.64
Raspberries	Jelly	65.0	64.78	–	–	–	–	–
Cherries	Jam	66.9	62.2	32.55	29.1	0.42	0.55	112.1
Red currants	Jam	66.1	58.65	47.6	10.1	0.43	0.95	60.73
Red currants	Jelly	66.3	66.3	–	–	–	–	–
Oranges	Jam	68.0	60.4	43.9	16.0	–	0.52	115.2

Source: Souci et al. (1989.)

for successful gels. Pectin and acid are added to overcome the deficiencies that occur in the fruit itself. Varieties of fruits with special and intensive flavor are often used for jelly products, because the fruit flavor is diluted by the large quantity of sugar necessary for proper consistency and good keeping quality (Anon 1999). Flavoring and coloring agents may also be added. The name of the fruit used in making the jelly must be stated with other ingredients, in order of decreasing weights, on the label of such products offered for sale in the United States (Smith 2009).

Fruit jellies are manufactured of the filtered, cleared fruit juice with high pectin content (apple, quince, strawberry, gooseberry, or citrus juice) or of strained fruit flesh by adding sugar, pectin, and food acids. Fruits for jelly processing should not be fully ripe (Szenes 1995). The intact, healthy, and cleaned fruit is cooked in little water; the juice should be filtered, sweetened, concentrated, packaged, and chilled without moving it. The package should be closed only if the surface is already dry (Körmendy and Török 1990; Smith 2003).

Fruit pudding is a special fruit preparation, which is made of homogenized puree of one single kind of fruit. It can be flavored and decorated with shelled nut varieties (Szenes 1995; Paltrinieri et al. 1997) (Tables 16.1 and 16.2).

Fruit-juice Concentrates

Fruit-juice concentrates are produced by the evaporation of the excess water in fruit juices. Removal of water can be performed by:

- Heating and evaporation of water at boiling temperature, generally under vacuum at relative low temperature in a multistage evaporator. Preliminary isolation of the aroma content by distillation and the reusage of it are important.
- Freezing of the juice and isolation of crystallized ice by centrifuging (cryoconcentration or freeze concentration) or sublimation of ice crystals under vacuum (lyophilization or freeze drying).
- By reverse osmosis (separation of water by a semipermeable membrane).

Natural fruit juice should be cleaned of the fiber content and colloids, by clarification and sieving. Soluble solid content of the concentrate should attain 62°–65°Brix to get a long-life product. The sugar ratio of the solids is variable depending on maturity and ripeness of the fruits. Sweetening effect of the concentrate may also vary in case of an equal sugar concentration because of sugar interactions. The fruit-juice concentrates contain nearly all valuable components of the fresh juice: sugars, organic acids, minerals, colorings, and natural antimicrobials. Therefore, they are popular additives in the bakery, confectionery, and dairy industry as natural sources of colorants and sweeteners.

Fruit-based sweeteners tend to be more expensive than high-fructose corn syrup and sugar, but they provide several advantages. They add soluble and insoluble dietary fiber, color, a unique flavor profile, several vitamins and minerals, and "label appeal." Sometimes, the technologist has to use a juice concentrate as natural sugar resource with reduced

Table 16.2. Mineral and Vitamin C Content of Jams, Marmalades, and Jellies, Used as Food Components

Name	Product	Minerals (mg/100 g)	Vitamin C (mg/100 g)
Apples	Jelly	130	–
Apricots	Jam	360	–
Raspberries	Jam	–	2.7
Raspberries	Jelly	220	–
Cherries	Jam	380	1.2
Red–currants	Jam	340	20.6
Red–currants	Jelly	Na + K + Ca = 90.0	–
Oranges	Jam	140	4.0

Source: Souci et al. (1989.)

Table 16.3. Chemical Composition of Soluble Solids of Shelled Nut Varieties, Used as Food Components

Name	Nutritional Value (kJ/100 g)	Protein (g/100 g)	Fat (g/100 g)	Carbohydrate (g/100 g)	Calcium (mg/100 g)	Phosphorus (mg/100 g)	Iron (mg/100 g)
Nut (*Juglans regia*)	2601	14.4	62.5 ± 6.5	12.14	544	409	2.5
Almond (*Amygdalus communis*)	2318	18.72	54.1 ± 0.9	9.08	835	454	4.1
Hazel-nut (*Corylus avelana*)	2521	11.96	61.6 ± 1.5	11.36	636	333	3.8

Source: Souci et al. (1989).

color, flavor, and acidity in order to design products without imparting a characteristic taste or color of the fruit.

Natural color extracts currently permitted by the US Food and Drug Administration (FDA) for industrial use are red cabbage, beet juice or powder, carmine, grape skin extract, and color extractives from grapes. These natural colorants are defined by the FDA as exempt from certification and are listed in US 21 CFR 73. More than 50% of the total reducing sugars are present as fructose which, being naturally hygroscopic, helps to prolong the shelf life of breads and bakery products (Buck 2001).

Frozen Fruits

The Hungarian cooling and refrigeration industry is processing and preserving by freezing several fruits: raspberries, elderberries, apples, quinces, strawberries, gooseberries, red and black currents, sweet cherries, sour cherries, strawberries, apricots, peaches, and chestnuts grown in Hungary. Fruits are frozen after they are harvested, received, selected, washed, cleaned, crushed, or sliced. After freezing, repeated selection and separation of debris follows packaging and storage of the frozen product. Chemical composition of frozen fruits is nearly equivalent to that of the fresh ones; therefore, they can be used as fresh fruits in bakery, confectionery, and dairy industry, for ice creams, desserts, sauces, and ready-made meals. In frozen fruits, undesirable changes are insignificant. Undesirable effects on the color can be controlled by following:

- Blanching
- Color-retention methods
- Packaging in concentrated sugar syrups or by
- Vacuum-packaging of the frozen product (e.g., vacuum-packaging of sliced apples soaked in 0.5% solution of $CaCl_2$ or NaCl)
- Ascorbic or erythorbic acid dip.

The most perishable quality parameter of frozen fruits is their consistency, which must be taken into consideration in the case of sensible fruits (raspberries, strawberries, sour cherries, etc.). Deterioration of the consistency can be an issue if recognizable whole fruits or pieces of well-defined form are needed for an application.

Color changes (darkening) of frozen, sliced apricots, peaches, and apples during storage suggest presence of peroxidase enzymes that can be inactivated by blanching and other methods indicated before. The darkening of sour cherries can be due to oxidation of kera-cyanin or polyphenols. The former causes discoloration, the latter induces browning (Pai 2003).

The period between harvest and freezing is playing a significant role in development of taste and flavor. Properly processed and packaged frozen fruits—stored under minimal fluctuation of the temperature—do not undergo significant loss of taste and flavor. They have a quality nearly equivalent to fresh fruits (Beke 2002, James 2003b).

Kernel of Nut Varieties, Used as Bakery and Confectionery Additives

Generally known as "shell fruits" in Europe, China, and the United States are nuts (*Juglans regia* L.), almonds (*Amygdalus communis*), and hazelnuts (*Corylus avelana* L.). Kernels of the shell fruits are frequently used as valuable additives of bakery and confectionery products, desserts, muesli, and icecream. They can be used unbroken, coarse broken or as grist, sweetened cream (marzipan: fondant, flavored with almonds), and syrup. These additives have an intensive, pleasant, and characteristic flavoring and decorating effect, and they increase the nutritive value of the product because of their high content of digestible solids. The composition of soluble solids of shelled nut varieties is shown in Table 16.3.

DAIRY PRODUCTS CONTAINING FRUIT COMPONENTS

In the food market, the most important dairy products containing fruit are fruit yogurts, milky desserts, and functional drinks. Soluble solid content of these products generally does not exceed 20%–30%. Sweetened berries (strawberries and raspberries) are very popular as dairy additives. These fruit preparations are usually either hot filled or aseptically packaged, and consist of fruit, sweeteners, starch, or other stabilizers and flavorings (Somogyi et al. 1996).

Fruit Yogurts

Fruit yogurts are milk products fermented by using special cultures of lacto-bacteria. Their consistency may be jelly-like or fluid. They contain the fruit additives either homogenously distributed or in layers. Fruit preparations in dairy products call for pectin. Pectin provides the required rheological properties and assures the following:

- Good dosing
- Regular fruit distribution in the container
- Homogenous mixing with the fermented milk product and a good shelf life.

In layered products, the special pectin has a stabilizing effect and keeps the fruit preparation separated from the yogurt without a jellifying effect (Szakály 2001; Anon 2004d). In fruit yogurts, pectin provides a smooth and creamy structure, fruit specific flavor, and prevention of syneresis (Lootens et al. 2003). The same result can be achieved by adding high nutritive and healthy whey proteins to the preparation (Anon 2008).

Average chemical composition of fruit yogurts is given in Table 16.4.

Milk-fruit Desserts

Milk-fruit desserts are semifinished products, made of sugar, buffer substance, fruit, and water mixed with the equal amount of cold milk. The result is a gel that forms within minutes after mixing. Stable, jelly-like consistency, prevention of syneresis, and a characteristic fruit aroma are requirements for the fruit additives of milk-fruit desserts.

Individually quick-frozen (IQF) berries and cherries are appropriate for premium dairy products such as refrigerated desserts. Some processors offer IQF fruits infused with a sugar solution to prevent them from freezing solid in frozen applications (Anon 2002).

Cheeses with Fruit Additives

Dried fruits are typically not used in dairy applications. However, finely chopped or diced versions can add a great deal of flavor to more unique applications such as cream, cheese spreads, Cheddar cheese and butter. Cheeses contain either finally pulped fruit additives uniformly dispersed or layers of fruit pieces, similar to fruit yogurts. Berry and cherry preparations are most suitable as cheese additives (Berry 2001, Anon 2002).

Raisins endow some types of cheeses with a characteristic taste and flavor (Anon 1990).

Table 16.4. Average Chemical Composition of Fruit Yogurts

Contents	Fruit Yogurts	Liquid Fruit Yogurts	Fermented Milk with Fruit Juice
Protein (g/100 g)	2.9–3.0	3.1	2.5
Carbohydrate (g/100 g)	12.1–13.8	11.6	11.0
Fat (g/100 g)	2.6–4.6	1.1	1.0
Energy (kJ/100 g)	353–454	290	266

Source: Anon (2004c).

Alcohol-free Milky Beverages

Fruit components are generally added to milky beverages in the form of fruit-juice concentrates. Carrageen or other hydrocolloid additives ensure homogeneity of the product. Milk beverages flavored with small quantities of banana puree have been developed mainly for children as a product of high nutritive value.

Avocado puree is frequently used for milk shakes and occasionally added to ice cream and other desserts (Naveh et al. 2002).

CONFECTIONERY PRODUCTS AND FROZEN SWEETS CONTAINING FRUIT COMPONENTS

The confectionery industry is using fresh and preserved fruits as filling for chocolates and candies and to decorate and enrich frozen desserts, fruit creams, and parfaits. Most frequently used fruit additives to sweets are—just like those for bakery products—sweet and sour cherries and berries, but the confectionery industry can use other fruits as well.

Enzyme hydrolyzed Jerusalem artichoke juice concentrate can be used as sweetener in dietary and low-energy fruit preparations, because 75%–80% of its sugar content is fructose. Limited amount of fructose can be metabolized by humans in the absence of insulin: 20–80 g daily is tolerated by diabetics. Its sweetening effect is 20%–50% higher than that of sucrose, so it can guarantee the same sweet taste in even lower concentrations (Barta 2000; Bray et al. 2004).

Chocolate Covered Fruits, Chocolates with Fruit Fillings

Cherries, strawberries, blueberries, apricots, whole apples dipped in caramel, diced and sweetened orange, or grapefruit peel can be processed as chocolate coated products. Cherries, apricots is pitted, apples are peeled; the cleaned fruits are slightly dried, dipped in caramel and/or milk-chocolate, covered with colored candy glaze, and packed in presentation tins (Anon 2004a).

A valuable and popular special product of the Hungarian confectionery industry is “sour cherries in rum”; pitted cherries are soaked in rum and coated with chocolate.

Confections contain high levels of sugar and have low water activity that reduces undesirable reactions. Consequently, fruit color pigments tend to be fairly stable in confections (Hegenbart 1994)

DISTILLERY PRODUCTS OR OTHER ALCOHOLIC DRINKS CONTAINING FRUIT COMPONENTS

Prepared, cleaned, pitted, and chopped or whole fruits are valuable components of distillery products (liquors, fruit punches, etc.) as well. Brined cherries are popular components of maraschino cocktails and desserts. The procedure of cherry brining is described by Somogyi et al. (1996).

After brining, maraschino cherries may be placed in NaCl solution to further control skin discoloration (Wagenknecht and Van Buren 1965; Anon 1968).

Fruit cocktail requires bleaching, firming, and drying of the fruit. Pitted cherries are firmed by soaking in hot 0.5%

$CaCl_2$; bleached, neutralized, and colored by treating with erythrosine dye; rinsed with water and acidified in citric acid solution to prevent bleeding of the dye (Chandler 1965; Woodroof and Luh 1975.). After the prescribed treatment, maraschino cherries are infused in a 48% sugar syrup. Once infused, the fruit is drained, and packed in a 45% sugar syrup with flavoring and enough citric acid to produce a final pH of 3.6. The maraschino pack is vacuum sealed and pasteurized (Woodroof and Luh 1975.).

Attempts have been made to use cherry in the production of flavored beers (Peill 1976). Production of this speciality necessitates the neutralization of the inherent malt liquor flavor. The liquor is then sweetened, collared, and flavored with cherry juice as necessary.

FROZEN DESSERTS, PARFAITS, AND ICECREAMS CONTAINING FRUIT COMPONENTS

In addition to yogurt, most dairy fruit preparations are used in frozen desserts. This category of preparation can be classified into three types:

1. Straight, no-particulate flavor systems added directly to the mix tank.
2. Variegates that do not contain particulates and are running through the variegating pump on the ice-cream freezing system.
3. Fruit feeder systems that have a higher percentage of particulates and are actually pumped into the ice-cream stream. Each of these categories has specific formulation. Fruit feeder preparations must be thicker so the juice does not drain out of the feeder into the ice-cream stream. They must be injected cleanly, without any excessive liquid run off. Variegates can be either thick or thin, and they usually do not contain much particulate fruit. The described variegate has to be evenly distributed, but there is no concern with fruit destruction, so the feeder construction is more simple.

A fruit preparation for a frozen application must have its freezing characteristics controlled so that it will not freeze solid in the ice cream or frozen yogurt product. The fruit content, solid content, and the stabilization system all play a role here. The stabilizer system affects the size and rate of ice crystal growth. Finding the correct solids content to control the freezing point depression requires looking at the actual Brix of the fruit used. The interplay between the total fruit content and the product's final solid content must be balanced for equilibrium of solids in the finished preparation to maintain softness and prevent icy texture.

An emerging trend in frozen fruit preparations is the use of aseptic preserved fruits in place of traditional whole or IQF fruit used in the fruit feeder. The aseptic fruits help to reduce concerns about microbial contamination of the mix by the fruit, and ensuring a matrix, that is firm to maintain texture at freezer temperatures (Hegenbart 1994).

BAKED PRODUCTS CONTAINING FRUIT COMPONENTS

The use of fruits in bakery and confectionery products has become popular in recent years. The question of how the fruits are used is mainly answered by the type and the manufacturing technology of the bakery product. The possibilities are fresh fruits and processed products like jam, jelly, fillings, etc. which are mainly used for long-life bakery products. The advantages of the "processed fruit components," compared to the fresh ones are:

- All season availability
- Simple storage conditions
- Longer shelf-life
- Simple handling.

Bakery fillings include a large variety of products. They include: simple pectin-based fillings with little or no bake stability; high-fruit low-solids pie fillings; homogenous, creamy preparations processed from fruit purees; high-solid fruit-cookie fillings, etc. These products must withstand a severe heating. Fruit components for breakfast products (croissant and muesli) have a lower a_w value than pie fillings. Bakery fruit preparations come in two general types: those that are designed thermally stable and those designed to be cold filled into the prebaked product.

They must be easy to process; their organoleptic and technological quality should be protected during processing. Preparations, being baked together with the dough, must endure high temperature without quality losses. Special pectin additives play a significant role in ensuring quality requirements. Besides pectin other stabilizers such as starch concentrates and microcrystalline cellulose can be also used (Anon 2009a).

The expression bakery products covers the product categories of long-life biscuits, crackers, cakes, waffles, gingerbread, etc., which are durable without cooling or freezing over a longer period (6–12 months) at ambient temperature (18–25°C).

Bakery products can be filled with various ingredients as cream, nut, nougat, fruits, jam, etc. These ingredients change different factors of the product, which again change the microbial and sensory properties of the bakery product. Combined food that consists of one or several layers differs in its composition. In such food, there is the possibility for moisture to migrate from one component to another. This migration happens from regions of high water activity to regions of lower water activity. The water activity is a physical parameter that indicates the "energy status" of the moisture in a material. Thus, it is better qualified for the description of the migration tendency of the moisture in a combined food, than by simply controlling the absolute water content of the components. The migration and equilibrium properties of water in combined food are an important point for the shelf life stability of the product. High baking temperatures support the level of the a_w equilibrium between the different components. Thus, the adjustment of the equilibrium between the different layers or components of the food is not only influenced by the baking process but also by the storage time between production and packaging.

The level of the water migration during the shelf life time of a combined food, hence the adjustment of the relative equilibrium humidity, if high enough, is what leads to rather homogenous a_w values in the different components. This simplifies the use of the water activity as an indicator for the microbial stability of combined bakery products. To produce a stable and sensory attractive product, the a_w should be monitored and hazard analysis and critical control points (HACCP) protocols should be followed. The technologist should know the baking parameters, interactions between the filling and the cake or dough, and whether the product is going to be open ended or totally encrusted (Hegenbart 1994).

Requirements on Baking Stable Fruit Preparations

Fruit preparations, which are baked together with the dough, are produced as bucket, drum, or container goods based on individual requirements. The properties of the fruit preparations are influenced by processing technology, recipe parameters (Ca^{++}-ion concentration, type of sugar, pH value, and type of fruit), the used pectin, and/or the combination of these factors.

Requirements Before Baking

The fruit preparation for bakery products is expected to be well processable and which not change its texture after mechanical stressing. To obtain a product that is easily pumpable and dispensable after filling, the fruit preparations are stressed mechanically during cooling and after they are filled cold. In this way, the forming of an elastic gel is avoided and nongelled, creamy product with the required firmness results.

Requirements During Baking

Both the dough and the fruit preparation are exposed to a defined heat for a certain time during the baking process in the oven (e.g., breakfast cookies, "croissants" filled with jam or marmalade). Baking stability of the preparation means that it does not start boiling or melting. The fruit filling must have excellent shape stability, but a limited melting on the surface will result in a nice gloss, giving the cake an attractive surface after cooling and firming. This is called a "limited baking stability."

Requirements After Baking

After baking, the products are usually packaged and stored. As baking-stable fruit preparations are mainly used for baked products with a long shelf life, it is important that the cakes keep their optimal quality over a longer period of time. Therefore, the fruit preparation is expected to be stable also after baking and it may not release water or show any tendency to syneresis. Ideally, a_w value of the fruit preparation complies with that of the baked product. In contrast to jams and marmalades, a pregelled texture is desired in the production of baking stable fruit preparations with low methyl-ester pectin. Pregelling by using special pectin or gellan gum additives can prevent precipitation of Ca-pectinate and syneresis and good processing properties can be achieved.

Application of Different Fruits in Baking Stable Fruit Preparations

Due to their components, the types of fruit pulp would influence texture and baking stability of baked products. In addition, the following factors can influence the quality of the final product:

- Soluble solids content
- The fiber content
- pH
- Total acid and calcium content of the fruit.

To produce products with constant properties, it may be necessary to consider the different kinds of fruit used in a recipe. A mixture of sugar syrup and berries, cherries, apricot, or apples is most frequently used as fruit filling for pies (Anon 2004b).

Among dried fruits, raisins play a significant role as fruit components for high-quality bakery products, milk loafs and cookies (Anon 1990).

Cherry pie filling is the typical extension of the canned, pitted cherry pack. Formulations for this pack vary depending on the starch source (Somogyi et al. 1996).

Alternative and novel combinations have been developed, for example, a reduced sugar cherry–apple filling (Wittstock et al. 1984).

HEAT TREATED AND FROZEN READY-MADE MEAT PRODUCTS CONTAINING FRUIT COMPONENTS

Sterilized or frozen ready meals generally contain besides the meat component, potatoes, rice, vegetables, or pastry as trimmings, but the increasing demand for healthy nutrition makes fruit trimmings and sauces more and more popular. Rice trimming with fruit component or other fruit trimmings, which can be preserved by heat or freezing are considered to characterize the nutrition habits of the Asian people.

Sauces, Dressings, and Ready Meals Sterilized by Heat

Fruits have become popular ingredients in sauces and dressings. Products of good taste may be prepared from cherries, and particularly from apples of desirable varieties, such as Gravenstein, Pippin, and Golden Delicious. Nearly all apple cultivars can be used for processing applesauce, but only a few are considered ideal. Quality attributes in raw apples that produce a high-quality finished product including high-sugar solids, high-acid content, aromatic, bright, golden or white flesh, variable grain or texture, and sufficient water-holding capacity (LaBelle 1971). The finished product can be flavored with spices or combined with other fruits.

The interaction between the stabilizer system and fruit preparation during and after the heat treatment can cause several problems. Starch may hydrolyze under low pH value, or may not cook out properly. The heat and high pH value of the system can affect the fruit pigments and acidity combined with heat can affect starch (Hegenbart 1994).

Frozen Ready-made Meals and Fruit-filled Pastas

Individual components of the multicomponent food are generally cooked or baked separately (as their cooking time and temperatures are different) considering the aspects of food safety and storage. Some components are used fresh while others are partially cooked or cooked. Packaging and closing (practically vacuum closing) of ready-made meals should protect organoleptic and nutritional values of the food. Cooling of the packed and hermetically closed product must begin instantly, and the product must have been cooled under 10°C as soon as possible. The storage life of a food with multicomponents is determined by the component with the fastest quality changes. However, normally, the fruit is not the most critical component (Beke 2002; James 2003a).

Industrial production of frozen pastas and fruit-filled frozen pasta meals have been developed in Hungary recently. Preferred products of this type are fruit-filled dumplings and jam pockets. The dough, containing water-soluble additives (sugar), eggyolk, or starch composed of amylopectin (rye-flour, potatoes) congeals and store well at a temperature of −18°C or lower. Requirements related to the fruit filling are determined by the user on technological and economical basis.

The deep-frozen "plum dumplings" processed from potato dough are filled with whole plums or plum jam. The maturity of the fruit may be about 70%–80%, the diameter of the fruits is about 26 mm. Deep-frozen "apricot dumplings" differ only in the filling from "plum dumplings." The longitudinal diameter of the fruits with sweet kernel may be maximum 30 mm. The maturity of the fruits should not exceed 90%. Only healthy apricots, being true to variety can be used for pasta fillings (Almási 1977).

CONCLUSION

Fruit preparations are important components of many products in nearly all foods. However, as ingredients they play a significant role in the dairy and bakery industry. The important quality requirements of fruit ingredients from the users' viewpoint are consistency, ease of processing, characteristic color, taste, aroma and stability, and nutritional benefits. The popular raw materials for fruit preparations used as components in combined foods are cherries, sour cherries, and berries—alone or mixed with apple preparations.

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17
Developments in Packaging of Fresh Fruits and Fruit Products

Poonam Aggarwal and Amarjit Kaur

Abstract: This chapter provides an overview of the developments in packaging of fresh and processed fruits right from packaging house unit operations, that is, precooling, presorting, cleaning/washing, sizing/grading, waxing, type of packaging materials, modified atmosphere/controlled atmosphere packaging, active/intelligent packaging, labeling, storage and transportation, cold chain management, and packaging requirements for fresh cut, frozen fruits, dried, thermally and nonthermally processed fruits and fruit products. Packaging requirements for fruits and fruit products processed by newer technologies such as high pressure processing (HPP), pulsed electric field, irradiation, and future research needs are also discussed.

INTRODUCTION

Specialized packaging is critical for shelf life, sensory, microbiological, and nutritional qualities of fresh and processed fruits. Food packaging has many dimensions including, preservation, convenience, safety, marketing, and promotion of products (Stilwell et al. 1991). It reduces food waste and spoilage during storage and marketing. This chapter provides an overview of developments in packaging of fresh and processed fruits.

PACKAGING HOUSE UNIT OPERATIONS

The typical packaging house unit operations are as follows:

PRECOOLING

Precooling is the first step in preserving quality of harvested fruits. The field heat of a freshly harvested crop is usually high, and it should be removed as quickly as possible before shipping, processing, or storage. Precooling is generally a separate operation requiring special equipment and/or rooms. Rapid precooling to the product's lowest safe temperature is most critical for fruits with inherently high respiration rates.

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

The following methods described by Wilson et al. (1995) are the most common:

- *Room cooling*: Produce is placed in an insulated room equipped with refrigeration units. This method can be used with most commodities, but it is slow compared with other options. Containers should be stacked in a way that cold air can move around and through them. Used refrigerated truck bodies make excellent small cooling rooms for field situations (Hardenburg et al. 1986).
- *Forced-air cooling*: Fans are used in conjunction with a cooling room to pull cool air through packages of produce. Although the cooling rate depends on the air temperature and the rate of air flow, this method is usually 75–90% faster than room cooling. Fans should be equipped with a thermostat that automatically shuts off as soon as the desired product temperature is reached (Patchen 1969).
- *Hydrocooling*: Dipping produce into cold water, or cold water running over produce, is an efficient way to remove heat and can serve as a means of cleaning at the same time. In addition, hydrocooling reduces water loss and wilting. Use of a disinfectant in the water is recommended to reduce microbial pathogens. Hydrocooling may not be appropriate for berries, grapes, cherries, or other soft fruits that do not tolerate wetting. To avoid over-cooling and dehydration of produce, it is recommended not to operate forced-air fans after the produce has been cooled to its optimum temperature (Wilson et al. 1995).

Water removes heat about five times faster than air, but it is less energy efficient. Well water, mechanical refrigeration, or a thermal storage immersion hydrocooler system can be used economically to suit various volume requirements. Used stainless-steel bulk farm milk coolers may be an option. If hydrocooling water is recirculated, it should be chlorinated to minimize microbial problems (Talbot et al. 1991).

- *Top or liquid icing*: Icing is particularly effective on dense products or palletized packages that are difficult to cool with forced air. In top icing, crushed ice is added to the container over the top of the produce by hand or machine. For liquid icing, slurry of water and ice are injected into produce packages through vents without removing the packages from pallets or opening their tops (Howell 1993).
- *Vacuum cooling*: Produce is enclosed in a chamber in which a vacuum is created. As the vacuum increases, water within the plant evaporates and removes heat from the tissues. To reduce water loss, water is sometimes sprayed on the produce prior to placing it in the chamber. This process is called hydrovac cooling. The primary drawback to this method is the cost of the vacuum chamber system (Sasseville 1988).

Presorting

The presorting process eliminates cull, overripe, misshapen, and otherwise defective fruits and separates product by color, maturity, and degree of ripeness (e.g., tomato and muskmelons). Electronic color sorters are used in some tomato sorting operations.

Cleaning and Washing

Cleaning and washing is an important process for removing surface dirt and organisms and contaminants (Fig. 17.1). The wash water must have permitted level of chlorine and other substances. The recirculating and stagnant water must not be used for the washing of organic produce (use only running water).

Sanitation and water disinfection: Preventive food safety programs, sanitation of equipment and food contact surfaces, and water disinfection should be integrated into every facet of postharvest handling of fruits. *Escherichia coli*, *Salmonella*, *Shigella*, *Listeria*, *Cryptosporidium*, *Hepatitis*, and *Cyclospora* are the major disease-causing organisms that have been associated with fresh fruits and vegetables. Water used in washing of organic produce should not contain any prohibited substances in dissolved form. Even incidental contamination from a prohibited material would keep the product from being certified as organic. Organic growers, shippers, and processors may use chlorine (or other natural food grade disinfectants) within specified limits. As a general practice, field soil on product, bins, and pallets should be kept to a minimum by prewashing, before loading the produce in it. Prewashing also removes plant exudates released from harvest cuts or wounds, which can react rapidly with oxidizers such as hypochlorite and ozone, and so requires higher rates of the chemical to maintain the target 4 to 10 ppm downstream activity. For both organic and conventional operations, liquid sodium hypochlorite is the most common form used (Boyette et al. 1993).

For optimum anti-microbial activity with a minimal concentration of applied hypochlorite, the pH of the water must be adjusted between 6.5 and 7.5. At this pH range, most of the chlorine is in the form of hypochlorous acid (HOCl), which delivers the highest rate of microbial kill and minimizes the release of irritating and potentially hazardous chlorine gas (Cl_2). Chlorine gas will exceed safe levels if the water is too acidic. Products used for pH adjustment must also be from a natural source such as citric acid, sodium bicarbonate, or vinegar.

Drying: After washing, drying is necessary without causing bruising or damage to outer surfaces (Fig. 17.2). Soft roller material is used to avoid bruising.

Sizing/Grading

After drying, grading is done to produce a uniform product as per the market requirements. Grading can be done manually as well as mechanically. The grading system must

Figure 17.1. Steam heat treatment. (*Source*: International Course on Fruits and Vegetables, Volcani, Israel.)

be sterilized before use. Color grading using sortex systems and size grading are the common procedures (Hardin 1995). After sorting for defects and color differences, produce are segregated into several size categories. Sizing is done manually for many of the produce, including the legumes, soft and hard rind squashes, cucumber, eggplant, chili peppers, okra, pumpkin, muskmelons, and watermelon. These may be sized by volumetric weights, or diverging roll sizers; sweet peppers are sized commonly by diverging bar sizers; and tomatoes are sized by diameter with belt sizers or by weight. Only after drying and grading, the postharvest treatment such as waxing (food grade only) and packaging can be done.

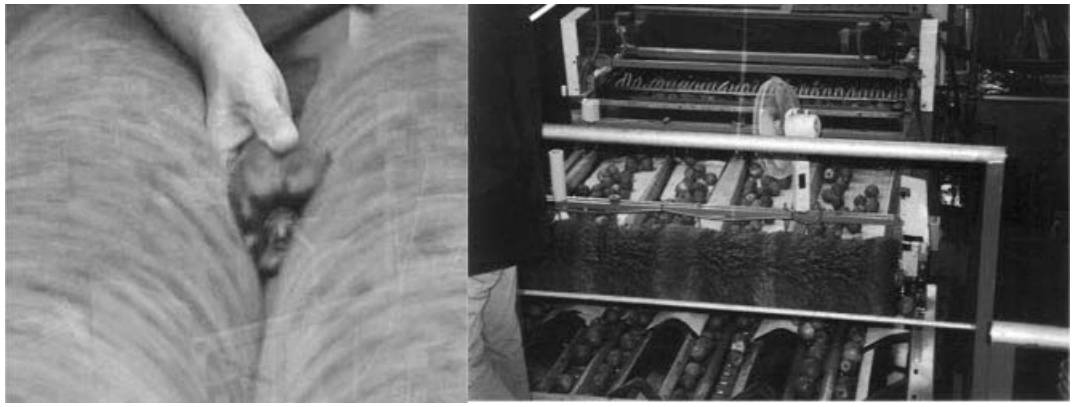

Figure 17.2. Drying of vegetables. (*Source*: International Course on Fruits and Vegetables, Volcani, Israel.)

Waxing

Waxing is done to remove surface organisms and save moisture loss during the storage and transportation. Food grade waxes are commonly applied to cucumber, eggplant, sweet peppers, cantaloupe, and tomato and occasionally to some summer squashes. The purpose is to replace some of the natural waxes removed in the washing and cleaning operations, to reduce water loss, and to improve appearance. Waxing may be done before or after sizing, and fungicides may be added to the wax. Application of wax and postharvest fungicides must be indicated on each shipping container (Hulbert and Bhowmik 1987). Waxing and fungicides are used only in packing house handling of fruit and vegetables. European cucumbers are frequently shrink-wrapped rather than waxed.

Various waxes like carnauba (palm), sisal (sisal waste), banana (shrub), sugarcane (cane), rice bran (bran oil); *petroleum waxes*: crude petroleum-(A), paraffin (B), microcrystalline waxes; *insect waxes*: shellac and bee waxes; and s*ynthetic waxes*: carboa waxes, polythene, santo waxes are used in the form of emulsions, which are applied either by dipping the fruit in emulsion or spraying or dripping foam or melted wax over the fruits.

Treatments to minimize water/transpiration loss during transportation: Transpiration, or evaporation of water from the plant tissues, is one of the major causes of deterioration in fresh horticultural crops after harvest. Water loss through transpiration not only results in direct quantitative losses (loss of saleable weight) but also causes losses in appearance (wilting, shrivelling), textural quality (softening, flaccidity, limpness, loss of crispness and juiciness), and nutritional quality. Transpiration can be controlled either through the direct application of postharvest treatments to the produce (surface coatings and other moisture barriers) or through manipulation of the environment (maintenance of high relative humidity). Treatments that can be applied to minimize water loss in fruits and vegetables include the following:

- Curing of certain root vegetables, such as garlic, onion, potato, and sweet potato.
- Waxing and the use of other surface coatings on commodities, such as apple, citrus fruits, nectarine, peach, plum, pomegranate, and tomato.
- Packaging in polymeric films that act as moisture barriers.
- Careful handling to avoid physical injuries, which increase water loss from produce.
- Spraying of water on to those commodities that tolerate moistening with water, such as leafy vegetables.

Packaging Materials

Bags, crates, hampers, baskets, cartons, bulk bins, and palletized containers are convenient containers for handling, transporting, and marketing fresh produce. Although the industry generally agrees that container standardization is one way to reduce cost, the trend in recent years has moved toward a wider range of package sizes to accommodate the diverse needs of wholesalers, consumers, food service buyers, and processing operations. Packing and packaging materials contribute a significant cost to the produce industry; therefore, it is important that packers, shippers, buyers, and consumers have a clear understanding of the wide range of packaging options available (Peleg 1985). A package performs the functions of containment, protection, and identification of the produce packed. The container must enclose the produce in convenient units for handling and distribution. The produce should fit well inside the container, with little wasted space. The package must protect the produce from mechanical damage and poor environmental conditions during handling and distribution. To a consumer, a torn, dented, or collapsed package usually indicate an unsafe product.

Air-freighted produce may require special packing, package sizes, and insulation. Marketers who export fresh produce should consult with freight companies about any special packaging requirements. In addition, the United States Department of Agriculture (USDA) and various state export agencies may be able to provide specific packaging information (Ashby et al. 1987).

The package must identify and provide useful information such as the produce name, brand, size, grade, variety, net weight, count, grower, shipper, and country of origin along with nutritional information, recipes, and other useful information directed specifically at the consumer. Universal product codes (UPC or bar codes) may be included as a part of the labeling. Although no price information is included, UPCs are used more and more by packers, shippers, buyers, and retailers as a fast and convenient method of inventory control and cost accounting. Efficient use of UPCs requires coordination with everyone who handles the package (Erdei 1993). There are different types of packaging materials used for food packing such as the following:

- *Wooden pallets*: These form the base on which most fresh produce is delivered to the consumer. Pallets (Fig. 17.3) were first used during World War II as an

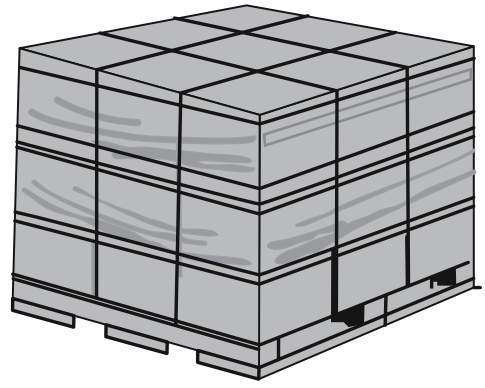

Figure 17.3. Well-packed produce over a pallet.

efficient way to move goods. The produce industry uses approximately 190 of the 700 million pallets produced per year in the United States. About 40% of these are single-use pallets. Because many are of a nonstandard size, the pallets are built as inexpensively as possible and discarded after a single use. Efforts have been slowly under way for standardization of pallets from many years. Over the years, the 40″-wide × 48″-long pallet has evolved as the unofficial standard size. Standardization encourages reuse, which has many benefits. Besides reducing cost by reusing, standard size pallets make efficient use of truck and van space and can accommodate heavier loads and more stress than lighter single-use pallets. In addition, the use of a single pallet size could substantially reduce pallet inventory and warehousing costs along with pallet repair and disposal costs. The adoption of a pallet standard throughout the produce industry would also aid efforts toward standardization of produce containers (Anon 1993).

Depending on the size of produce package, a single pallet may carry from 20 to over 100 individual packages. Because these packages are often loosely stacked to allow for air circulation, or are bulging and difficult to stack evenly, they must be secured (unitized) to prevent shifting during handling and transit. Although widely used, plastic straps and tapes may not have completely satisfactory results. Plastic or paper corner tabs should always be used to prevent the straps from crushing the corners of packages (Paine 1987).

Plastic stretch film is also widely used to secure produce packages. A good film must stretch, retain its elasticity, and cling to the packages. Plastic film may conform easily to various size loads. It helps protect the packages from loss of moisture, makes the pallet more secure against pilferage, and can be applied using partial automation. However, plastic film severely restricts proper ventilation. A common alternative to stretch film is plastic netting, which is much better for stabilizing some pallet loads, such as those that require forced-air cooling. Used stretch film and plastic netting may be difficult to properly handle and recycle (Aharoni et al. 1996).

- *Pallet bins*: Substantial wooden pallet bins of milled lumber or plywood are primarily used to move produce from the field or orchard to the packing house. Depending on the application, capacities may range from 12 to more than 50 bushels. Although the height may vary, the length and width is generally the same as a standard pallet (48″ × 40″). More efficient double-wide pallet bins (48″ × 80″) are becoming more common in some produce operations (Stokes 1974).

Most pallet bins are locally made; therefore, it is very important that they must be consistent in materials, construction, and especially the size. Pallet bin can add up to bigger problems when several hundred of these are stacked together for cooling, ventilation, or storage. It is also important that stress points be adequately reinforced. The average life of a hardwood pallet bin that is stored outside is approximately 5 years. When properly protected from the weather, pallets bins may have a useful life of 10 years or more (Hardenberg et al. 1986).

Uniform voluntary standards for wood pallets and other wood containers are administered by the National Wooden Pallet and Container Association, Washington, DC, and the American Society of Agricultural Engineers, St. Joseph, MI, publishes standards for agricultural pallet bins (ASAE S337.1) (Hardenberg et al. 1986).

- *Wire-bound and wooden crates*: These crates are used extensively for snap beans, sweet corn, and several other commodities that require hydrocooling. Wire-bound crates are sturdy, rigid, and have very high stacking strength that is essentially unaffected by water. Wire-bound crates come in many different sizes with open space to facilitate cooling and ventilation. Although few are reused, wire-bound crates may be dissembled after use and shipped back to the packer (flat). In some areas, used containers may pose a significant disposal problem. Wire-bound crates are not generally acceptable for consumer packaging because of the difficulty in affixing suitable labels (Anon 1982). Wire-reinforced wood veneer baskets and hampers of different sizes were once used for a wide variety of crops from strawberries to sweet potatoes. They are durable and may be nested for efficient transport when empty. However, cost, disposal problems, and difficulty in efficient palletization have severely limited their use to mostly local grower markets where they may be reused many times (Anon 1982).

Wooden crates have been almost totally replaced by other types of containers due to a greater concern for tare weight, and advances in material handling have reduced their use to a few specialty items, such as, expensive tropical fruit. The 15-, 20-, and 25-pound wooden lugs still used for bunch grapes and some specialty crops are being gradually replaced with less costly alternatives (Anon 1982).

- *Corrugated fiber board*: Most of the corrugated fiberboard (Fig. 17.4) is made from three or more layers of paperboard containing wood and synthetic fibers so as to give it the additional strength, sizing (starch), and other materials to give it wet strength and printability. Most of the fiberboard contains some recycled fibers. Tests have shown that cartons of fully recycled pulp have about 75% of the stacking strength of virgin fiber containers. The use of recycled fibers will inevitably lead to the use of thicker walled containers (Anon 1992).

Corrugated bulk bins used for fresh produce which require high stacking strength, may have double- or even triple-wall construction. The inner layer may be given a special coating to resist moisture. Corrugated fiberboard manufacturers print box certificates on the bottom of containers to certify certain strength characteristics and limitations. There are two types

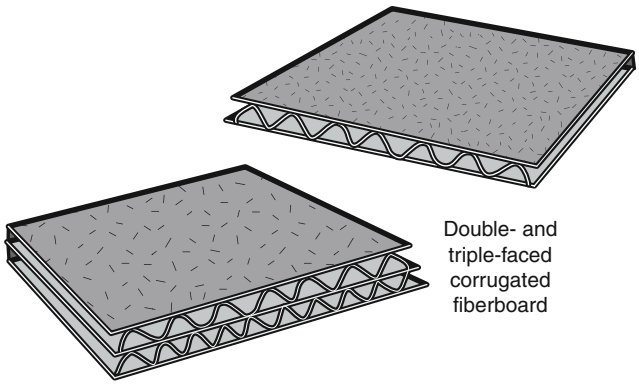

Figure 17.4. Corrugated fiber board.

of certification. The first certifies the minimum combined weight of both with a minimum bursting strength. The second certifies minimum edge crush test (ETC) strength (Anon 1993).

Both the moisture absorbed from the surrounding air or contents and the cold temperature can reduce the strength of the container by as much as 75%. New antimoisture coatings (both wax and plastic) are now available to substantially reduce the effects of moisture (Anon 1993). Waxed fiberboard cartons (the wax is about 20% of fiber weight) are used for many produce items that must be either hydrocooled or iced (Parsons et al. 1972).

Stacking strength of the container is of major consideration. Fresh produce usually cannot carry much of the vertical load without some damage. Therefore, one of the primary desired characteristics of corrugated fiberboard containers is stacking strength to protect the produce from crushing. Because of their geometry, most of the stacking strength of corrugated containers is carried by the corners. For this reason, hand holes and ventilation slots should never be positioned near the corners of produce containers and be limited to no more than 5% to 7% of the side area (Patchen 1969).

Interlocking the packages (cross stacking) is universally practiced to stabilize pallets. To reduce the possibility of collapse, the first several layers of each pallet should be column stacked (one package directly above the other). The upper layers of packages may be cross stacked as usual with very little loss of pallet stability (Patchen 1969).

There are numerous styles of corrugated fiberboard containers. The two most used in the produce industry are the one piece, regular slotted container (RSC) and the two piece, full telescoping container (FTC). The RSC has relatively low stacking strength and therefore must be used with produce, such as potatoes, that can carry some of the stacking load. The FTC, actually one container inside another, is used when greater stacking strength and resistance to bulging is required. A third type of container is the Bliss box, which is constructed from three separate pieces of corrugated fiberboard with maximum stacking strength. The bottoms and tops of all three types of containers may be closed by glue, staples, or interlocking slots (Patchen 1969).

Large double-wall or even triple-wall corrugated fiberboard containers are increasingly in use as ship bulk produce to processors and retailers. The container cost per pound of produce is as little as one-fourth of traditional size containers. Some bulk containers may be collapsed and reused (Stokes 1974).

For many years, labels were printed on heavy paper and glued or stapled to the produce package. The high cost of materials and labor has now eliminated this practice. The ability to print the brand, size, and grade information directly on the container is one of the greatest benefits of corrugated fiberboard containers. There are basically two methods used for printing the corrugated fiberboard containers:

- *Postprinted*: When the liner is printed after the corrugated fiberboard has been formed, the process is known as postprinting. Postprinting is the most widely used printing method for corrugated fiberboard containers because it is economical and may be used for small press runs. However, postprinting produces graphics with less detail and is usually limited to one or two colors (Erdei 1993).
- *Preprinted*: High-quality, full-color graphics may be obtained by preprinting the linerboard before it is attached to the corrugated paperboard. Although the cost is about 15% more than standard two-color containers, the eye-catching quality of the graphics makes it very useful for many situations. The visual quality of the package influences the perception of the product because the buyer's first impression is of the outside of the package. Produce managers especially like high-quality graphics, which they can make use of in super market floor displays (Erdei 1993).

Preprinted cartons are usually reserved for the introduction of new products or new brands. Market research has shown that exporters may benefit from sophisticated graphics. The increased cost usually does not justify use for mature products in a stable market, but this may change as the cost of these containers becomes more competitive.

- *Pulp containers*: Containers made from recycled paper pulp and a starch binder are mainly used for small consumer packages of fresh produce, can absorb surface moisture from the product, which is a benefit for small fruit and berries that are easily harmed by water. The more sturdy mesh bag has much wider use. In addition to potatoes and onions, cabbage, turnips, citrus, and some specialty items are packed in mesh bags. Sweet corn may still be packaged in mesh bags in some markets. In addition to its low cost, mesh has the advantage

of uninhibited air flow. Good ventilation is particularly beneficial to onions (Lee et al. 2009).
- *Plastic bags*: Plastic bags (polyethylene film) are the predominant material for fruit and vegetable consumer packaging. Film bags are clear, allowing for easy inspection of the contents, and readily accept high-quality graphics and may be engineered to control the environmental gases inside the bag. Modified atmosphere packaging (MAP) material may be specially engineered for each item to extend the shelf life of fresh product.

In addition to engineered plastic films, various patches and valves have been developed that affix to low-cost ordinary plastic film bags. These devices respond to temperature and control environmental gases (Rich 1980).

- *Shrink wrap*: One of the newest trends in produce packaging is the shrink wrapping of individual produce items. Shrink wrapping has been used successfully to package potatoes, sweet potatoes, apples, onions, sweet corn, cucumbers, and a variety of tropical fruit. Shrink wrapping with an engineered plastic wrap can reduce shrinkage, protect the produce from disease, reduce mechanical damage, and provide a good surface for stick-on labels (Kelly 1980).
- *Attractive food packaging*: Food packaging is booming industry. But along with the boom, there is a cut-throat competition. Besides being very cautious of all minute details with respect to materials used to manufacture food packaging supplies, the competition also pushes the big and known brands to go in for appealing, attractive, and creative food packaging designs. Food packaging boxes, bags, pouches, and containers all can be seen in colorful, attractive, and creative packaging designs (Fig. 17.5).

Materials used for food packaging boxes are chosen depending upon the foods to be packed. Food packaging boxes have come of age and are open to experimental designs. Various types of food packaging boxes are in the market. Some of the main categories in food packaging boxes are as follows:

- *Paper food packaging boxes*: Paper food packaging is a popular and preferred food packaging option for a lot of reasons. It is light weight, nontoxic, and eco friendly. The "go green" initiative has further popularized the paper food packaging boxes. In the drive to make paper food packaging boxes and packaging bags more popular, creative food packaging boxes are being manufactured to lure the customers. The other advantage of using them is that they are disposable and are easy to carry while out and on the go. Today more and more people look for sustainable containers and boxes for their traveling needs and purposes. These disposable food packaging boxes need to be light and biodegradable (Kirwan 2003).
- *Clear and rigid plastic packages*: Packages with a top and bottom that are heat formed from one or two pieces of plastic are known as clamshells making clear food packaging boxes. Clamshells are gaining popularity because they are inexpensive, versatile, provide excellent protection to the produce, and present a very pleasing consumer package (Fig. 17.6).

Clamshells are most often used with consumer packs of high-value produce items such as small fruit, berries, mushrooms, etc., or items that are easily damaged by crushing. Clamshells are used extensively with precut produce and prepared salads. Molded polystyrene and corrugated polystyrene containers have been test marketed as a substitute for waxed corrugated fiberboard. At present, they are not generally cost competitive, but as environmental pressures grow, they may be more common. Heavy-molded polystyrene pallet bins

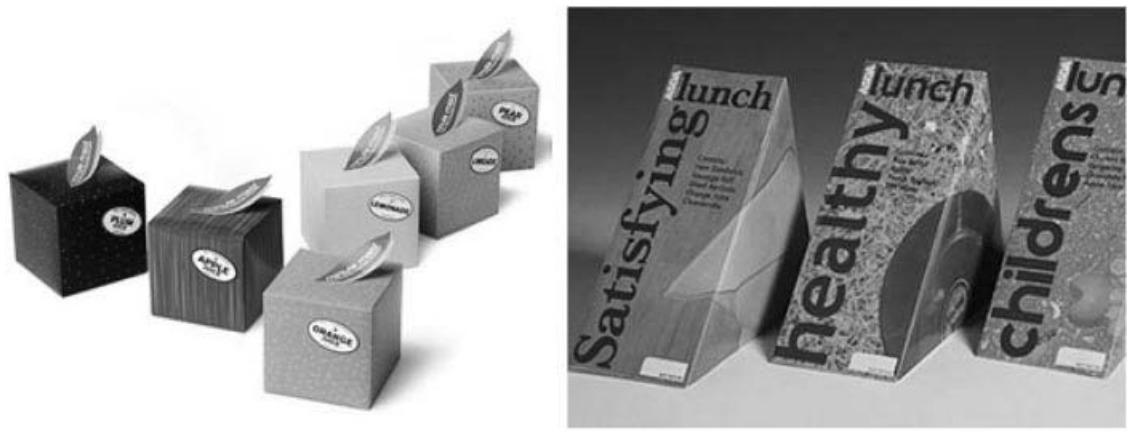

Figure 17.5. Paper food packaging boxes.

Figure 17.6. Clear food packaging boxes.

have been adopted by a number of growers as a substitute for wooden pallet bins. Although at present their cost is over double that of wooden bins, they have a longer service life, are easier to clean, are recyclable, do not decay when wet, do not harbor disease, and may be nested and made collapsible (Kirwan and Strawbridge 2003).

- *Biodegradable food packaging boxes*: As environmental pressures continue to grow, the disposal and recyclability of packaging material of all kinds will become a very important issue. Common polyethylene may take from 200 to 400 years to breakdown in a landfill. The addition of 6% starch will reduce the time to 20 years or less. Packaging material companies are developing starch-based polyethylene substitutes that will break down in a landfill as fast as ordinary paper.

The move to biodegradable or recyclable plastic packaging materials may be driven by cost in the long term, but by legislation in the near term. Some authorities have proposed a total ban on plastics. Eco-friendly food packaging is the new trend. Paper packaging bags, cardboards boxes, and all biodegradable materials are preferred for biodegradable packaging.

Modified Atmosphere/Controlled Atmosphere Packaging

MAP is a technique used to extend the shelf life of fresh or minimally processed foods. In this preservation technique, the air surrounding the food in the package is changed to another composition. This way the initial fresh state of the product may be prolonged. One of the major benefits of MAP is the prevention or retardation of fruit senescence (ripening) and the other associated biochemical and physiological changes.

Temperature is the most effective environmental factor in the prevention of fruit ripening. Both ripening and ethylene (C_2H_4) production rates increase with an increase in temperature. To delay fruit ripening, fruits should be held as close to 0°C as possible, without causing chilling injury. The use of MAP as a supplement to proper temperature maintenance in an effort to delay ripening is consequentially more effective for chilling-sensitive fruits, but it is generally beneficial for all fruits. Reducing O_2 concentration below 8% and/or elevating CO_2 concentration above 1% is known to retard fruit ripening. It has been established that at 2% O_2 level, the anaerobic respiration may result in the development of off-flavors and off-odors. Fruits exposed to such low O_2 levels may also loose their ability to attain uniform ripeness upon removal from MAP. Successful applications of MAP on fruits include Royal Gala apples, Granny Smith apples, lemons (whole, peeled, and sliced), and oranges (whole, peeled, and sliced). The effectiveness of modified atmospheres and packaging materials on the growth of *Penicillium expansum* and patulin production in Granny Smith apples was determined by Moodley et al. (2002). They showed that polyethylene is an excellent packaging material for the storage of apples since it inhibited the growth of *P. expansum*, thereby preventing patulin production, regardless of gaseous environment.

A lot of work has also been reported on the effect of MAP on the other fruits. Fresh-cut Conference pears were packaged under different MAP conditions, stored in refrigeration, and the effects of packaging atmospheres on the microbial viability as well as on quality parameter were studied (Soliva-Fortuny and Martin-Belloso 2003). The use of plastic bags of a permeability of 15 cm^3 O_2/m^2/bar/24 h and initial atmospheres of 0 kPa O_2 extended the microbiological shelf life of pear cubes for at least 3 weeks of storage. The changes in sensory quality and proliferation of spoilage microorganisms on lightly processed and packaged cactus pear fruit were also measured as a function of storage temperature and MAP (Corbo et al. 2004). It was found that cactus pear fruit had longer shelf life at 4°C. Also the three different varieties of pear (Williams, Conference, Passacrassana) that had reached their commercial ripening stage were evaluated for suitability for minimal processing (Arias et al. 2008). Conference pear was found to be the most suitable variety. An integrated strategy was developed to control postharvest decay of Embul banana by combining essential oils with MAP (Ranasinghe et al. 2005). Treatment with emulsions of cinnamon oils combined with MAP is recommended as a safe, cost-effective method for extending the storage life of Embul bananas up to 21 days in a cold room and 14 days at 28 ± 2°C without affecting the organoleptic and physicochemical properties. The effect of MAP on chilling-induced peel browning in banana was also studied (Nguyen et al. 2004).

The combined influence of mild heat pretreatments (MHPT) and two types of MAP conditions on metabolic

response of fresh-cut peaches was studied during 8-day-long storage under refrigeration (Steiner et al. 2006). The quality of "Royal Glory" peaches was also evaluated using a combination of hot water treatment and MAP (Malakou and Nanos 2005). Hot water treatment did not cause any fruit damage but reduced firmness loss. The effect of MAP in nonretractile plastic film and storage in air on the ethylene production, respiratory activity, development of chilling symptoms, water loss, and ion leakage and accumulation of ethanol and acetaldehyde in wild type and ethylene-suppressed melons were compared during storage at 2°C (Flores et al. 2004). Fresh-cut Amarillo melon was stored under passive MAP for 14 days at 5°C using three commercial films [microperforated polypropylene (MPP), polypropylene (PP), and oriented polypropylene (OPP)] and the quality was evaluated (Aguayo et al. 2003). The change of headspace gas concentrations to describe the respiration of fresh-cut melon under low- or superatmospheric oxygen conditions had also been studied (Oms-Oliu et al. 2008). A mathematical model was also tested to make changes of in-package O_2 and CO_2 concentrations throughout the storage, in order to predict the respiratory activity of the commodity. The modified atmosphere package combined with ozone and edible coating films were used for improving the effect of preservation of strawberry (Zhang et al. 2005). The optimum gas composition of MAP test for strawberry was 2.5% O_2, 16% CO_2. Also the integrated model approach was used to study the effect of modified atmosphere conditions on keeping quality of "Elsanta" strawberries as limited by spoilage (Hertog et al. 1999). Headspace fingerprint mass spectrometry had been used to characterize strawberry aroma at superatmospheric oxygen conditions (Berna et al. 2007). Ethyl acetate is one of the most important off-flavors in strawberries. The results showed that after 4 and 7 days of storage under superatmospheric oxygen concentrations (without CO_2), the production of ethyl acetate was suppressed.

The storage of table grapes in 80% O_2 or 40% O_2 and 30% CO_2 improved berry hardness, springiness, chewiness, flavor, and membrane integrity over control samples stored in air (Deng et al. 2005). It was observed that the quality of SO_2-free "superior seedless" table grapes was preserved in MAP. The improvement of the overall quality of table grapes stored under MAP in combination with natural antimicrobial compounds had also been studied (Guillen et al. 2007). The effects of MAP on the storage life of loquat fruit were investigated by Ding et al. (2002, 2006). "Hass" avocado fruit showed potential for long-term storage (up to 9 weeks) under modified atmosphere in a commercial size package (Meir et al. 1997). The influence of MAP and postharvest treatments on quality retention of litchi was studied (Sivakumar and Korsten 2006). The emission of some of the metabolites, such as acetaldehyde and ethanol from litchi fruit, has also been monitored during maturation and storage (Pesis et al. 2002). The effect of an antioxidant dipping treatment (in an aqueous solution of 1% ascorbic acid and 1% citric acid for 3 minutes) and of modified atmosphere (90% N_2, 5% O_2, and 5% CO_2) packaging on functional properties of minimally processed apples have been investigated by Cocci et al. (2006).

Storage of mango fruits at 12°C caused slight chilling injury symptoms on the fruit peel expressed as red spots around the lenticels (Pesis et al. 2000). An integrated approach was employed for the control of postharvest brown rot on sweet cherry fruit (Spotts et al. 2002). Treatments included a preharvest application of propiconazole, a postharvest application of a wettable dispersible granular formulation of yeast, storage in modified atmosphere at 2.8°C for 20 days or −0.5°C for 42 days. The postharvest quality of papaya was enhanced significantly by combining methyl jasmonate (MJ) treatments and MAP (Gonzalez-Aguilar et al. 2003). In case of ber fruit (*Ziziphus mauritiana* Lamk), postharvest dip in water at 50°C for 5 minutes significantly increased the shelf life (Lal et al. 2002). Fruits packed in sealed polythene bags significantly lowered the loss in fruit weight, spoilage, and had accelerated ripening with consequent increase in acidity and organoleptic score.

The MAP technique consists of the enclosure of respiring produce in polymeric films in which the gaseous environment is actively or passively altered to slow respiration, reduce moisture loss, and decay and/or extend the shelf life of the products.

Many of the films used in MAP alone do not offer all the features required for an MAP. To provide packaging films with a wide range of physical properties, many of these individual films are combined through processes such as lamination and coextrusion. There are several such groupings in MAP films. Polyethylene is most commonly used to provide a hermetic seal and other characteristics like anti-fogging.

The degree to which atmospheric modification takes place in a package is dependent upon film's permeability to O_2 and CO_2, product's respiration rate, and the influence of temperature on these variables (Beaudry 1999; Cameron et al. 1994; Beaudry et al. 1992). Consequently, O_2 levels decline, and CO_2 levels increase as the temperature increases (Beaudry et al. 1992; Cameron et al. 1994). Thus, with an increase in temperature, the resultant increase in film permeability cannot keep pace with the increase in the demand for O_2 by the produce, leading to the observed decline in O_2. In perforated packages, this effect is more pronounced because there is only a minimal increase in O_2 transport through perforations with increasing temperature. The concentrations of O_2 and CO_2 within a package can be modeled. Useful models have been developed that would allow fresh produce handlers to choose suitable packaging materials. A common mathematical model involves the use of what is known as a Michaelis–Menten type respiratory model to describe the influence of temperature, O_2 (and potentially CO_2) on respiration. This approach has been used for blueberries (Cameron et al. 1994), strawberries (Joles 1993), raspberries (Joles et al. 1994), and apple slices (Lakakul et al. 1999).

Table 17.1. Selected Examples of Active Packaging System

Active Packaging System	Mechanisms	
Oxygen scavengers	Iron based Metal based/acid Nylon M∗D_6 Metal (e.g., platinum) catalyst	Dried foods and beverages
Carbon dioxide emitters	Ascorbate/metallic salt Enzyme based	
Ethylene scavengers	Potassium permagnate Activated carbon Activated clays/zeolites	Fruit, vegetable, and other products
Preservative releasers	Organic acids Silver zeolite Spice and herb extracts BHA/BHT antioxidants Vitamin E antioxidants Chlorine dioxide/super dioxide	Fruit and vegetable
Moisture absorbers	PVA blanket Activated clays and minerals Silica gel	Dried foods, fruits, and vegetables
Flavor/odor absorbers	Cellulose triacetate Acetylated paper Citric acid Ferrous salt/ascorbate Activated carbon/zeolites	Fruit juices, fruits
Temperature-control packaging	Nonwoven plastics Doubled walled containers Hydroflurocarbon gas Quicklime/water Ammonium nitrate/water Calcium chloride/water Super corroding alloy/salt water Potassium permagnate/glycerine	Beverages
Temperature *compensating* film	Side chain crystallizable polymers	Fruit, vegetables, and other horticultural products

Active/Intelligent Packaging

Active packaging includes components of packaging system that are capable of scavenging oxygen; absorbing carbon dioxide, moisture, ethylene, and/or flavor/odor taints; releasing carbon dioxide, ethanol, antioxidants, and/or other preservatives; and/or maintaining temperature control or compensating for temperature changes. Active packaging material that can extend the shelf life of fruit and vegetable products is shown in Table 17.1.

Active packaging is different from intelligent packaging, which refers to packaging that senses and informs (Day 2003). Robertson (2006) defines intelligent packaging as packaging that contains an external or internal indicator to provide information about the history of the package and/or quality of food. Intelligent packaging devices are capable of sensing and providing information about the function and properties of packaged food and can provide assurance of pack integrity, tamper evidence, and product safety and quality. This system has been used in applications such as product authenticity, antitheft, and product traceability. Intelligent packaging devices include time–temperature indicators; gas sensing dyes; microwave "doneness" indicators; microbial growth indicators; physical shock indicators; and numerous examples of temper proof, anticounterfeiting, and antitheft technologies.

Smart packaging can encompass active, intelligent, and functional packaging. Oxygen scavengers help maintain food quality by decreasing food metabolism, reducing oxidative rancidity, inhibiting undesirable oxidation of labile pigments and vitamins, and controlling enzymatic discoloration.

Labeling

The labeling of fruit and vegetables, which are prepacked for sale on the same premises or prepacked for sale by the

packer on his market stalls, requires that labeling should be either on a notice or adjacent to the food, which is clear and conspicuous to customers. The true identity of the food (e.g., potatoes and melons) must also be marked with their variety (e.g., Maris Piper potatoes, Ogen melons) and place of origin (e.g., English strawberries or Tasmanian apples). Waxed fruit must be labeled. Some prepared salads, dried fruits, and peeled potatoes are treated with preservative solution to keep them fresh. These must be labeled as "contains preservative."

Food or ingredients that have been irradiated must be declared and labeled "irradiated" or "treated with ionizing radiation." Organic fruits and vegetables can only come from producers, importers, or processors that have been inspected and approved by a body authorized by the government. Food from any other sources is not "organic" and to describe it as such is an offence.

Laser Etching

The small labels that are placed on fruits and vegetables hardly appear to be a major environmental concern. When we consider the resources used—from ink to paper—on a global scale for something that is immediately thrown away, the equation becomes rather problematic. But a new laser etching technology utilizes a low-energy carbon dioxide beam to safely create labels directly on to produce. The technique is already being used in New Zealand, Australia, and Pacific Rim and has recently been approved in Asia, South Africa, Central and South America, Canada, and the European Union. In the United States, it is still under review by the Food and Drug Administration (FDA).

Storage and Transportation

Temperature abuse during transportation, storage, and marketing of fresh products is a primary concern in the fresh produce industry. To reduce the transportation losses, the fresh produce should not be allowed to transport without refrigeration except during short journey in the field. Proper ventilation must be provided in the packaging materials as well as in the vehicle. The vehicle should be properly covered to protect the produce from the direct sunlight. A second, white painted roof can be fixed as a radiation shield 8 or 10 cm above the main roof to reflect the sun's heat and hence to keep the product cool. Proper care should be taken while loading and unloading. The produce should be protected from the rain during transportation.

Cold Chain Management

Cold chain management of perishable and temperature-sensitive products is a specialized element of supply chain management. Product deterioration is slowed down by using a variety of temperature control techniques. Although loss of product quality can occur at each point along the chain, most damage to perishable products results from a breakdown in the cold chain and/or poor handling. By monitoring and analyzing their cold chain, grocery retailers can minimize losses and maximize profits, while retaining the loyalty of their customers (Bogh-Sorensen and Olsson 1990).

PACKAGING REQUIREMENTS FOR FRESH-CUT PRODUCE

Postharvest quality loss is primarily a function of respiration, onset or progression of ripening (climacteric fruit), water loss (transpiration), enzymatic discoloration of cut surfaces, decay (microbial), senescence and mechanical damage suffered during preparation, shipping, handling, and processing (Schlimme and Rooney 1994; Watada et al. 1996). The quality changes of treated fresh-cut tropical fruits packaged in thermoformed plastic containers had been tested and evaluated (Singh et al. 2007). Extended shelf life was observed in fresh-cut mangoes, pineapples, and mixed fruits packaged in polyethylene terephthalate (PET) due to reduced O_2 and elevated CO_2 atmosphere. Modified atmosphere of 6% O_2 and 14% CO_2 achieved in PET extended the shelf life of fresh-cut pineapples from 6 to 13 days. The results suggest that shelf life of fresh-cut fruit could be extended using appropriate semi-rigid containers. Fresh-cut processing increases respiration rates and causes major tissue disruption as enzymes and substrates, normally sequestered within the vacuole, and become mixed with other cytoplasmic and nucleic substrates and enzymes. Cutting and peeling operations increase wound-induced C_2H_4 production, water loss, and enhanced microbial growth (Watada et al. 1990; Wiley 1994; Watada and Qi 1999).

These physiological changes may be accompanied by flavor loss, discoloration, softening, shrinkage, and a shorter storage life. Increased water activity and mixing of intracellular and intercellular enzymes and substrates may also contribute to flavor and texture changes/loss during and after processing. Therefore, proper packaging, temperature management during product preparation and refrigeration throughout distribution and marketing, is essential for maintenance of quality. The effect of MAP on the quality of many fresh-cut products has been studied. Successful applications include mushroom (Simon et al. 2005), apples (Soliva-Fortuny et al. 2005), tomato (Aguayo et al. 2004; Artes et al. 1999; Gil et al. 2002), pineapple (Marrero and Kader 2006), butterhead lettuce (Escalona et al. 2006), potato (Beltrán et al. 2005; Tudela et al. 2002), kiwifruit (Rocculi et al. 2005), salad savoy (Kim et al. 2004), honeydew (Bai et al. 2003), mangoes (Beaulieu and Lea 2003), and carrot (Barry-Ryan and O'Beirne 2000; Kakiomenou et al. 1996).

Nitrogen (N_2) gas packaging for fresh-cut vegetables (lettuce and cabbage) has been examined as a means of MAP for extending the shelf life of cut vegetables (Koseki and Itoh 2002). Degradation of cut vegetables in terms of

appearance was delayed by N_2 gas packaging. Because of this effect, the appearance of fresh-cut vegetables packaged with N_2 gas remained acceptable at temperatures below 5°C after 5 days. Fresh-cut cantaloupe cubes were placed in film sealed containers in which the internal gas mixture was attained naturally (nMAP), was flushed with 4 kPa O_2 plus 10 kPa CO_2 (fMAP), or was maintained near atmospheric levels by perforating the film. While both nMAP and fMAP maintained the saleable quality of melon cubes at 5°C, fMAP maintained quality better than nMAP (Bai et al. 2001). Also quality of fresh-cut tomato slices was compared during cold storage under various modified atmosphere-packaging conditions (Hong and Gross 2001). MAP provided good quality tomato slices with a shelf life of 2 weeks or more at 5°C.

PACKAGING REQUIREMENTS FOR FROZEN FRUITS

Packaging of frozen fruits is aimed at minimizing moisture loss and protection from harmful effects of light and oxygen. Freezer burn (frozen products damaged by oxidation and dehydration) of frozen fruits during extended storage in packages which are not air-tight sealed is a major concern due to exposure of air or other gaseous atmosphere. The result is undesirable surface discoloration and dehydration. The sublimation of ice crystal in fruits due to fluctuating temperatures (temperatures going above 0°F) results in dehydration with a concomitant loss of weight.

Common polymeric films have satisfactory water vapor transmission rates at freezer temperatures (Robertson 1993). The earliest form of packaging material for frozen fruits and vegetables was waxed carton board, often with a moisture-proof regenerated cellulose film (RCF) overwrap. These were replaced with folding cartons with a hot melt coating of Polyvinylidene chloride (PVDC) copolymer and ability for the flaps to be heat sealed. Although still used to a small extent for low production volumes, the majority of frozen fruits and vegetables today are packaged in polymeric films based on blends of polyolefins, the major component of which is low-density polyethylene (LDPE). Sufficient plasticizer is added to ensure that the films retain their flexibility at low temperature. It is common for the film to contain a white pigment to protect the contents from light that could oxidize the pigments in the packed food material. The film is usually supplied in roll form from which it is converted into a tube, then filled and sealed continuously in a form/fill/seal type of machine. Premade bags are used for low-volume packaging operations (Jenkins 1991).

PACKAGING REQUIREMENTS FOR DRIED FRUITS

The packaging of dehydrated fruits and vegetables requires the use of a package that will prevent or, at the very least, minimize the ingress of moisture and, in certain instances, O_2. For example, products containing carotenoid pigments (e.g., carrots and apricots) can undergo oxidative deterioration, and dehydrated potatoes are liable to develop stale rancid flavors unless O_2 is excluded. Vacuum or inert gas packaging may be used if the product is particularly sensitive to oxidation (Spencer and Humphreys 2003).

For packaging of dehydrated fruits and vegetables, the material must be good barrier to water vapor and, depending on the particular product, a good barrier to O_2, SO_2, and certain other volatiles. For premium products, it is common to use a laminate where the center layer is aluminum foil coated on both sides with polymeric films (Lange 2000).

PACKAGING REQUIREMENTS FOR THERMALLY PROCESSED FRUIT PRODUCTS

Canned/Retort Pouched/Bottled/Aseptically Packed

The thermal processes used for canned fruits and vegetables differ markedly depending on the pH of the product: low acid products with a pH greater than 4.5 (which includes most vegetables) require a full 12D process, typically 60 to 90 minutes at 121°C. In contrast, those products with a pH less than 4.5 need only a mild heat treatment, typically 20 minutes in boiling water. Some products are acidified to lower the pH below 4.5 and thus avoid the most severe heat treatment (Scott Smith and Hui 2004).

The majority of "canned" fruits and vegetables are packaged either in tinplate or electro-chromium coated surface (ECCS) cans or the glass jars. The cans must have the correct internal enamel applied to avoid corrosion of the tinplate. It is important that all the air is removed from the product prior to packaging to minimize internal corrosion. For acid fruits such as raspberries, which contain red/blue anthocyanin pigments, the enamel coating must be particularly rigorous because pigments act as depolarizers, accelerating the rate of corrosion. With some fruits, only the ends of the can are enameled, and for pineapple, a plain can is used. The tin that dissolves from the tinplate reacts with certain constituents of the pineapple and a yellow color develops. White aluminum-pigmented epoxy resin enamels are used with fruits in some countries (Robertson 2006).

Many vegetables contain sulfur compounds that can break down during heat processing to release H_2S. This can react with the tin and iron of the metal can to form black metallic sulfides or white zinc sulfide on the inner surface of the can. Therefore, white aluminum-pigmented enamels based on epoxy resins are also used for cans containing vegetables that release H_2S during heat processing (Siddappa et al. 1986).

Cylindrical, wide-mouth glass jars with either a twist-off or pry-off cap are commonly used for filling of jams, jelly,

salsas, chutneys, and pickles, and glass bottles with crown corks are used for purees, ketchups, juices, and beverages. Glass containers are still used because of the lower production rates than those possible for metal cans. Greater operator skills are required to retort glass jars compared with metal cans, because failure to control the overpressure correctly can result in either shattered containers or the loss of pry-off caps (Girling 2003).

Retortable pouches made from laminates of plastic film with an aluminum central layer can be used for the packaging of fruits and vegetables that are preserved by the use of heat. In addition, the use of retortable paperboard laminate cartons has recently commenced for fruits and vegetables (Kirwan and Strawbridge 2003).

Packaging of Juices

There are three categories of juices: single strength (10°–13°Brix), concentrated juices (42°Brix or 65°Brix), and nectars (20°–35°Brix).

The traditional packaging procedure for single-strength juices involved heating the deaerated juice to around 90–95°C in a tubular or plate heat exchanger, filling the hot juice directly into metal cans, sealing and inverting the cans, holding them for 10–20 minutes, and then cooling. This hot-fill/hold/cool process ensured that the juice was commercially sterile, provided that the seams were of good quality, the cans had an acid-resistant enamel coating, and the juice had been properly deaerated. With above conditions, a shelf life of at least 1–2 years was attainable (Siddappa et al. 1986). However, because of the acidic nature of fruit juices, any imperfections or scratches in the enamel coating or tin layer resulted in rapid corrosion, dissolution of metal into the juice, production of hydrogen gas, and container failure owing to swelling. The use of glass container obviated these problems provided that the container closure (typically metal) was resistant to damage by the juice (Girling 2003).

The use of glass bottles for the packaging of fruit juices is widespread, although the hot-fill/hold/cool process has to be applied with care to avoid breakage of the glass containers. Glass is still the preferred packaging medium for high-quality fruit juices. However, in recent years, an increasing proportion of fruit juices and concentrates have been packaged aseptically, generally into laminates of plastic/alufoil/paper board. These products are then held at room temperature and the shelf life and nutrient composition are greatly influenced by the barrier properties of the carton, the interactions of the juice with the carton, and the storage environment (Sizer et al. 1988). The shelf life is typically 6–8 months and is related to the extent of nonenzymatic browning and the sorption of key aroma and flavor compounds by the plastic in contact with the juice, the latter process being referred to as "scalping" (Nielsen and Jagerstad 1994). Because of its lipophilic nature, the oil fraction of citrus juices will be absorbed onto many nonpolar packaging polymers (Tawfik et al. 1998).

Flexible packaging is used for juices and sports drinks. A variety of laminate constructions are available for beverages, the most common structure (from outside to out) is LDPE–PET–aluminum foil–PET. For specific applications, ethylene vinyl alcohol polymer (EVOH), orthophthalaldehyde (OPA), or polypropylene (PP) can be included in the structure. A HDPE neck and "straw" is sealed into the top portion of the pack, which is filled through the neck and then sealed by a tamper-evident closure. The packs can be cold or hot filled (up to 95°C) and pasteurized after filling, if required (Tacchella 1999). Recent developments in barrier coatings for PET have led to increasing use of PET bottles for fruit juices and drinks, and this trend is likely to accelerate as production ramps up and costs come down (Turtle 1984).

Mannheim et al. (1988) compared the quality of citrus juices aseptically packaged into laminated cartons and glass containers. Due to absorption by polyethylene, D-limonene content of the juices in laminated cartons was reduced by about 25%. The presence of pulp particles in orange juice decreased absorption of volatile compounds into polymeric packaging materials (Yamada et al. 1992).

A study (Imai et al. 1990) on the amount of D-limonene adsorbed by three different films as a function of storage time showed LDPE as a poor barrier, while PVDC copolymer and EVOH copolymer had excellent barrier properties but not at high humidity. Polyesters such as PET, polyethylene naphthalate (PEN), and polycarbonates (PC) have more polar character than the polyolefins and therefore show less affinity to the common flavor compounds and absorb fewer flavor compounds. In the United States, frozen concentrated orange juice (FCOJ) of 42°Brix held at −12°C temperature is packed in spiral wound paperboard tubes with aluminum ends or aluminum cans (Hui 2004).

PACKAGING REQUIREMENTS FOR FRUITS AND FRUIT PRODUCTS PROCESSED BY NEWER TECHNOLOGIES

Products processed by nonthermal technologies such as high-pressure processing (HPP), pulsed electric fields (PEFs), ultraviolet-C (UV-C), irradiation, microfiltration, active packaging (oxygen scavenging or antimicrobial packaging), or biopreservation (antagonistic culture) require right packaging material and processes to be successful (Devlieghere et al. 2004).

To maintain the sterility of nonpumpable foods, the foods should be packaged before nonthermal processes such as pulsed light emission, irradiation, batch high-pressure process, or antimicrobial packaging. Therefore, similar to the heat resistance of packaging materials to thermal treatment, the packaging materials for nonthermal processing should have appropriate resistance to high-energy light, irradiation, pressure, or chemicals. This means that the chemical and

physical requirements of packaging materials for nonthermal processing are different from those for thermally processed foods. To identify these special requirements of packaging materials for nonthermal processing, it is necessary to understand the process parameters and microbicidal mechanisms/kinetics of the nonthermal process and their effect on mechanical and physical properties of packaging materials. Besides the mechanical and physical characteristics of packaging materials, various other factors of food packaging systems should be considered in designing the package for the nonthermal processes, which may include, as in, for example, high-pressure process, volume of the package, headspace gas, dissolved oxygen in foods, and deformation characteristics of packaged foods (Balasubramaniam et al. 2004).

Characteristics of Packaging Materials for Nonthermally Processed Foods

Packaging materials for nonthermal processing should have strong resistance (physical and mechanical properties) to the nonthermal process mechanisms. For example, packaging materials for HPP should be restored from the deformation under pressure to their original shape without any mechanical and physical change of properties. The packaging materials for irradiation should be chemically stable under the radiation dose without depolymerization or significant changes in elastic modulus of the packaging materials. For pulsed UV-C/white-light emission process, the packaging material must be transparent during pulsed light emission. There is no general requirement for packaging materials for all nonthermal processes. However, from the above examples, most characteristics of packaging materials required for the various nonthermal processes are related to the barrier properties of the packaging materials (Min and Zhang 2005).

This is due to the satisfaction of the primary functions of packaging systems: containment, protection, and preservation. Nonthermal processes do not utilize increased temperature to inactivate decomposing microorganisms and enzymes. This is the biggest advantage of nonthermal processes because this low-temperature pasteurization does not overcook food and/or degrade foods thermally. Furthermore, this low-temperature treatment also widens the selection of packaging materials and systems. Owing to the low-temperature treatment, the packaging system does not require high melting temperature for heat seal. Low-temperature sealing methods can utilize various polymers and sealants, if required, or cold sealing using adhesives. These methods produce far less volatile odor of plastics, additives, and printing solvent. This is very beneficial to high-fat foods and frozen/refrigerated foods (Min and Zhang 2005).

Antimicrobial Edible Films and Coatings for Nonthermally Processed Foods

Nonthermal food-processing technologies comprise an important area of study and application in food science and engineering. These technologies are being developed to satisfy consumer demand for fresh-like foods. They are intended to inhibit both spoilage and the growth of pathogenic microorganisms in foods without significant loss of flavor, color, taste, nutrients, viscosity, and functionality of the food by minimizing thermal effects on foods (Min and Zhang 2005). Fresh-like food products optimally processed by these technologies require appropriate packaging to preserve their qualities for desired shelf life during storage. Antimicrobial edible films and coatings draw attention from the food and packaging industry because of increasing consumer demand for minimally processed products. Antimicrobial edible films and coatings can control microbial contamination occurring on the surface of the food during restorage after opening or because of package defects. In addition, since antimicrobial films and coatings have self-antimicrobial abilities, the need for chemical sanitization or sterilization of packaging materials may be obviated and aseptic packaging processes may be simplified (Hotchkiss 1997).

A combination use of nonthermal food processing and antimicrobial films and coatings is suggested because the bioactive films and coatings are expected to provide an additional barrier for the contamination and the growth of both spoilage and pathogenic microorganism in nonthermally processed food products. The benefit of nonthermal processing will not be altered because the antimicrobial films and coatings do not add either heat or synthetic chemicals to the nonthermally processed food. Both production of minimally processed foods and extension of their microbial stability can be made possible by combining these technologies (Appendini and Hotchkiss 2002).

Packaging for High Pressure Processing

Packaging materials for HPP are required to be flexible enough to withstand the compression forces while maintaining physical integrity. They must recover their initial volumes after the pressure is released (Caner et al. 2004). This is a reason why metal cans, glass bottles, and paperboard-based packages are not well suited for HPP (Lambert et al. 2000; Caner et al. 2004). The presence of headspace must be kept as small as possible (Lambert et al. 2000). Kubel et al. (1996) investigated the effect of HPP on the sorption of aroma compounds, *p*-cymene, and acetophenone into plastic films and found that the sorption of aroma compounds was lower in films exposed to 500 MPa pressure compared with nonpressurized films.

Packaging for Irradiated Foods

Foods are generally prepackaged before irradiation to prevent recontamination. The use of irradiation is also becoming a common treatment to sterilize packages in aseptic processing of foods and pharmaceuticals (Ozen and Floros 2001). Any packaging materials must be accepted by FDA before use

in food irradiation because gases (e.g., hydrogen) and low-molecular-weight hydrocarbons and halogenated polymers formed during irradiation at doses accepted for food use have a potential to migrate into foods (Kilcast 1990; Lee et al. 1996; Olson 1998). Some chemical and physical properties of polymeric packaging materials can be changed by irradiation (Ozen and Floros 2001). The changes depend on the type of polymer, processing exposure, and irradiation conditions (Crook and Boylston 2004).

Predominant reactions during irradiation in most plastics used for food packaging [e.g., polyethylene, PP, polystyrene (PS)] are cross-linking and chain scission (Ozen and Floros 2001). Cross-linking can decrease elongation, crystallinity, and solubility and increase the mechanical strength of the plastics. Chain scission can decrease the chain length of plastic materials, providing free volume in the plastics, and can produce hydrogen, methane, and hydrogen chloride for chlorine-containing polymers under vacuum. In the presence of oxygen, additional chain scissions would be able to form peroxide, alcohol, and various low-molecular-weight oxygen-containing compounds (Ozen and Floros 2001).

A 25 kGy irradiation ($Caesium^{137}$) had a significant effect on increasing the volatile compounds in crystalline and oriented semirigid PET homopolymer (Komolprasert et al. 2001). Major volatile compounds that evolved from the PET specimens are formic acid; acetic acid, 1,3-dioxolane; and 2-methyl-1,3-dioxolane (Komolprasert et al. 2001). Irradiation on LDPE, HDPE, PET, and polyvinyl chloride (PVC) packaging materials can release hydrogen, carbon dioxide, carbon monoxide, and methane gases and form volatile oxidation products including peroxides, alcohols, aldehydes, ketones, and carboxylic acids (Crook and Boylston 2004).

Packaging for Pulsed Electric Field Processed Food Products

The permeation values are very important in determining packaging materials for PEF-processed food products. Aseptic food packaging is considered the most appropriate way of packaging for PEF-processed food products (Qin et al. 1995). The effect of packaging materials on the quality preservation of orange juice treated by PEF (35 kV/cm, 59 s, pilot plant scale PEF system) has been studied by Ayhan et al. (2001). Some chemical and physical properties of PEF-treated orange juice packaged in four different packaging materials, sanitized glass, PET, HDPE, and LDPE bottles, were evaluated. Glass bottles and PET bottles were effective at retarding degradations of flavor compounds, vitamin C, and color of PEF-treated orange juice during storage at 4°C for 112 days. Vitamin C and the flavor compounds were labile in polyethylene (HDPE and LDPE) bottles, which might be due to their relatively low barrier property of polyethylene to oxygen. The degradation of lycopene of PEF-processed tomato juice in a PP tube was found most significant during the first 7 days of the storage at 4°C (Min et al. 2003). The main cause of carotenoid degradation in foods is oxidation (Thakur et al. 1996), and thus the significant reduction was caused by the oxygen available in the headspace of the PP tubes (Min et al. 2003). The MAP, which limits oxygen in the headspace, may be applied as a complement to PEF to reduce oxidation of PEF-processed food products.

Jin and Zhang (2002) reported that total operational cost for PEF-treated orange and tomato juices was 6 to 7 cents per liter, which was considered competitive with a conventional thermal processing of the juices.

FUTURE RESEARCH NEEDS

In selecting food products, consumers look for attributes such as convenience, portability, health benefits, and great taste. They demand clean and safe products with good economic value and tamper-evident packaging made with ecofriendly materials and fewer preservatives. Consumers expect labeling to clearly educate about food safety, food ingredients, composition, nutrition, storage, and instructions for use. Consumers would generally switch brands for attractive packaging with complete labeling. However, convenience is the most important attribute, especially among time-pressed working adults, as well as among elderly buyers who like single-serve, easy-to-open, resealable containers and which have label which is easy to read.

Processors have different interests from consumers, and this translates into a conflict of priorities in package design and production. From the processors point of view, in contrast, the strongest drivers of packaging design include simplicity of operation in filling, sealing, efficiency of materials and labor usage, consumer convenience, product safety, faster line speeds, shelf life extension, size flexibility and customization, improved automation, improved graphics, cost of materials, environmental concerns, and labeling and coding improvements. Of these, only convenience and safety are really key concerns of consumers. The rest are more responsive to the manufacturers and distributors.

In addressing the current global mega trends of convenient and healthy retail and foodservice, processors must incorporate all of the demands of the consumer base, as these evolve and accumulate over time. Packaging innovation is a key factor in ensuring continued product success, while new graphics are needed to differentiate and self-sell the novel products regardless of the category under consideration. In future, the focus should be on developing functional packages which are more in trend among consumers as functionality outweighs nearly everything else, including design and graphics considerations.

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Part 4
Processing Plant, Safety, and Regulations

18
Fruit Processing Plants and Equipments

József Barta

Abstract: There are legal, engineering, and economic conditions for establishing a fruit processing plant. It is necessary to examine the technological, manufacturing, financial, and environmental conditions, which are needed for building the plant.

Processing technology deals with various procedures and processes for the preservation finished products and then packaging and storing. Planning of a plant based on technological design and energy needed. The technological calculation, the information system, etc. have to be documented of the technological planning of fruit processing.

Lot of instruments and equipments are available for a fruit processing plant: mechanical fruit harvest, transportation device, washing and rinsing machines, washers, grading, peeling, destemming devices, chopper machines, heat exchangers, filling and closing machines, and heat treatment equipments.

INTRODUCTION

This chapter discusses important aspects of a fruit processing plant including its establishment, demand and capacity analyses, unit operations, engineering designs and equipment considerations of a modern fruit processing plant.

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

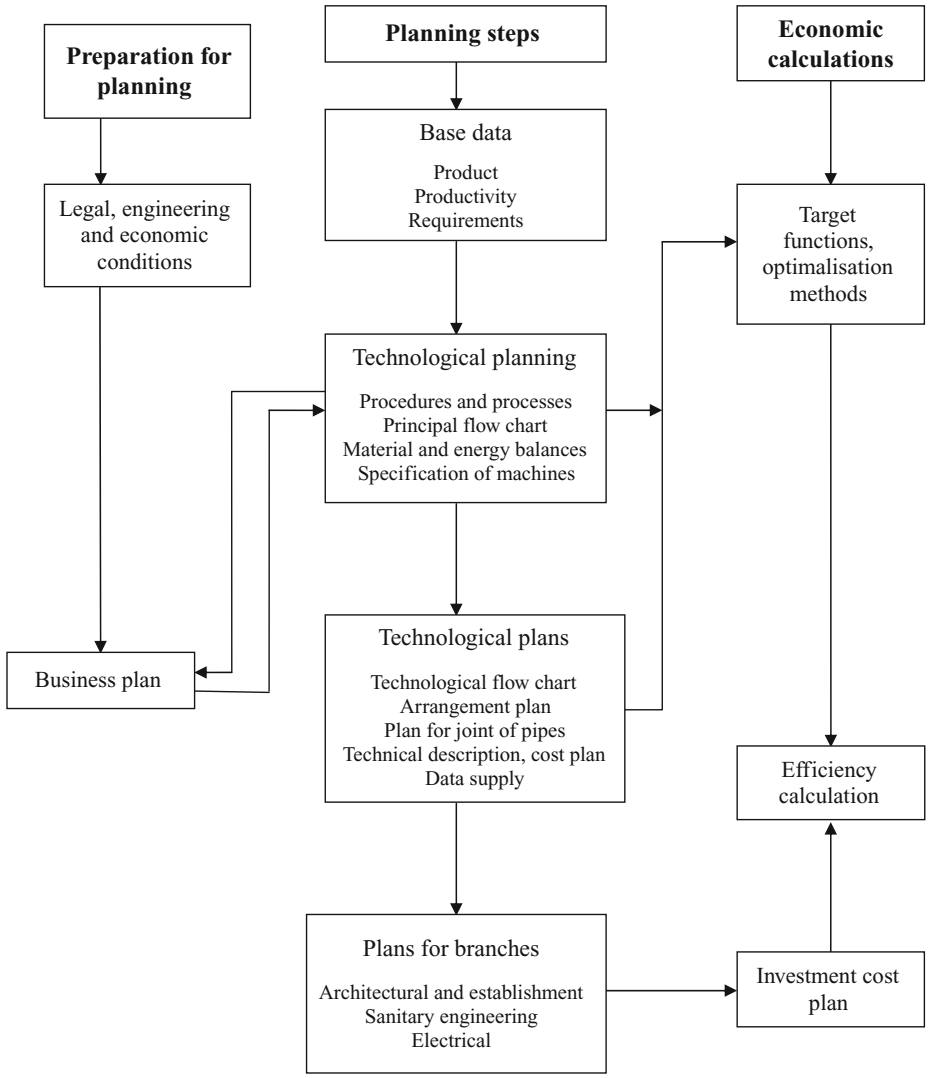

Figure 18.1. Flow chart for planning of a plant (Berszán and Várszegi 2000).

GENERAL CONDITIONS FOR ESTABLISHING A FRUIT PROCESSING PLANT

Before establishing and operating a fruit processing plant, it is necessary to evaluate all legal, engineering and economic factors. Legal conditions are: laws related to the establishment and operation of a plant. Engineering conditions are: the architectural, environmental, electrical, technological, sanitary engineering and hygienic, work safety and other features of the plant. The design and features of the plant should make it possible to manufacture quality products. Economic considerations are: creating a marketing plan and demand forecast to justify investments to manufacture products profitably.

COURSE OF PLANNING

Planning, establishing and developing a plant are complex engineering and economic tasks demanding the cooperation and coordination of various professionals. The planning scheme is summarised in Figure 18.1.

A technical planner with knowledge of processing a given product and conditions for establishing a plant is important. Pre-planning starts with an examination of the demand for the product and whether demand will be long lasting. A feasibility study should be done before a financial investment is made. It is necessary to examine the technological, manufacturing, financial and environmental conditions required for the economic production of a given product followed by details of the conditions needed for building the plant. The

basis of the technical planning is the fruit processing operations, which will be carried out. The long-lasting and safety management of the plant must be ensured by the work of the professional designers. Dimensions of the plant are based on the requirements for processing.

The technical planning and processing steps are aimed at ensuring the safety of the employees, and manufacture of safe and quality products for the customers. The technological flow charts showing detailed architectural, sanitary, engineering, and electrical plans are important basic documents. The investor requires assurance that the plant is ready to use, while the task of the designer is to ensure that the plant meets all of the technological requirements (Bastian 1996).

FEATURES OF THE TECHNOLOGICAL PLANNING OF FRUIT PROCESSING

A fruit processing plant transforms the raw materials, base additives and auxiliaries into preserved finished products that can be packaged and stored. The products are transported to the customer through the trade. Some steps of this complex process are shown in Figure 18.2.

The planning of a fruit processing plant starts with the following questions:

- For the choice of products: what do we want to produce?
- For the quantity of the products: what amount of product do we want to produce?
- For the technological procedure: how do we want to produce?

The product is the carrier of the following information and basic data for the plant calculations:

- *The formula of the product*: gives the amounts of raw materials needed for the given product. This is the basic data for calculation of the material balance.
- *The shape and dimension of the product*: influence the type of processing machines and dimensions of material handling and storing equipment and spaces.
- *Quality of the product*: the palatability or quality-preserving period, the composition, the organoleptic properties, the packaging and functional properties affect the technological process. Determination of these properties is done by evaluating customer demands and preferences (marketing plan).
- *Product volume*: determines the requirement for the productivity of the machinery, storage space and the economics of production (Rouweler 1991).

Processing technology consists of all the methods, procedures and processes used to produce the finished product from raw materials. The processing technology is realised by a definite sequence of various procedures (e.g., sorting, classifying, washing, chopping, etc.) and of processes (e.g., heat treatment, parboiling, pre-cooling, etc.).

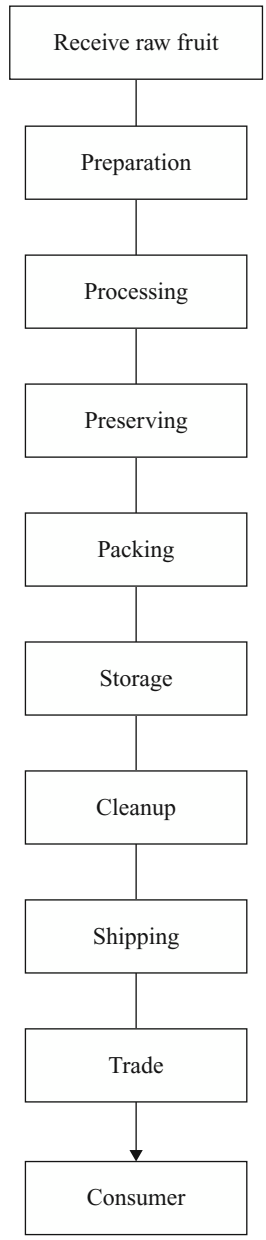

Figure 18.2. The general flow chart of fruit processing.

Fruit Processing Technology, Manufacturing Process

Planning of a plant based on technological design should be flexible so manufacturing can be varied even with the same formula and the same processing sequence. Generally, the raw material is seasonal. The type of raw material, the harvesting time and the quality determine the production time and the continuous or campaign feature of the manufacturing process. Fruits degrade quickly; therefore, it is necessary to process soon after harvesting. Processing is

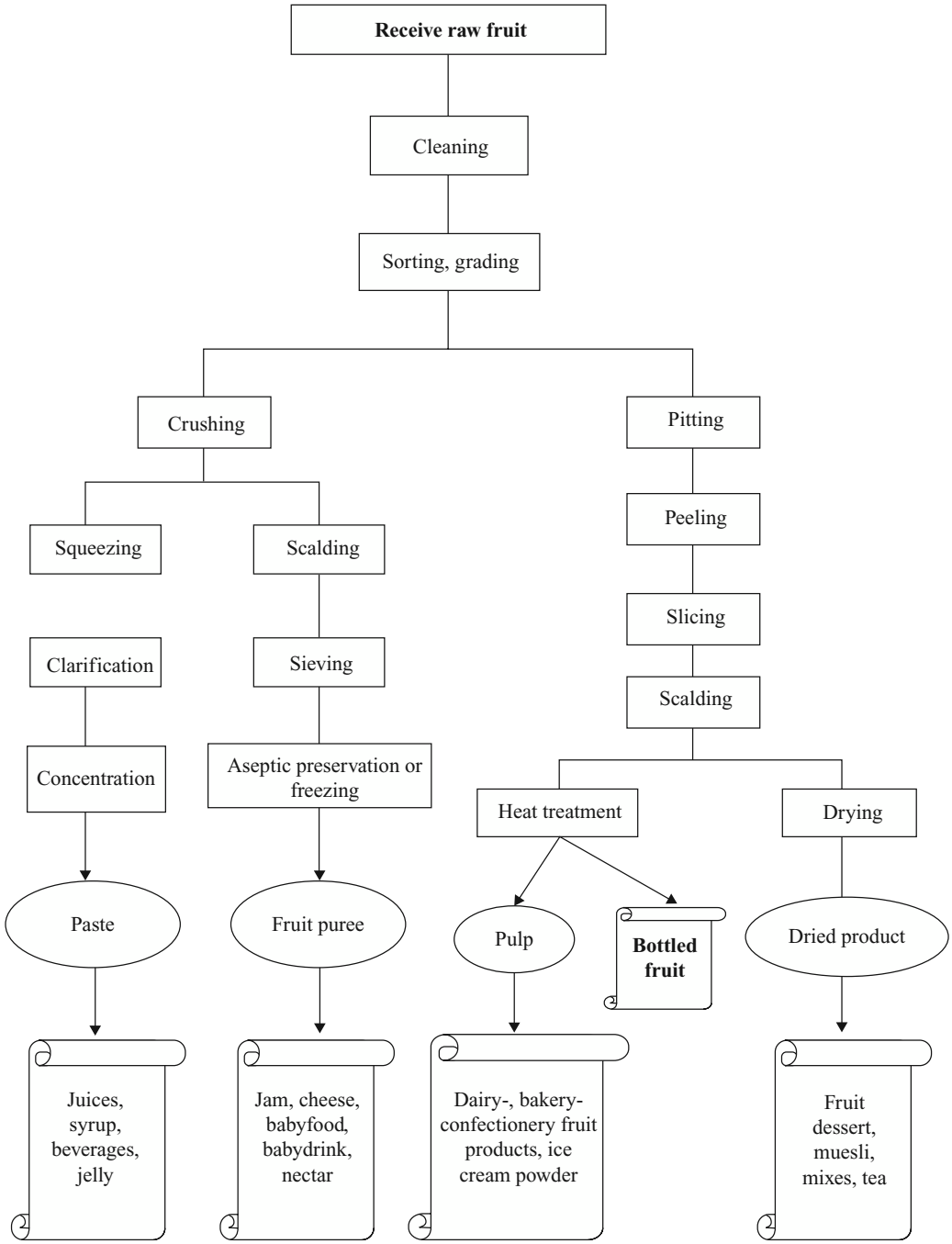

Figure 18.3. Theoretical scheme of fruit processing.

generally done in two steps. The first step is the so-called post-harvest treatment that helps to save the freshness of the raw materials. Another choice can be the primary processing of the fruits, resulting in semi-finished products. At the second step, or secondary processing, extension of shelf life and production of end products are also possible (De Raaijl 1991; Shewfelt and Prussia 1993; Kushwaha et al. 1995). Examples of primary processing are production of paste, puree, as well as pulp and dried products. Examples of secondary processing are: juices, syrups, beverages, jelly, jams, dairy- and confectionery fruit products, muesli, etc., products that can be manufactured depending on market demand. A theoretical scheme of fruit processing is shown in Figure 18.3.

In order to perform the same tasks, various procedures and processes can be used. For example, the production of a paste can be performed with the following processes: thermal evaporation, concentration by freezing, separation by a membrane (ultrafiltering or reversed osmosis) or application of thickening agents to improve the consistency of the product. Thus, the raw materials as well as the final food product can be preserved. In the following, we summarise how to evaluate each process and choose the most appropriate for manufacturing. In the course of process analysis, the following are examined:

- Operation alternatives.
- The effect of the procedure on the material.
- Productivity: incoming and outgoing materials losses.
- The realisation mode of a procedure: manual or mechanised.
- Machines used for the procedures.
- Character of the human labour: numbers of the workers, craftsmanship.
- Linkability of the procedures.

Table 18.1 summarises the incoming and outgoing data for procedure analysis.

As a result of procedure analysis, features affecting quality and quantity characteristics of product manufactured are determined. Features affecting the quality of the product are:

- Types of procedures and processes.
- Working quality of the machines.
- Labour skills.
- Monitoring system, degree of instrumentation.

Table 18.1. Procedure Analysis

Incoming Data	Operation Analysis	Outgoing Data
Raw material: base, additives and auxiliaries	Material balance, capacity calculation	Processed product (finished product), residual product and waste matter
Machines, tools: electric energy, water, steam, compressed air, vacuum, cleaning matters and disinfectants	Specification of machines, energy balance, hygiene and work safety	Vapour, drain, technological sewage, noise, pollution and odour
Workers	Demand for numbers of workers, craftsmanship and hygiene	Municipal sewage

- Material handling.
- Continuity, off-times.
- Features affecting the quantity of the product and productivity are:
  - Dimension of the material.
  - Yield, residual products (off-quality raw material and process waste).
  - Productivity (capacity) demand.
  - Degree of mechanisation, automation.
  - Continuity, off-times.

As an example, determination of the working quality of a chopper is done by analysing the size and shape of the material (e.g., cube or grits). Analysis would show the sizes of the particles present in the product and the percentage distribution of the various size fractions. The productivity of the machine is an important criterion, as the peeled products should be chopped as soon as possible to minimise quality degradations. The manpower requirement to run and manage the operations is critical. Highly skilled manpower would be needed for some specialised operations processes (heat treatment, fermentation, etc.) or packaging for consumers. Product safety can be improved by automation of the machines and production. The quality of the product, especially the organoleptic properties, needs the craftsmanship and care of operators in addition to the quality of the raw materials (Locin and Merson 1979; Okos and Balint 1990; Floros 1992).

Material Transport of Fruit Processing

A yield norm would provide the types and quantity of raw materials needed. It can also help in estimating labour and machinery requirements. Yield normatives can be found in technical books (Burits and Berki 1974; Szenes and Oláh 1991). The yield is a function of the quality of the raw material, the type of the product as well as the applied technology. In the following, some data are given for the usual or expected yields (Barta et al. 1990). For drying some fruits, the following yields can be taken into account for calculations:

- Dried fruit made of peeled apple: 8–10%.
- Dried fruit made of unpeeled apple: 14–16%.
- Dried plums: 30–35%.
- Rose hips: 40–50%.

The formulations of a product, that is, the composition would provide the amount of material needed for manufacturing a given product. The compositional normative, generally, is the quantity of materials needed to produce 100 kg of a finished product including material losses (Baert 1995). Yield is a phrase used to explain disintegration of raw materials during processing. The yield relates to how much finished product can be gained from given amount of base matter (raw materials), additives and auxiliaries. While the requirement for additives is included in the normative, the demand for packaging material must be calculated for each type of

packaging material. The quantities of flasks, metal, and cartons (e.g., daily, weekly demands, etc.) can be calculated on the basis of the product and the volume of the given packaging materials. Generally, it is necessary to account for some losses, for example, glass breakage (Szenes and Oláh 1991).

The material balance is the sum of incoming materials and outgoing products from the technological process, that is, the balance of the materials. Material balance can be determined by calculation. The simplified equation for material balance to the yield is:

$$m_{\text{in}} = \sum_{i=1}^{n} m_{i,\text{out}}$$
$$m_{\text{in}} = \sum_{i=1}^{n} (m_{\text{in}} \times x_{i,\ \text{out}}) \tag{18.1}$$

where

m_{in} = the mass or mass flow of the starting material (kg or kg/s);
$m_{i,\text{out}}$ = the mass or mass flow of the *i*th product, auxiliary or residue (kg or kg/s);
$x_{i,\text{out}}$ = yield ratio of the ith product, auxiliary or residue (kg/kg).

Material balance can be illustrated in three different formats:

- Narrative description of the calculation.
- Table format.
- Graphic presentation (Shankey diagram) (Berszán and Várszegi 2000).

If a plant produces several types of products, first it is necessary to calculate the material balance for each type of product. Then, these can be summarised and the material balance for the plant can be calculated.

Capacity Calculation

Capacity means efficiency and cubic capacity. The capacity of the production equipment, tools or plant determines the product output. Therefore, capacity is the possibility. The ratio of product volume to capacity is capacity utilisation. The capacity can be expressed as the product of the unit capacity (capacity norm) and of the production time (time base):

$$K = k_{\text{n}} I$$

where k_{n} is the capacity norm (kg/h, m^3/h or piece/h) and I is the time base (h).

Capacity norm is related to production units (machine, production line and "cross section"). Time basis can be day, week, month, year as well as season, depending on the character of production.

Capacity Norm

The capacity norm of a batch type machine can be determined as the ratio of the single cubic capacity to the total processing time [useful, i.e., running time + service (attendance) time]:

$$k_{\text{nl}} = \frac{60 \times m_{\text{a}}}{t_{\text{c}}} \tag{18.2}$$

where m_{a} is the single cubic capacity of the machine, that is, the mass of one charge (kg) and t_{c} is the processing time (cyclic time) (minute).

Capacity norm of a continuously running machine can be calculated based on the technical parameters of the machine. The performance (capacity norm) of a chopper with pulley transport is given as:

$$k_{n2} = a \ \times \ 60\frac{\pi}{4}\left(D^2 - d^2\right) n \ \times \ s \ \times \ \rho \tag{18.3}$$

where

a = the charging, filling parameter;
n = the number of revolutions of the pulley (l/min);
D = outer diameter of the pulley (m);
s = pitch of the pulley (m);
d = core diameter of the pulley (m);
ρ = density of the material (kg/m^3).

The capacity norm of a rotary filling machine is determined by using a single-filling volume, the mass of transported material per cycle and the number of revolutions. For liquids, the basis of the calculation is the performance of the pump carrying the liquid. Capacity norms are determined for the total production as well as production at a specific point in time (cross section). Cross section is a machine or tool by which one process of the total production is performed. The main cross-section process (e.g., heat treatment and juice production) is the process having primary importance for the total production. Extension in production of the main cross-section is very expensive. A bottleneck in production is a machine or tool, with the lowest capacity. Often, the main cross-section and the bottleneck are the same (Berszán and Várszegi 2000).

Mechanisation of Fruit Processing: Specifications of Machines

Production can be performed manually, by using hand-driven machines, or by automatic equipment. Material handling devices linking technological tools are considered as machines. In the planning stage, technological tools that are well constructed and reliable are chosen for all steps in the production of a product. The modern technological arrangement (realisation of the technological plan) is characterised by large number of various machines and devices. An important part of the machine specifications is the mobile material handling and auxiliary production tools. These are vehicles for transport, containers, tanks, etc., used for transporting the

materials. Specifications are necessary for the types, parameters and quantities of machines and auxiliary devices needed for production of a specific product. While calculating the quantity of devices, the following points are considered:

- The device is a part of the production.
- The device being used must be cleaned before the next run.
- A part of the device must be in maintenance.

All the features of a machine that affect production must be put into the specifications; the effect of a machine on production is as follows:

1. Effect on the quality of the product, such as the effect of a blade of a chopper on the quality of the material, the effect of heat treatment on the taste of the product as well as the effect of automation on quality control.
2. Effect on hygiene, which is also a quality feature, for example, how quickly can the equipment be disassembled, cleaned, sanitised and reassembled.
3. Effect on the choice of products. How can the features of a machine be changed for varying product type?

The effect of a machine on the technological plan and on the production run is the following:

- Capacity.
- Energy demand.
- Emission effects on the environment.
- Dimension and mass data.
- Safety techniques.
- Maintenance demand.

The following data must be added to the specification of a machine in the technological plans (based on the previous evaluations):

- Denomination of the machine.
- Type of machine (instrument, device).
- Number of pieces of the machine.
- Engineering properties of the machine: capacity, dimensions.
- Notes related to the machine: line production, individual machine, mounting instructions.

Specifications of a machine are included in the following technological documents:

- Technological flow chart.
- Technological arrangement plan.
- Engineering arrangement and mounting plan.
- Technological plan for joining of pipes (Ábrahám 1980, Berszán and Várszegi 2000).

PACKAGING MATERIALS FOR FRUIT PRODUCTS

By using various packaging materials and auxiliary products (tags, adhesives, clips, caps, and taps), several packages (bag, box, flask, pocket, keg, etc.) and parcels (customer, collecting and transferring packs) can be made. The function of packaging materials is to ensure the safety and quality of the product from production through transportation to the customer including storage, transporting and selling the product and informing the customer (Fellows 1988; Floros and Gnanasekharan 1994). Table 18.2 summarises the requirements for packing. Selection of the packaging material must be made using the knowledge of product characteristics and requirements for food safety and quality control.

Various packing materials are used for packaging-processed fruits. However, plastics are applied in the largest quantity. Combined packaging materials were developed for better product safety and various forms of the product. Processing of foil combinations of paper, metal (Al), and plastics are used most frequently. For frozen fruits, the best quality is given by the polyethylene (PE)/paper, Al/PE combinations.

Table 18.2. Some Requirements for Packing for Saving the Quality of the Product

Environmental Effect	Form of Deterioration	Packing Requirements
Oxygen	Fatty acid oxidation, vitamin degradation, protein loss, colouring, material oxidation	Sealing against oxygen
Moisture	Loss of nutrients, organoleptic changes, lipid oxidation	Sealing against moisture
Light	Oxidation, rancidity, vitamin degradation, protein and amino acid transformation, colouring agent, oxide	Light tightness
Micro- and macro-organisms	Formation of faulty product, loss in nutrients and in quality, potential risk to infection	Sealed packing
Mechanical burdening (dropping down, pressure, vibration, attrition and coarse handling)	Organoleptic change, deterioration and other changes in the quality, susceptibility for deterioration due to changes of the sealing, formation of micro holes	Mechanical strength, tightness
Customer handling, faulty usage	Product loss, quality deterioration, loss in nutrients, organoleptic degradation	Mechanical strength, clear information

Source: Berszán and Várszegi (2000).

Table 18.3. Features of Some Packing Tools

Packing Tools	Features
Tools with rigid walls	
Metal boxes	Stiffness, acknowledged by customers, safety
Metal kegs, vessels	High capacity, low costs
Glasses	Strength, stiffness, fragility
Paper-Based Tools	
Paper–plastic–plastic cartoon	Environmental friendly
Pre-boarded cartoon	Easily formable, etc.
Semi-Rigid Plastic Tools	
Heat-formed boxes, trays	High productivity, low-space requirement, easily formable, variability
Pre-mould boxes, trays	
Tools with elastic walls	
Blown plastic flasks	Sterile and pre-fabricated, no need for space for the packing tools
Bags, pockets, bag-in-box	Low costs, simple, mechanisation, minimum space requirement for storage

For dehydrated (dried) fruits, the paper/Al/PE or paper/Al/ionomer is best, while for packing under vacuum or some protective gases, combinations of polyamide (PA)/PE or polyethylene terephthalate (polyester)/Al/PA/PE combinations are best. Besides plastics, the following packaging materials are frequently applied: paper, carton, glass, and metal (Szenes and Oláh 1991; Monspart-Sényi 2000). Table 18.3 summarises packaging materials and tools.

Besides requirements for saving the quality of the product, the effects of the packing on the environment are also very important.

ENERGY REQUIREMENTS OF FRUIT PROCESSING

The basis of planning for energy needs for a given technological procedure including the energy needed by individual machines is the energy (heat) demand of the technology as well as the recovery possibilities of the heating energy.

Energy Balance of Fruit Processing

The energy balance is the application of the law of conservation of energy. The mathematical formula can be described as follows:

$$\Sigma Q_{\mathrm{m\,in}} + Q = \Sigma Q_{\mathrm{m\,out}} + Q_{\mathrm{l}} \pm Q_{\mathrm{r}}$$

where

ΣQ_{min} = heat content of the incoming materials,
$\Sigma Q_{\mathrm{m\,out}}$ = heat content of the outgoing materials,
Q_{l} = energy loss,
Q_{r} = heat demand or heat production of the chemical reactions,
Q = energy demand of the procedure.

The unit of all parameters is kJ or kW/h. On the left side of the equation is energy coming into the procedure, while on the right side is energy outgoing from the procedure. The heat content of incoming and outgoing materials can be calculated as follows:

$$\Sigma Q_{\mathrm{m}} = m_{\mathrm{m}} c_{\mathrm{m}} T_{\mathrm{m}}$$

where

m_{m} = the mass of the material or its components or phases processed during the given period (kg),
c_{m} = specific heat of the material or its components or phases (kJ/kg/°C),
T_{m} = temperature of the material, or its components or phases (°C).

Losses are determined empirically or by calculation. In the simplified calculations, only those components that are the main part of the total energy demand are taken into account, and processes without losses are estimated. For example, at boiling temperatures, the heat energy needed for evaporation is taken into account and the energy demand required for warming to the boiling point is eliminated since the energy required for this step is of several orders of magnitude less than the energy needed for evaporation. The energy demand of the process is determined by summing the energy demands of all procedures and taking into account heat recovery and coincidental losses (Barta et al. 1991).

Energy Optimisation of the Procedures

Optimisation of operations, procedures, and processes can be done from various viewpoints; one is minimisation of the cost of applied energy. Generally, the energy cost (E_{c}) can be calculated as follows:

$$E_{\mathrm{c}} = (Q/\eta) e_{\mathrm{c}}$$

where

Q = energy demand on the basis of the energy balance (kJ or kW/h),
η = efficiency of the system,
e_{c} = energy costs ($/kJ or $/kW h).
Calculation of the units: 1 kWh = 3600 kJ.

It can be seen from this expression that minimisation can be achieved by decreasing the amount of energy used or by using cheaper energy. An evaluation of the technical and engineering processes must be done together with a complex economical analysis of the product for a given

quality requirement (Locin and Merson 1979; Körmendy and Török 1990; Okos and Balint 1990).

Energy Consumption of Fruit Processing by Energy Carriers

In food processing technology, electrical energy is required by electrical engines of machines and tools. Planning this system is a responsibility of an electrical engineer, who must consider the energy demand on the machines and coincidentals.

Energy demands of machines and tools used for heating or cooling are given in brochures and technical books. Often, heat exchange occurs during the pre-heating or pre-cooling stages of fruit production. Heating energy (warm water or steam) used in heat exchangers is ensured from the supply system. For calculating the average energy demand of heat exchangers, the following relationships are used. For a batch process

$$Q = cm\,\Delta T$$

where

c = specific heat of the material (kJ/kg/K),
m = mass of the charge (kg),
ΔT = temperature difference between the starting and ending temperatures of the product (°C or K).

For a continuous process

$$Q = cm\,\Delta T t$$

where

m = mass flow of the material (kg/s),
t = process time (s).

Temperature and time are technological data obtained from the technical literature. The actual warming or cooling of a product to the required temperature (in a device) depends on transmittance of heat. The calculation is as follows. For a batch type device, the energy uptake of pre-heating or pre-cooling is:

$$Q = cm\Delta T = kA\Delta T_{\mathrm{m}} t.$$

For a continuous device,

$$Q = cm\Delta T t = kA\Delta T_{\mathrm{m}} t.$$

In both cases,

k = parameter of heat transmittance of a heat exchanger (kJ/s/m^{2}K),
A = heat transferring surface of a heat exchanger (m^2),
ΔT_{m} = logarithmic average temperature of heat exchange or the difference between the average temperatures of the two media (heat carrier and the product) (°C),
t = process time (s).

By determining the various energy demands, it is possible to determine the quantities of the heat carriers as well as the temperatures and pressures. Planning requires determining the quantities of the heat carriers instead of the heat energy. Quantities of heat carriers (warm water, steam) can be calculated as follows. The mass flow of the warm water is:

$$m_{\mathrm{w}} = Q/(c_{\mathrm{w}}\Delta T_{\mathrm{w}}).$$

The mass flow of the steam is:

$$m_{\mathrm{g}} = Q/r$$

where

c_{w} = specific heat of the water: $c_{\mathrm{w}} = 4.2$ kJ/kg K,
ΔT_{w} = temperature decrease of the heating water: $\Delta T_{\mathrm{w}} \leq 20$°C,
r = evaporation heat of the water vapour: $r \approx 2400$ kJ/kg (mean value due to the pressure dependence of it).

Energy Consumption of Fruit Processing

The users of energy in fruit processing are:

- Processing equipment.
- Equipment for storage, transportation and material handling.
- Devices used by the informatics system of the enterprise.
- Lighting, heating and climatisation of work place.
- Users mentioned previously require various sources and carriers of energy.

Energy sources are:

- Electrical energy.
- Heat energy, fuel sources: natural gas, fuel oil, wood and coal.
- Renewable energies:
  - Biological materials: wood, wood waste, sawdust, cuttings and biogas.
  - Solar energy, energy of some thermal sources.
  - Wind energy.

In practice, the first two types of energy are important; however, from a regional point of view, some other sources can have importance too. The quantities of the natural sources are not constant, there is uncertainty in their presence, and therefore, sole application is not generally proposed. Energy carriers are:

- Heat energy: warm water, water vapour, dew and steam.
- Cool energy: recirculation (from a cooling tower) cooling water, natural cooling water, icy water, brine, glycol, liquid nitrogen, ice water and dry ice.
- Compressed air and vacuum.

Production of the previously mentioned energy carriers can be done in the plant or obtained from public utilities.

DOCUMENTATION OF THE TECHNOLOGICAL PLANNING OF FRUIT PROCESSING

The technological calculations, the analysis of the material, machine and labour demands, and that of the information system, that is, determination of the base data, make it possible to outline the plant, construct the arrangement drawings and the technological plan. The flow chart shows the materials for production, the production procedures and sometimes the machines and their connections. The principal connections of the systems, materials and tools are shown without the accurate data of the spatial arrangement; however, the main directions of the technological process are indicated. The technological arrangement drawings show the connections of equipment and tools in the space and their arrangement. By means of the architectural and sectional drawings, the technological arrangement plan shows all the tools needed in the manufacturing of the product and those in direct contact with the raw material and product. The knowledge of the construction and dimensions of the plant are required for making the base drawings and cross-sections. The basis for establishing the architectural plan is the technological plan. The apparent contradiction can be solved by the following:

1. The designer of the technological plan has architectural knowledge (the technological designer is generally a mechanical engineer or a food technologist).
2. The technological designer adjusts the preliminary plan with the architect.
3. In the course of the technological planning, further adjustments are required. During this time, compromises are made to achieve an optimum plan that has a criterion for product quality and operational efficiency (Burits and Berki 1974; Mikus and Barta 1998).

The general principle is that the architectural and other planning must meet the requirements of the technology. The technological plan consists of the following documentation:

- Plans for the main technological procedures and manufacturing of the food product.
- Plans of the technological auxiliary procedures or subsystems: processing of the subsidiary products, waste disposal, cleaning of sewage water and a neutralizing system to prevent air pollution.
- Plans of the service sub-systems:
  - Analytical, organoleptic and microbiological laboratories.
  - Personnel and tools of the hygiene department.
  - Personnel facilities for plant employees including changing rooms, bathrooms, WC, break room and dining room.
  - Auxiliary (sub)-factories connected to the technology, for example, box-making factory.
  - Establishments of the vehicle stock carrying the raw material and the finished product.
  - Maintenance shops.
- Forms of documentation are:
  - Technological flow chart.
  - Arrangement plan for machines, technological arrangement plan.
  - Base drawings.
  - Sectional drawings.
  - List of the items (list of the machines or machine specifications).
  - Plan for routing material transport and personnel traffic.
  - Plan for tubes, technical description.
  - Financial plan.

According to the targets (permission plan, data supply), flow charts can be made in several variations. Designing of the arrangement plan for machines is more or less uniform. Flow charts can be done:

- For the authority that issues the necessary permits.
- Flow chart made by the designer or producer of the technological process to present its offer.
- For informing the technological designer and the employer.
- For construction of the quality, safety and process-control systems.
- Technological flow charts are of three types:
- Principal schematics.
- Block schematics.
- Material transport schematic and Shankey diagram.
- (Heat) Energy transport schematics and Shankey diagram.
- Flow charts.
- Drawings for joining pipes.

Information on the aforementioned things can be found or obtained from: Ábrahám 1980; Szenes and Oláh 1991 and Berszán and Várszegi 2000. The General references relating to fruit processing plant can be obtained from: Alzamora 2000, Arthey and Ashurst 2000, Dris 2003 and Thompson 2003.

FOOD SAFETY AND QUALITY

Food products must fit the dual requirements of food safety and food quality. Besides, there is a third requirement: a continuous supply of the required products in the quantity needed by the customers. Food safety means that the food is free from microbes and/or toxins causing foodborne illness and free from foreign matter dangerous to human health. In other words, the product must meet public health requirements for microbiological quality (Schlotke et al. 2000). The concept of food quality means that the product meets expectations for nutrient content and organoleptic characteristics

Table 18.4. Food Safety and Quality Features

Quality Features	Features of Quality Changes and Their Phenomena
Physical quality features	Features of the physical quality changes
Appearance: colour, shine, smoothness	Fainting, browning, taint, wrinkling
Texture: fragile, fibrous, tough, crackling, crumbling	Softening, desiccation, hardening
	Melting, recrystallisation, phase separation
Phase state: liquid/solid	Physical impurities: metal, glass, powder
Shortage of physical impurities	
Chemical quality features	Features of changing of the chemical quality
Protein and amino acid composition	Browning reactions
Sugar content, types of starch	Vitamin deterioration, coagulation of mineral salts
Nutrients, vitamins, mineral salts	Solvent residues, alien matters
Permanent composition	
Free from chemical impurities	
Enzymolitic quality features	Features of changing of the enzymolitic quality
Shortage of the rotting enzymes	Enzymolitic browning
Presence of the anti-rotting enzymes	Oxidation
Presence of starch-hydrolysing enzymes	
Microbiological quality features	Features of changes of the microbiological quality
Shortage of toxin producers	Microbial growth and toxin production
Shortage of degradation causing	Degradation: smell bad and bad taste, degradation of nutrients

Source: Berszán and Várszegi (2000).

(appearance, taste and smell); the labelling accurately describes the product; and packaging maintains quality while meeting customer expectations. The quality of similar products can vary due to the variations in previously mentioned features (Thorner and Manning 1983; Jen 1989; De Wit 1991; Surak 1992; Stauffer 1994; Balla and Binder 2002). Food safety and quality are determined by several parameters. These quality features are classified into four groups as given in Table 18.4.

EQUIPMENTS

Mechanical Fruit Harvest

Instruments are available for the mechanical harvesting of most fruits. However, appropriate quality of fragile and delicate fruits can be ensured only by manual picking. Most of the shaking machines that are applied for harvesting consist of vibrators operated by combustion engines. These devices shake the tree trunk and limbs. Falling fruits are caught by the collection umbrella. In case the umbrella is in a slanting position, fruits can directly go onto the conveyor belt that leads the fruits into the transporting vehicle. Fragile fruits are manually collected into boxes from the umbrella. Vibration shaking may damage trees; therefore, it has to be performed with due precautions.

Transportation Devices

In processing industry, there are production lines. Production line means the complex system of devices that perform individual operations. Connection between individual machines, such as pre-cooking, filling and closing device, is enabled by conveyor belts and other means of materials handling.

Appropriate synchronisation (performance, size and variability) of machines, transporting devices and storage systems, is a crucial factor, particularly in case of high-performance equipment.

Transportation devices would fall into the following categories:

1. Conveyor belts.
2. Elevators.
3. Screw conveyors.
4. Pumps for materials containing solid particles.
5. Pneumatic transportation devices.
6. Forklift trailers.

Washing and Rinsing Machines

Washing is an extremely important step in the food industry. It is an essential part of almost all technological processes. All incoming raw materials have to be washed after reception, in order to eliminate different contaminants (soil, pesticide residues, foreign materials, etc.). Cans, boxes, bottles and other packaging containers have to be cleaned by washing prior to filling. Furthermore vessels, tanks, machines, utensils, processing areas and the whole production building need to be cleaned. This complex washing challenge cannot be implemented without specific washing devices

Washing equipment categories:

- Raw material washers.
- Packing material washers.
- Devices for washing machines and storage containers.
- Others, for example, cleaning machines.

Raw Material Washers

1. Soaking tubs.
2. Ventilation-based washing devices.
3. Soft-product washers.
4. Brush-based washing machines.

Packing Material Washing and Rinsing Devices

1. Bottle rinsing, double-phase can washers.
2. Bottle washing devices.
3. Case and crate washers.
4. Box washers.
5. Tank washers.

Grading, Peeling, Destemming, Seeding and Cleaning Equipment

Grading Devices

1. Barrel-based grading devices.
2. Cascade-based classifiers.
3. Roll-based diameter classifiers.
4. Colour classifiers.
5. Selectors.

Peeling Devices

1. Knife-based, mechanical peeling devices.
2. Rub peelers.
3. Alkaline peelers.
4. Steam peelers.
5. Combined peelers.

Destemming Devices

1. Barrel-based destemmers.
2. Strawberry destemmers.
3. Cherry destemmers.
4. Red currant destemmers.

Pitter and Halver Machines

1. Peach and apricot pitter and halver machines.
2. Cherry pitters.
3. Destoning pulping devices.
4. Universal destoners.

Fruit-chopper Machines

Some fruits are processed in its natural form. However, a significant amount of fruits is chopped/diced prior to processing and preservation. Chopping is an important technological step—for example, to increase the surface before drying or pressing. Its target can be the achievement of particle size that is defined by the processing technology.

Chopping is a purely mechanical step, but it can be followed by certain non-desired chemical and biochemical procedures such as browning, oxidation, enzyme activation, etc.

Chopping can be performed on slicing, cubing or crusher, masher and homogenisation devices.

Achieving regular shape is not a criterion for crushing, pulping and homogenisation; the basic target is to open up the material.

Following the chopping, raw materials is processed immediately to avoid deterioration. Materials to be chopped are transported by means of conveyor belt, elevator or individual feeder device into the chopping equipment.

Chopping Devices

1. Cubing, slicing and striping machines.
2. Hammer crushers.
3. Fruit millers.
4. One or more stage pulper devices.
5. Colloid mills.

Machines of Juice Production

Except the homogeniser, juice production devices perform physical separation.

- *Pressing*: juice is separated from the crushed fruit by applying pressure.
- *Centrifuging*: solid particles are separated from the liquid, or liquids of different density are separated in the centrifugal space.
- *Filtration*: fine contaminations are separated from the liquid by flowing through the filtration media.
- *Homogenisation*: colloid size chopping is done, thus liquid is homogenized by the tearing force applied.

Equipment Categories

1. Universal horizontal basket fruit-pressing machines.
2. Continuous belt press devices.
3. Universal pneumatic press devices.
4. Centrifuges.
5. Homogenisers.
6. Filtration devices:
   - Bag filters.
   - Flat filters.
   - Rotary vacuum drum filters.
   - Ultra filters.

Heat-Exchangers

Generally all equipment, where a material is heated or cooled, can be called heat exchanger. As there are many materials in food industry that have to be heated or cooled, applied devices are designed to suit different technological requirements. Heat exchangers are defined as equipment, where only the temperature of the material changes neither the physical condition nor biological and chemical properties are changed.

Usually flowing, liquid phase materials are treated in heat exchangers. Heating medium is usually saturated steam or possibly liquid. Cooling media is water or cooling liquid.

Heat exchange takes place via the wall. Flow arrangement of the fluids can be parallel, counter-current or cross-counter stream. Thus, heat-exchanger equipments can be parallel-flow, counter-flow or cross-counter-flow devices.

Heat-Exchanger Categories

1. Shell and tube heat exchangers.
2. Multi-tube heat exchangers.
3. Micro-tube heat exchangers.
4. Plate heat exchangers.
5. Scraped-surface heat exchangers.
6. Spiral-drum heat exchangers.
7. Heat pipes.
8. Multi-tube spiral heat exchangers.

Blanching and Cooking Devices

As part of the processing technology, certain fruits have to be cooked, pre-cooked or blanched. This step can be carried out in continuous-system pre-cooking devices. Within the pre-cooking machine products are transported by screw conveyor, bucket or conveyor belt. Thus, there are screw conveyor-, bucket- and belt-based pre-cooking devices. Pre-cooking can be performed in water and steam. In case it is done in water, dilution may occur; if we apply steam, heat exchange is more efficient and the risk of dilution is smaller. When pre-cooking is done in steam, products are transported on stainless steel wire mesh band. The band is moved in a water barrier tunnel. Steam is circulated by a special ventilator in order to ensure even temperature distribution. The internal space of the device is closed at the input and output sides by cell-based feeding elements. The heating steam is saturated steam under atmospheric pressure.

Evaporator Categories

1. Double-coated, rotary, single stage vacuum evaporators.
2. Multiple effect evaporators:
   - Two- or three-stage forced circulation evaporators.
   - Plate evaporators.
   - Film evaporators.

Filling and Closing Machines

Filling machines carry out some of the most intensive steps in the industry: they fill the products to be preserved into packaging containers—bottle, box, or plastic bottle, etc. Closing machines hermetically close the containers that are already filled.

The material to be filled can show a great variability in shape, physical condition and density. Packaging materials are also diverse. The filling machine is selected based upon the properties of the material to be filled. The closing machine is should be suited to packaging material.

Filling-Machine Categories

1. Filling machines for broken or lumpy products.
2. Fillers for materials containing pulp or coarse particles.
3. Puree and pulp fillers.
4. Liquid fillers.
5. Fillers for powdered products, etc.

Closing-Machine Categories

1. Jar-closing devices.
2. Bottle-closing machines.
3. Can-closing machines.
4. Closing machines for plastic containers, etc.

Heat-Treatment Equipment

In food industry, product preservation with heat treatment under 100°C is called pasteurisation; above 100°C it is called sterilisation. Pasteurisation is generally used for products under pH 4.5. Products above pH 4.5 are preserved by sterilisation.

Pasteurisation Equipment

These are devices with open-water basin, where products are heated up to the extent required for preservation in water bath or under water curtain.

Categories:

1. Batch-type pasteurisers.
2. Tunnel pasteurisation devices.
3. Belt pasteurisers.

Sterilisation Equipment

As sterilisation temperature is above 100°C, this step can be performed under pressure—when the heat-exchange medium is water—or by applying other heat-exchange media with higher boiling point. In sterilisation devices used nowadays, heat transmission is done by water or steam under pressure (higher than atmospheric pressure). Thus, these devices can be closed hermetically.

Retorts:

1. Retorts with vertical or horizontal basket.
2. Retorts with heat recuperators.

Continuous sterilisers:

- Hydrostatic sterilisers.
- Tower sterilisers.
- Segmented hydrostatic sterilisers.

Aseptic Devices

The principle of aseptic technology is that products—it can be fruit juice, pulp or concentrate—processed with traditional technology are heat treated on flow-through heat-exchanger devices, then filling, closing and storage are done under aseptic conditions.

Aseptic preservation can also be carried out on lumpy materials up to 15–20 mm particle size, where solid parts are evenly distributed in liquid phase juice or pulp.

Aseptic Technique Requires the Following Devices

- Pumps.
- Heat-exchangers.
- Accessories.
- Pipelines.
- Tanks.
- Filling machines:
  - Tetra brik aseptic.
  - Combibloc (PKL).
  - Aseptic barrel fillers.
  - Aseptic bag fillers.

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19
Fruit Processing Waste Management

Judit Monspart-Sényi

Abstract: This chapter is a review of the environmental impact of waste and by-products of fruit processing. Fruit processing waste characteristics and treatment options with regard to the economic feasibility are mentioned. Also included are the current utilization opportunities of fruit processing waste and related technologies. For example, converting fruit waste and by-products into valuable new products (pectin derivatives, polygalacturonase, citric acid, alcoholic beverages, etc.) or additives in other products (e.g., utilization of fruit waste fiber). Attention is drawn to present-day techniques of waste management in apple, citrus, peach, and banana processing technologies. New research areas for fruit waste utilization are also mentioned. The main environmental regulations are summarized. Finally, it is essential to consider the food safety aspects with a conscious effort to control pollutants that enter the environment as a result of food processing.

INTRODUCTION

It is believed that in undeveloped economies, the amount of waste generated exceeds the environment's waste processing potential. A sustainable development requires reduction in

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waste generation, recycling, and reuse of an increasing proportion of the waste. Every year almost 45 million tons of fresh vegetables, fruits, milk, and grain products are lost to waste just in the United States. The disposal of this costs approximately $1 billion. According to research from the UK Waste and Resource Action Programme (WRAP), total annual food waste in the United Kingdom amounts to around 18–20 million tons—with food processors estimated to generate about 20% of this. Every ton of food waste means 4.5 tons of CO_2 emissions. The food wastes are generated largely by the fruit and vegetable/olive oil, fermentation, dairy, meat, and seafood industries (Kosseva 2009; Anon 2010).

Retailers are believed to generate about 1.6 million tons, with food service and restaurants producing about another 3 million tons. The remainder comes from the agricultural and horticultural sector, and commercial food waste from such sources as hospitals and schools. Household food waste contributes to an estimated 6.7 million tons per year (Harrington 2010).

This chapter discusses the existing trends in the fruit waste processing technologies. It consists of three major parts: fruit waste treatment technologies, which distinguish recovery of added-value products (the upgrading concept); fruit processing chain management for sustainable food system development; and innovation in the fruit waste sector.

INFLUENCE ON THE ENVIRONMENT

Exponentially growing population, traffic, energy and industrial production, agriculture (which apply tremendous amount of chemicals), and the food processing industry cause significant environmental pollution that endangers all living systems including humans.

Environmental protection efforts are a social responsibility to preserve our biosphere. These efforts are aimed at protection of the environment from unintentional polluting and destroying impacts of human activities. Many polluting and destroying effects that hurt environment and living creatures are the consequences of industrial activities.

Environment can be protected by a balance approach to development and efficient use and protection of the natural environment (Anon 2003).

FRUIT PROCESSING WASTE

Waste includes material outputs, immaterial factors (such as noise pollution, waste heat, etc.), surplus and unsellable products, etc.

General Waste Categories

Economic and industrial developments have led to an increase in the amount and diversity of wastes. Consequently, wastes can be categorized based on the following:

Venue of waste formation:

- Resource extraction,
- Economical activity (production, services),
- Consumption.

Waste origin:

- Production (industrial, agricultural, service related),
- Communal waste.

Physical condition:

- Solid,
- Liquid,
- Slurry,
- Gas.

Safety/hazardous:

- Nondangerous wastes,
- Dangerous wastes.

Wastes, which contain higher concentrates of hazardous (mercury, cadmium, lead, chromium, arsenic, cyanide, organic phosphorus, and chlorine compounds) or less hazardous (copper, zinc, and flour compounds) substances than regulated in legislation, can also be evaluated dangerous. Radioactive wastes and wastes with radioactive contamination are registered separately and regulated by separate legal rules.

FRUIT WASTE MANAGEMENT

The aim of waste management is to achieve rational management of resources and minimize the amount of waste disposed into the environment. The main areas of waste management include prevention and decrease of waste formation, reutilization, recovery, waste selection, waste handling, waste transformation or destruction, waste placement, and storage.

Opportunities of Waste Reduction in Fruit Processing

There are numerous approaches to reduce the amount of fruit processing wastes. New processing establishments (especially, fruit processing plants) already completed and existing plants are examined and treated differently. In case of new installations, the selection of processing technology is of crucial importance. It is recommended to use waste-free or low-waste technologies.

Waste-free technologies are designed to use low amount of water and air. Another relevant criterion is the closed cycle design, which means that there should be no contaminating waste formation during production, neither liquid nor gas and solid. This approach is becoming widespread not only in fruit processing industry but also in the agriculture, where by-products and waste can be utilized in closed cycle.

The introduction of waste-free technology can create two situations in the fruit processing plant:

- The new technology does not pay off, but the introduction of waste-free technology is beneficial compared with traditional cleaning procedures.
- The technology is profitable for the plant.

Even if operating and investment costs are higher than in case of the traditional technology, they are still cheaper than the total costs of the traditional technology and the cleaning procedure.

Due to the gradual increase of raw material and energy prices, the competitiveness of waste-free technologies will further improve in the future.

Procedures for the Management of Fruit Processing Waste

Fruit Processing Slurry Treatment

Slurry treatment has two aims, decreasing the amount of slurry and slurry processing to develop the structure and composition that is suitable for placement. This latter can be performed by stabilization and disinfection. The decrease of slurry quantity practically means water removal, which is carried out by mechanical procedures or heat treatment or by the combination of both. Taking the general composition of slurry into consideration, it can be seen that 90% of the water content, which is pore water and capillary water, can be removed by thermal separation procedures. The main steps of slurry treatment and placement are as follows:

- Slurry concentration;
- Slurry conditioning;
- Disinfection;
- Water removal;
- Aerobic stabilization;
- Anaerobic stabilization;
- Combustion;
- Final placement and waste deposition.

The goal of slurry concentration is the decrease of easily removable water content and thus the decrease of slurry quantity. The most frequently applied procedures are gravitational and flotation-based slurry condensating devices, slurry centrifuges, and membrane separation techniques. Depending on the construction, the following dry matter levels can be achieved by different water removing procedures: gravitational condensation 4–5%, centrifuges 10–20%, and membrane separation 30–40%.

The aim of slurry conditioning is to decrease the water content, stabilize organic substances, and reduce the number of microorganisms. Physical conditioning can be performed by pasteurization, thermal conditioning, and washing. Washing means the elimination of colloid organic contaminants from the slurry, which are then driven back for biological cleaning.

Pasteurization leads to the decrease of pathogen microorganisms, meanwhile thermal conditioning opens up cell wall forming materials. In this latter procedure, due to the damage of the cell wall, the water content of the cells is released and can be removed. Heat-treated slurry becomes better filterable, because of the structural changes, thus better water removing efficiency can be achieved. The damage of cell walls leads to the release of cell fluid and other cell constituents, which become better accessible for microorganisms. Thus, the oxygen need of the treated slurry will increase. In chemical conditioning, pathogens are destroyed by the addition of chemicals, the rotting ability of the slurry is inhibited, and the filterability is improved. In aerobic stabilization, organic substances are decomposed in the presence of oxygen. The speed of the process can be increased by enzyme addition.

Anaerobic stabilization (rotting) is performed under oxygen-free conditions. The transformation of organic compounds starts with hydrolysis that is followed by acidic fermentation and methane formation. Prior to the addition of methane bacteria, bacterial cultures are added, which decompose proteins, fats, and carbohydrates to fatty acids and small-chain organic acids. Substrates, thus formed, can be utilized and the desired methane content can be achieved. Anaerobic stabilization of 1 kg organic material leads to the formation of 0.44–0.75 m^3 gas, which contains 60–70% methane, 30–35% carbon dioxide, and 1–2% other gases (nitrogen, hydrogen, oxygen, and hydrogen sulfide). The flammable part of the biogas is methane (CH_4); its heating value depends on other nonflammable compounds (N_2, CO_2). The level of methane is determined by organic acid content and the technology applied. Besides an average methane content of 60%, the heating value of biogas is 22.4 MJ/m^3. Disinfection procedures are applied, if the slurry is intended for agricultural utilization or in case of epidemic risk. Disinfection effect is achieved by chemicals, heat impact, or preliminary composting. The conditioned slurry is then submitted to water removal. The most frequent equipments of slurry treatment are slurry dehydrate basins, centrifuges, separators, filter pressing devices, belt press, and rotary vacuum drums. Drying is performed not only to decrease water content but also to destroy pathogens and weed. Slurry drying is done in etage-, smoke-gas, and belt-based dryers. If sewage contains toxic compounds or there is no other opportunity for utilization or placement, the slurry is pretreated and inactivated by combustion. The heating value of rotten slurry is the half of raw slurry (25.5 MJ/kg dry matter). Ash remaining after combustion has to be processed as well.

Composting Fruit Processing Wastes

Composting is a method for the disposal of organic waste, which is known and applied for a long time. Its principle

is that wastes containing organic materials (fruit processing waste, slurry) are decomposed in the presence of microorganisms and oxygen besides appropriate environmental conditions. Composting results in stable organic compounds and inorganic mineral substances.

Heat development occurs during the composting process, which can attain 50–70°C depending on applied technological factors. Consequently, pathogen microorganisms, present in the waste, are destroyed, except spore-forming species. Decomposed organic material (compost) contains no pathogens. The result of the procedure is a soil-like material with 40–50% moisture content, which can be used as fertilizer and soil conditioner in the agriculture due to its humus-forming organic compounds.

Composting is a biotechnological procedure, where

- The substrates are mainly in solid or water insoluble phase;
- The surface is covered by a water film;
- The microorganisms work under aerobic circumstances.

The general aims of composting are as follows:

- Decreasing the volume and mass (moisture content) of the material.
- Prevention of pathogenicity.
- Utilization of N, P, K, and C content present in the slurry.

Composting is mainly an aerobic biochemical process. The enzymes of microorganisms, which participate in the process, decompose organic substances by biological oxidation.

The deficiency and unevenness (large wet particles) of oxygen supply can form anaerobic conditions within aerobic systems as well. However, anaerobic processes may cause environmental problems, because of the development of volatile derivatives with low molecular weight. Therefore, the proper balance of aerobic and anaerobic processes (odor emission) has to be ensured. Consequently, large-scale composting systems are practically aerobic-type systems. Numerous experts recommend the wet storage of materials intended for composting as pretreatment in order to initiate preliminary anaerobic decomposition. After reaching the desired moisture content and free gas phase ratio (free air volume), composting will be a clearly aerobic process. Chemical reactions that take place in aerobic microbiological processes can be described as follows:

$$\mathrm{n\ C_6H_{12}O_6 + 6n\ O_2 \rightarrow 6n\ CO_2 + 6n\ (H_2O) + n\ (2.88 \times 103\ kJ)}$$

Microorganisms (thermophilic bacteria, fungi, and mesophilic bacteria), performing the composting process, obtain the energy needed for their growth and reproduction by decomposing organic waste materials.

The decomposing and transformation process of organic materials includes the following stages:

- Initiation stage (rapid warming).
- Mesophilic stage with slow warming.
- Thermophilic stage with slow cool down.
- Postripening, total cool down.

The Composting Process of Fruit Processing Waste Easily degrading organic substances (carbohydrates, proteins, etc.) decompose quickly and are transformed in the initial stages of composting. The heat formed during biological decomposition is used for heating the material and evaporating its moisture content. Therefore, the heating value is lower than the heat of combustion. Heating value and the heat of combustion can be directly calculated from the carbon, hydrogen, oxygen, and sulfur content of the flammable material. Sulfur has to be taken into consideration in combustion, since it also forms oxydized products. However, in biological processes, sulfur content is usually transformed to sulfides, making no significant contribution to heat development. The most frequently measured parameter of biological degradation processes is chemical oxygen demand (COD). According to practical experiences, the combustion heat of different substances can be described as 3.4 kcal/g COD, which shows low variability in different organic compounds. Surviving pathogens may increase the microbiological risk of compost, particularly if raw materials include sewage slurry or industrial waste with pathogen content. In order to avoid the diseases they cause, the number of these organisms and their spores should be minimized. This can be carried out by the sterilizing impact of temperature, which develops during composting procedures. There are other methods for sterilization, but in the practice of composting, they are not significant. Sometimes, chalk/lime (alkaline pH, heat development) is added. Pathogen microorganisms can be inactivated by the antagonistic activity of other microorganisms as well. Enteropathogen organisms (pathogen viruses, bacteria, protozoa, fly larva) can be inactivated usually by thermal means in the 55–60°C range in some days.

According to different research findings, the optimal moisture content for composting the waste of fruit processing industry is 45–55%. This moisture level can be achieved by artificial moistening (irrigation) or with the combined treatment with communal slurry. This effect justifies the significance of joint composting. Even moisture distribution is a very important factor; thus, homogenization is a basic step of composting. Aerobic circumstances play a decisive role in degradation processes, so permanent or periodic aeration is necessary for the oxygen supply of microorganisms. Without the appropriate level of oxygen, decomposition becomes anaerobic and results in adverse odors (ammonia, hydrogen sulfide, etc.). Besides permanent mixing (e.g., rotary drum), degradation is quick, but it requires a lot of energy. If periodic rotation/aeration is applied, decomposition is slow and requires large storage areas. Therefore, modern equipments apply continuous aeration, adding 0.6–2.0 m^3 air to 1 kg organic (dry) material. The nutrient level of wastes, particularly

C/N ratio, plays a decisive role in the speed of composting procedures. The optimal C/N ratio is in the 15–25 range. The composting process can be accelerated by the addition of nitrogen-containing materials. Chemical fertilizers with high nitrogen content can be suitable, but it is recommended to mix other wastes, such as communal and industrial slurry. Particle size of waste materials also influences aeration and the speed of degradation. Chopped materials possess bigger surface and provide higher access to degrading microorganisms. Optimal particle size is 25–40 mm. Too small particle size favors anaerobic procedures (due to solidification). Solid waste composting technologies apply grinding and chopping devices to achieve the desired particle size.

OPPORTUNITIES FOR UTILIZING FRUIT INDUSTRY WASTES AND BY-PRODUCTS

Fruit industry wastes and by-products are of large volume, low nutritional value, and geographically scattered. There is an opportunity to convert environmentally polluting waste into by-products of economic value through new scientific and technological methods.

The utility of raw materials (the extent it can be converted to the end product) depends on the following factors:

- Nature and quality of raw material.
- Type, characteristics, and quality criteria of the finished product.
- Technological process.
- Technical level and condition of the machinery.
- Human factors.

Fruit industry wastes are usually organic substances, which can pollute the environment if not disposed off prudently. All in all, fruit industry wastes and by-products are substances that originate from production and can be utilized in some form. For example, fruit wastes from cleaning and seeding are used for feed without further treatment.

Fruit processing companies conform to the "best available techniques" or BAT principles (Anon 1996). The term "BAT" is defined in Article 2(11) of the EC Directive (Integrated Pollution Prevention and Control). It is "the most effective in technique for providing in principle the basis for emission limit values, to prevent and, where that is not practical, to reduce emissions and the impact on the environment as a whole."

In Europe, the BAT group is working to develop and distribute information on how to avoid pollution when using production methods for various commercial products. The aim is to further the utilization of the BAT within selected fields (e.g., fruit processing). Due to the diversity of operations, the techniques and methods successful to minimize waste generation in one processing operation can, not necessarily, be easily followed by others. Therefore, each operation would need to assess this issue considering age of plant, scale, geographic location, as well as the product portfolio and the type of process. The strategy should be to define policies and establish a working group to monitor the environmental impact of specific activities and set up goals to enhance performance.

The application of this principle contributes to decreased quantity of waste and water consumption and has several environmental advantages. Nevertheless, the amount of food processing wastes and by-products that are important issues of food processing environmental strategies is significant even if this principle is applied properly (Perédi-Vásárhelyi 2004).

Utilization of By-products for Feeding

Feed production has become a new industry. More and more plants are processing by-products as raw materials that were not used in traditional feeding technologies. The feed thus produced can be mixtures or concentrates to be mixed at local fodder plants. Sometimes, these products are patented and producers enclose directions for use. Factories preparing, producing, and using the feed are interdependent and operate in a complex ecological system (Adebowale 1985). Disposition is a top priority in waste management in addition to profitability (Subburamu et al. 1992).

Role of Biomass in Waste Utilization

Biomass refers to all organisms (microorganisms, plants, and animals) both living and recently dead; products of biotechnology-related industries; and all biological products, wastes, and by-products (human, animal, processing industry, etc.). Food industry production, where the agricultural raw materials become foodstuffs, is a primary source of biomass transformation (Hammond et al. 1996).

Evaluating the potential of biomass production and utilization and developing a system that includes relevant recommendations for practical applications have been discussed in scientific literature (Mahadevaswamy and Venkataraman 1990; Viswanath et al. 1992; Bouallagui et al. 2004). Animal feeding is a potential utilization. Mass feed production takes substantial amounts of land; however, these areas could be used for plant production for export, meanwhile by-products could be partially substituted for feed. The profitability of ruminant farming requires a cost decrease without a decline in production.

Evaluation of Waste Utilization Techniques

A higher return can be obtained by the introduction of by-products in human nutrition; meanwhile, burning (if its energy is not utilized) is primarily "waste elimination."

Primary conditions for the introduction and implementation of technologies selected for utilization are as follows:

- Preserving and storing by-products of different origins geographically. This means that they are decentralized. To gather them, distant transport is required.

- Reasonable solutions for transport. That is, the best traffic logistics for the minimum cost and the most effective transportation technology.
- Ensuring the space, building, machinery, equipment, energy, and personnel requirements of processing.

Before making a decision to utilize by-products, an evaluation of the by-products should be made on the following issues:

- Concentrated or widely scattered origin?
- Seasonal or continuous availability?
- Quantity (large or small)?
- Concentration of valuable substances (high or low)?

The ideal utilization choice is usually determined by complex evaluation and short-run economical analysis. According to international experiences, by-product utilization and waste-free technologies are most sophisticated in developed countries, where food production is also on a high level. In less developed countries, the use of such technologies can commensurate with the financial resources (Polpraser 1996), thus

- The easiest use for by-products of plant origin is plant fertilizer.
- Biogas production and burning combined with energy recovery are still not widespread.
- The use of food industry by-products (bran, coarse or oleaginous seeds, and feed yeast) as a feed supplement is a cheap and simple procedure.
- By-products with high water content need to be dried or concentrated prior to further processing.
- Primarily by-products, rich in protein, are used for feeding.
- Human application is the most expensive, due to high requirements for equipment and energy. Fruit processing (e.g., pectin production) is a good example to illustrate this kind of utilization.

MAIN TYPES OF WASTES AND BY-PRODUCTS OF FRUIT PROCESSING

The aim of fruit processing is to transform fresh fruits into preserved products. The selection and elimination of components unsuitable for human consumption can lead to by-products and wastes. There is no sharp distinction between waste and by-product; the by-product from one process/product can be a secondary raw material for another producer. Apple processing is a good example of this. Although apple products such as canned apples, apple juice, etc., are finished products, apple peel and pomace can be important secondary raw materials for production of pectin as a by-product of these processes. In general, in Hungary as well as the rest of the world, the majority (60–65%) of food industry by-products become waste and a burden to the environment (Szenes 1995).

In order to meet environmental requirements, modern fruit processing should minimize the amount of by-products and waste, decrease energy utilization, and produce high-quality foodstuffs without polluting the environment (Barta et al. 1997).

The processing of fruits produces two types of waste: solid waste, for example, peel/skin (Larrauri et al. 1997; Negi et al. 2003; Fernández-López et al. 2004), seeds (Noguchi and Tanaka 2004), and stones (Lussier et al. 1994) and liquid waste, juice (Gil et al. 2000) and wash water. Careless handling and disposal of wastes can attract flies and rodents in the processing facilities. If there is no plan to use the waste products, they should be buried or disposed off as animal feed.

Fruit processing wastes differ from other wastes:

- They are organic and, therefore, decompose. Most go back into the soil, due to natural biomass circulation, or decompose without pollution.
- They are large in volume with high water content. In spite of the high volume, their origin is scattered, making gathering and utilization difficult and expensive.
- They tend to deteriorate, thus limiting the storage period, even under appropriate circumstances, which include low temperatures, controlled humidity, and storage in dark and dry places.

Apart from the main finished product, unused substances are considered as waste and by-products. These can be utilized in different ways depending on their texture and content.

Certain by-products can be valuable resources for human nutrition if special technologies are used. They include the following:

- Precooling techniques (Brosnan and Sun 2001).
- Solid-state production (Zheng and Shetty 2000).
- Gas chromatic evaluation of residues (Pugliese et al. 2004).
- The beneficial effects of grinding, soaking, and cooking on the degradation of dangerous matters in fruit waste (Tuncel et al. 1995).
- Others.

Some examples are as follows:

- Pectin from apple pomace.
- Aromas and coloring agents from fruit waste.
- Oils from seeds.
- Tartaric acid from wine lees.

Also, further processing of by-products can transfer their valuable compounds into new products:

- Distillery wastes can be added to feed after appropriate treatment.
- Household and gardening wastes are utilized for soil improvements.

- All organic by-products can be utilized in a profitable way, if used for biogas production (methane production) or burning (especially if combined with recovery) (Mahadevaswamy and Venkataraman 1990; Prema-Viswanath et al. 1992).

Solid Fruit Wastes

There are possible ways to use some solid fruit wastes, which are discussed later. However, it is stressed that a full financial evaluation should be done before the implementation of any of the suggestions.

One major concern in using fruit wastes is microbiological quality. This means that one should process waste products on the same day as they become available. It is not advisable to store wastes until the end of the week's production before processing them. Even with this precaution, the wastes being used will most likely contain moldy fruit (discarded during processing), insects, leaves, stems, soils, etc. This will contaminate any products derived from such wastes.

Therefore, some preliminary separation is needed during processing, such as the following:

- Peel and waste pulp in one bin.
- Moldy parts, leaves, soil, etc., in a second bin, which may be discarded.
- Stones, seeds, etc., in a third bin.

Other Possible Fruit Waste Products

The six main products from fruit wastes are as follows:

- Candied peel,
- Oils,
- Pectin,
- Re-formed fruit pieces,
- Enzymes,
- Wine/vinegar.

Each is discussed in the following paragraphs:

Candied peel: Peels of citrus fruits (orange, lemon, and grapefruit) can be candied for use in, for example, baked goods and snack food. In addition, shreds of peel are used in marmalades, similar to the process of candying. That is, boil the slices or shreds of peel in 20% sugar syrup for 15–21 minutes and progressively increase the sugar concentration in the syrup to 65–70°Brix during soaking of the food for 4–5 days. It is then removed, rinsed, and given a final drying in the sun or in the hot air dryer. This can serve as a secondary product for a fruit juice or jam processor. This assumes that a large food company is interested in buying the candied peel as an ingredient for their products. In one application, candied melon skin has been used to substitute for sultanas in baked goods and, in another, candied root vegetables have found a similar market.

Oils: The stones of some fruits (e.g., mango, apricot, and peach) contain appreciable quantities of oil or fat, some of which have specialized markets for culinary or perfumery/toiletry applications. Palm kernel oil is well known as a cooking and industrial oil. In addition, some seeds (e.g., grape, papaya, and passion fruit) contain oil with a specialized market. Of course, for any commercial product in any country, the goal is to identify the import/export agents interested in such products. After that, the processor's responsibility is to produce the oil to satisfy the customer in terms of sufficient quantity and stringent quality standards.

The process involves grinding the seeds and nuts to release the oil without a significant rise in temperature, which would spoil their delicate flavors, with the exception of palm kernel oil. In general, a powered hammer mill is needed for nut and kernels. A press is needed to extract the oil. Since the existing manual presses have not been tried for this application, a certain amount of experimentation is needed to establish oil yields and suitability of the equipment. Solvent extraction is not recommended for small-scale applications. However, steam distillation of citrus peel oils is well established for small-scale operations. The crude oil may be sold refining elsewhere.

Pectin: This is a gelling agent used in jams and some sweets and occurs in most fruits, ranging from a low to a high level. Commercially, pectin is extracted from citrus peel and apple pomace, the residue left after apple juice has been removed. Other tropical fruits may contain high levels of pectin, passion fruit being a notable example. The utilization of the "shells" remaining after pulp removal may permit pectin extraction.

In most developing countries, pectin is imported from Europe or United States. This may look like a good market or opportunity for processors in these countries to provide pectin locally to substitute for imports. However, there are major problems:

- In countries where this has been tried, it has not been possible to produce pectin at a cost lower than the imported products.
- It is difficult to produce pectin powder on a small scale, although liquid pectin is possible.
- There are many types of pectin, each with specific properties suitable for a particular application. For example, pectin for jams differs from that used in jam as an ingredient in baked goods.

Re-formed fruit pieces: Fruit pulp can be recovered and formed into fruit pieces. Although the process is relatively simple, the demand for this product is low. Therefore, a thorough evaluation of the potential market is recommended before investing in the enterprise (Kilham 1997).

The process involves preparing a concentrate by boiling the fruit pulp, followed by sterilization. Sugar may also be added. A gelling agent, sodium alginate, is then combined with the cooled pulp and then mixed with a strong solution of calcium chloride. Being legal food additives in most countries, all

ingredients are safe for human consumption. The calcium and the alginate combine to form a solid gel structure and the pulp can therefore be re-formed into fruit pieces. The most common way is to pour the mixture into fruit-shaped moulds and allow it to set.

It is also possible to allow drops of the fruit/alginate mixture to fall into a bath of calcium chloride solution where they form small grains of re-formed fruit, which can be used in baked goods. Commercially, the most common product of this type is glaced cherries.

Enzymes: Commercially, the three most important enzymes from fruit are papain (from papaya), bromelain (from pineapple), and ficin (from figs). Each is a protein-degrading enzyme used in such applications as meat tenderizers and washing powders and is also used in leather tanning and beer brewing. However, it is unlikely to be economical to harvest these enzymes from fruit processing waste. Currently, even the more efficient process of collecting enzymes from fresh whole fruit is no longer economical. Changes in both large-scale production with higher quality standards and use of biotechnology to produce "synthetic" enzymes mean that small-scale producers can unlikely compete effectively. In addition, there are proposals to phase out the use of these enzymes in food products in Europe and United States. Their market is therefore declining. Consequently, it is not cost-effective to harvest enzymes from fruits processing waste.

Wine/Vinegar: Although products such as wine or vinegar should be produced from fresh, high-quality fruit juices in order to obtain high-quality products, it is technically feasible to produce them from both solid and liquid fruit wastes. Solid wastes should be shredded and then boiled for 20–30 minutes to extract the sugars from the fruit and to sterilize the liquid. Several batches of waste may be boiled in the same liquid to increase the sugar concentration. This is then filtered through boiled cloth to remove the solids and cooled in preparation for inoculation with yeast. Liquid wastes should be separated during production to ensure that fruit juice is kept separate from wash water. For example, the juice could be drained from a peeling/slicing table into a separate drum. The juice is then boiled for 10–15 minutes and treated as described earlier.

The liquid is then inoculated with "wine" yeast and not bread or beer yeast and fermented in the normal way for wine production. This can then undergo the standard second fermentation to produce fruit vinegar.

In summary, each of the above-mentioned uses of fruit waste requires

- A good knowledge of the potential market for the products and the quality standards required.
- An assessment of the economics of production.
- A basic familiarity with the production technique.
- A reasonable capital investment in equipment.
- A fairly large amount of waste available to make utilization or harvesting worthwhile.

For small-scale operations, where reducing pollution or increasing waste disposal is more important than process economics, the most likely solution is to use wastes as animal feeds.

SPECIAL BY-PRODUCT TREATMENT AND UTILIZATION IN THE CASE OF CERTAIN FRUIT-BASED PRODUCTS

Apple Waste Utilization

In the temperate zone, apples are the most significant fruit economically. Apple production achieves approximately 10% of the world's fruit production, with one-fourth produced in Europe.

There are opportunities for the utilization of apple press cakes:

- Drying,
- Feeding,
- Composting,
- Storing.

However, both environmentally and economically, the best technique is drying for pectin extraction.

Apple Pectin

Pectin for use in food is defined as a polymer containing galacturonic acid units (at least 65%). The acid groups may be free, combined as a methyl ester, or as sodium, potassium, calcium, or ammonium salts, and in some pectins, amide groups may also be present.

Commercial Apple Pectin Production Process details vary between different companies, but the general process is as follows:

The pectin factory receives apple residues or pomace (Carson et al. 1994) or citrus–orange peels from a number of juice producers (El-Nawawi and Heikal 1996). In most cases, this material has been washed and dried, so it can be transported and stored without spoilage.

If the raw material is dry, it can be assessed and selected from storage when the need arises. If wet citrus peel is needed, it has to be used immediately on receipt because of rapid deterioration (Kim et al. 2004).

The raw material is added to hot water containing a processing aid, usually a mineral acid, although others such as enzymes could be used (Schieber et al. 2003). Water alone will extract only a very limited amount of pectin.

After pectin is extracted, the remaining solids are separated, and the solution clarified and concentrated by removing some of the water. The solids can be separated by filter, centrifuge, or other means. The solution is then filtered again for further clarification if necessary.

Either immediately or after a holding period to modify the pectin, the concentrated liquid is mixed with an alcohol to precipitate the pectin. The pectin can be partly de-esterified at this stage, or earlier or later in the process.

The precipitate is separated, washed with more alcohol to remove impurities, and dried. The alcohol wash may contain salts or alkalis to convert the pectin to a partial salt form (sodium, potassium, calcium, and ammonium).

The alcohol (usually isopropanol) is recovered very efficiently and reused to precipitate further pectin.

Before or after drying, the pectin may be treated with ammonia to produce amidated pectin if required (Braddock 1999). Amidated pectins are preferred for some applications.

The dry solid is ground to a powder, tested, and blended with sugar or dextrose to a standard gelling power or a product with other functional property such as viscosity or stabilizing effect.

Pectins are also blended with other approved food additives for use in commercial applications.

The various raw materials yield different amounts of extractable pectin: pomace, 10–15%; sugar beet chips, 10–20%; sunflower infructescence, 15–25%; and citrus peels, 20–35%.

Application of Apple Pectins Apple pectin is one of the most versatile stabilizers available. Its gelling, thickening, and stabilizing properties make it an essential additive in the production of many food products.

Traditionally, pectin is primarily used in the production of jams and jellies. It produces the desired texture, limits the creation of water/juice on top of the surface as well as an even distribution of fruit in the product. Product and application development by the major pectin producers has over the years resulted in a large expansion of the opportunities and applicability of pectin. Pectin is a key stabilizer and is used in many food products as follows:

- Fruit applications in jams, jellies, and desserts.
- Bakery fillings and toppings in fruit preparations for dairy applications.
- Dairy applications in acidified milk and protein drinks, yogurts (thickening).
- Confectionery in fruit jellies, neutral jellies.
- Beverages.
- Nutritional and health products.
- Pharmaceutical and medical applications.

This wide range of applications explains the need for many different types of commercial pectin, which are sold according to their application, for example,

- Rapid set pectin traditionally used for jams and marmalades.
- Slow set pectin used for jellies and some jams and preserves, especially for vacuum cooking at lower temperatures. It is also important for higher sugar products such as bakery and biscuit, jams, sugar confectionery.
- Stabilizing pectin used for stabilizing acidic protein products such as yogurts, whey, and soya drinks during thermal processing.
- Low methyl ester amidated pectin used in a wide range of low-sugar products, reduced sugar preserves, fruit preparations for yogurts, dessert gels and toppings, and savory applications such as sauces and marinades. It can also be used in low-acid and high-sugar products such as preserves containing low-acid fruits (figs and bananas) and confectionery.

Apple By-products: Coloring and Noncoloring Sweetener

After distilling the alcohol used for the precipitation of apple pectin and other fruit extracts, such as sugar and fruit acids, the natural flavors will remain. For example, apple extract obtained from pomace will be used as sweetening agents for the preservation of freshness and/or coloring of food. A further possibility is to ferment it to form apple ethanol.

At a further processing stage, special technologies are used to remove dark natural coloring agents, mineral substances, and fruit acids from these fruit extracts. The resulting products will only contain the sugars of the respective raw material that has been processed. They will be used by the food industry as sweetening agents (Khachatourians and Arora 2001).

Apple Pectin By-product: Fodder

After apple pectin is extracted, the various residues of the original raw material are dried and pressed into pellets. Due to their high energy content and nutritive value, these products are in demand as fodder. The residual moisture and the fodder value of these products are checked continuously so as to ensure that products of uniform quality are obtained (Bennett 2002).

Apple Pomace Processing (Fiber Utilization)

After adding wine yeast to the apple pomace, remaining from fruit juice and apple pulp production, the marc is fermented at 30°C in solid phase, resulting in a liquid with a 4–5% ethyl alcohol content. Then it is concentrated to 10% by vacuum distillation. With further fermentation, high-quality apple vinegar can be obtained.

If we add "*Aspergillus niger*" mold and methyl alcohol to the apple pomace, its sugar content will decrease by 81% in 5 days. Meanwhile, from 1 kg of apple marc, we can extract 90 g of citric acid or a yield of 88%, if expressed in sugar. If apple marc is treated with a thin alkali solution, we get two fractions: fibers comprising alpha-cellulose pentosanes (26%) and pectin (10–18%). Both fractions can be used for apple products as a thickener and a calorie-free texture modifier.

In civilized societies, there is a preference for refined and cleaned foodstuffs. However, consumers deprive themselves of many substances that are considered healthy. A lack of fiber, for example, would result in diseases and abnormalities, which are unknown in uncivilized societies. Nutrition scientists are researching the degree to which refined food will trigger health problems (Barta 1993). There are ongoing efforts to add back important substances, such as dietary fibers (Larrauri 1999; Miguel and Belloso 1999), coloring matters, aromas, volatile compounds, vitamins, etc. These substances have been removed or cleared during operations to purify the food for a convenient "end product." They may also be the result of a negative effect from an essential processing. However, some of such "removed" substances are very important for our health. Examples include fibers or vitamins (Ramadan and Mörsel 2003), which are added back, for health reasons or legal requirements, after removal during processing. Today, fiber products are very important dietary supplements. The indigestible parts of plant cell wall, such as cellulose and lignin, were considered as unnecessary parts of foodstuffs that decrease the energy, compositional, and sometimes even the sensory values.

The nutritional effect of dietary fiber components is due to their physical and chemical properties. The human body does not have enzymes to digest fibers. Fibers are resistant to digestion by gastric juices; only some bacterium can decompose a certain quantity. Consequently, fibers possess slight nutritive value, but they play an important role in digestion (Barta et al. 1989).

Citrus Waste Utilization

Citrus processing produces a large amount of waste materials, which can be divided into three categories: animal feed, raw material used for further extraction of valuable components, and food by-products. Dried citrus meal that is used for animal feed is probably the main waste-recovery product. The meal is produced by liming the slurry followed by pressing to remove moisture. The moisture is further reduced to about 8% using rotating dryers. This material is similar in feed value to beet pulp.

Citrus pulp consists mainly of the rag, peel, and seeds of oranges with minor amounts from other fruits. This waste usually collects on concrete slabs or in open pits at canneries.

Citrus pulp usually is used as a source of energy because of its composition. Fat and protein of citrus pulp vary with the seed content, which ranges from 1.0% to 17.7% depending upon the variety of fruit. The citrus seeds are also used efficiently. They can be used for oil extraction and also the production of a citrus seed meal for feed rations.

Citrus molasses is a good material that can be used as a feed supplement. Some work has been done on mixing sodium carbonate with waste peel and pulp materials from some citrus fruit processing operations (Braddock 1999). This treatment raises the product's pH and results in deesterification of pectin, forming a gel. Waste production is decreased in some products where a fraction of the pulp is comminuted and becomes part of a fruit-drink base. The raw material that is further extracted produces peel oils, flavonoids, and seed oil. Food items produced are brined and candied peels, marmalades, syrups, and peel products used in food seasoning. The peel juice, or press liquor, can also be utilized as a fermentable carbohydrate source for the production of feed yeast, industrial alcohol, vinegar, butylene, and lactic acid. The practical use of these products depends on the economics of the process. Waste coming from the processing of such other fruits, such as apples and pears, can also be used in the manufacture of pectin, but not as economical as from citrus (Salunkhe and Kadam 1995).

Citrus Pectin

Citrus peels and residues contain 2.5–5.5 % pectin. After the extraction of essential oil from the peel and juice from the fruit, the residue is dried. The peel is sliced and ground. The residue is washed with cold water on a sieve, and the washed material is boiled with 0.015–0.20 N hydrochloric or sulfuric acid, or with 0.025 M citric acid for 40–45 minutes. The liquid is pressed and filtered to obtain the pectin solution. This solution is then centrifuged to remove the sediment. The pectin solution is then treated with enzymes and with decolorizing carbon to obtain the pure product. The pectin solution is then concentrated, and finally pectin powder is prepared (Salunkhe and Kadam 1995).

Citrus Oils

Fresh orange peel yields about 0.54% oil by the cold-press methods. Citrus peel oil, extracted by the cold process, fetches a better price than distilled oil, which is of inferior quality.

By-products of the Citrus Industry

Citrus fruit production can be divided depending where it arises in the juice extraction process:

- Juice and juice cells, which form about 40–45% of the fruit.
- Peel (flavedo) and rag (albedo), which constitute about 45–60 % of the fruit: the flavedo contains the essential oils and carotenoid pigments; the albedo contains cellulose, pectins, and flavonoids.

Table 19.1 shows different products produced from citrus fruit. The main by-products from the endocarp, or inner part of the fruit, are juice cells and pulpwash (Salunkhe and Kadam 1995).

Table 19.1. Products of the Citrus Industry

Juice and Cells	Peel and Rag	Essential Oil
Concentrated juice	Pectin	Cold pressed oil
Juice	Cloudy concentrate	Terpenes
Premium pulp	Hesperidin	Concentrated oil
Pulpwash concentrate	Naringin	Distilled oil
Dehydrated cells	Dried peel	
Water and oil phase	Molasses	
Volatiles	Alcohol	
	Natural color	

Source: Arthey and Ashurst (2001).

Citrus Waste as Ethanol Feedstock

In the 1990s, the USDA Citrus Lab developed an ethanol production process that used the residual sugars and cellulose in citrus peel. A series of citrus-specific enzymes was developed to convert the cellulose to sugars for the fermentation process. From there, the ethanol process is similar to that used in corn-ethanol production (Anon 2008).

Peach Waste Utilization

Processing of peach results in the generation of waste in the form of peel, seeds, and trimmings, and washing water having high biological oxygen demand (BOD) and COD, see in Table 19.2.

The waste contains proteins, polysaccharides, sugar, amino acid, and pectin. Therefore, it can be processed into useful products. Nevertheless, it has to be treated to reduce BOD as per the stringent standards laid down by environmental protection agencies.

Seeds of peach also constitute waste, but due to their high protein and fat contents, they have potential for utilization, perhaps after detoxification. Agricultural residue including peach leaf litter, after pretreatment and fermentation, has proved to be a good source of methane gas. Enzymatic pretreatment of peach solid waste for ethanol production has been investigated for the utilization of the waste. However, more research is needed before it is advocated for industrial application (Salunkhe and Kadam 1995).

Table 19.2. Characteristics of Waste Generated from Processing of Peaches

Characteristics	Amount
Peach fruit processed	1100×10^3 tons
Waste water	4400×10^3 gal
Biological oxygen demand	60 lb/ton
Suspended solids	10 lb/ton
Solids residuals	500 lb

Source: Salunkhe and Kadam (1995).

Banana Waste Utilization

About 1000 banana plants are estimated to yield 20–25 tons of pseudostems, which contain about 5% edible starch, useful for sizing in the textile industry. The process for the manufacture of starch from banana pseudostem has evolved and its physicochemical properties studied. Researchers studied the utilization of banana stem waste for growing food yeast. The residual fiber portion of the stem left over after extraction of starch can be used for the preparation of paper pulp. The composition of different fruit waste is given in Table 19.3.

The central core of banana pseudostem constitutes 10–15% of stem and can be candied or crystallized into a highly acceptable product that resembles tender bamboo shoot candy. The fresh material, commonly used as a vegetable, can be canned along with potato and tomato as a curried product. After blanching and steeping in dilute citric acid solution containing a small amount of potassium metabisulfite, the slices can also be dehydrated into a fairly acceptable product. Green banana fruit, pseudostems, and foliage are suitable as animal feed. They mainly provide a source of energy and require supplementation with a protein source. Bananas are economical as a source of animal feed only where the livestocks are nearby, because of the high cost of transport. Corns, shoots, and male buds find widespread use as an animal food in Asia and Africa (Salunkhe and Kadam 1995).

NEW RESEARCH AREAS FOR FRUIT WASTE UTILIZATION

Several valuable substances—fibers, coloring agents, gelling agents—can be extracted from the wastes of fruit-based products. The utilization is determined by the economic efficiency of extraction and the market potential. It is not easy to collect data about the quantity of fruit waste and widespread treatment techniques.

The following literatures review the types of by-products, modern treatment technologies, and approaches of utilization. It does not deal with traditional methods, which can be found in standard literature:

- Fruit stones constitute a significant waste disposal problem for the fruit processing industry. High-quality activated carbon can be produced from waste cherry stones (Lussier et al. 1994).
- Fruit processing wastes including apple, cranberry, and strawberry pomace were used as substrates for polygalacturonase production by *Lentinus edodes* through solid-state fermentation (Zheng and Shetty 2000).
- Watermelon peel constitutes 44% of the whole fruit weight. In the study of Madhuri and Kamini-Devi (2003), the potential to produce preserved products such as pickles, tutti-frutti, vadiyams, and cheese using the white portion of watermelon rind was investigated.

Table 19.3. Composition of Different Parts of the Banana Waste (Per 100 g)

Waste Product	Moisture (g)	Protein (g)	Fat (g)	Minerals (g)	Fibers (g)	Carbohydrates (g)
Banana peel	79.2	0.83	0.78	2.11	1.72	5.00
Banana stem-central core	95.1	0.30	0.03	1.04	0.68	1.20
Banana stem-outer hard fibrous sheath	91.9	0.12	0.06	0.98	1.81	2.44
Banana stem-pressed juice from stem	98.6	0.05	–	0.63	–	0.41

Source: Salunkhe and Kadam (1995).

- Fruit wastes (pineapple, mixed fruit, and maosmi) were investigated as possible substrates for citric acid production by solid-state fermentation using *A. niger* (Kumar et al. 2003).
- A study was conducted by Hammond et al. (1996) to assess ethanol production potential from banana waste.
- "*Citrus junos*" is one of the important citrus fruits in Japan. The fruit juice is an ingredient used in sauces and salad dressings for its special flavor. After juice extraction, the fruit pulp is usually dumped as waste at a large cost. The manipulation of food processing wastes is now becoming a very serious environmental issue. The peel of *C. junos* fruit was found to possess potent allelopathic activity and a methanol extract of the peel inhibited the growth of several weed species (Fujihara and Shimizu 2003).
- A method is described by Drunen and Hranisavljevic (2003) for the enrichment of fruit products with beneficial substances (e.g., antioxidants) extracted from processing waste, for example, fruit peel.
- The progress is described in a project in European Union (EU) (QLKI-1999-00124) on anthocyanin bioactivities. The investigation covers the functional properties and the effects of anthocyanins and anthocyanin-rich food ingredients on heart disease. This study aims to use such compounds as colorants and in the development of new anthocyanin-rich functional foods (Anon 2002).

Nutritional Components from Sea-Fruit and Brewing Waste

UK government funded project focused on extracting value from beverage processing waste shows the process could potentially recover nutritional components such as glucosamine.

The UK-based technology development company is leading the 3-year EXCIL project that involves collaboration with key stakeholders including Heineken UK waste management firm SITA UK and Imperial College London.

The research is being funded by a UK government agency, the Technology Strategy Board, with the stated objective being to provide a new approach to solving the environmental and financial costs involved in disposal of sea-fruit and brewing waste through a sustainable and resource efficient method.

Ionic Liquids

Highly selective extraction of material from complex systems can be achieved under mild conditions using custom-designed ionic liquids, and the project hopes to allow recovery of glucosamine, chitin, and chondroitin from sea-fruit waste as well as polyphenols from brewing. This EXCIL project also aims to model sea-fruit and brewing waste streams, develop a waste extraction prototype, and then scale it up to industrial level.

These ionic liquids, which are a salt in a liquid state, have high selectivity in terms of similar compound separation. They are also nonvolatile, recyclable, environmentally benign, and economically viable on a large scale. Much research has focused on the use of ionic liquids for the separation of synthetic goods, plastics, and metals in a mixed waste stream.

The early results from this research are promising and indicate that the project's goal of being able to extract compounds such as glucosamine and chondroitin from processing waste is achievable (Byrne 2010).

Bioplastic Packaging Made from Fruit Skins

Researchers in Malaysia have developed a biodegradable plastic packaging from tropical fruit skins that is durable and economical to produce. The Fruitplast product has been pioneered at the University Sain Malaysia (USM) and made from the skins of tropical fruits such as bananas, rambutans, and chempedak. The idea to produce plastic from fruit waste came about because of the perceived potential for biodegradable plastic, which is forecasted to grow by up to 30% a year. Commercial biodegradable plastic such as polylactic acid (PLA) and polycaprolacton (PCL) that are available in the West are at least eight times as expensive as the petroleum-based, non-biodegradable plastic such as polyethylene (PE) and polypropylene (PP). This study is to produce biodegradable plastic using waste products from fruits to reduce costs but which can compete with the quality of the commercial plastics that are currently available in the market. Fruitplast is estimated to be 10% cheaper than the petroleum-based commercial plastics (PE, PP) and is able to biodegrade within

3–6 months, said the team. This innovation also has huge commercial prospects not only in Malaysia but also worldwide because it is based on the concept of sustainability, is cheap, and is excellent for the packaging industry. The durability of the plastic also has met the standards that have been determined and if it is not exposed to the elements (soil and weather). Fruitplast can remain in its original condition for up to 2 years (Harrington 2010).

ENVIRONMENTAL MANAGEMENT OF FRUIT PROCESSING COMPANIES

Environmental regulations in food industry aim to ensure that fruit processing companies plan and perform their activities in a way that is not detrimental to the environment. The following are some of the environmental management imperative:

- Improving or at least not worsening environmental conditions. Permitted levels of pollution (norms) have to be determined.
- Environmental pollution of fruit processing plants has to be controlled and measured.
- Sanctions have to be worked out against those not respecting the norms. Sanctions should provide incentives to farmers and processors to implement modern innovations, switch to environment-friendly technologies and products.
- Given environmental quality has to be achieved with the lowest social investment.

Regulation has to take into consideration that the market is nowhere perfect (it is influenced by state interventions and monopolies). Environmental regulations have to suit other economical regulating mechanisms. It has to be acceptable politically (concerning both environmental norms and sanctions against those not respecting the norms). It should be flexible to adapt to changing economic conditions. It has to be transparent: In case of too complicated regulatory systems, difficulties of enforcement worsen its effectiveness. It should gather sources to enable the establishment of financing funds for certain environmental tasks.

Two Main Forms of Environmental Regulations

- Direct or normative regulations (norm, license).
- Indirect or economic regulations (subvention, tax, mercantile license, quota system).

Environmental norms are direct interventions of authorities; thus, they are not market economic tools. Impact studies are always performed prior to the establishment of standards. Their implication is clearly justified in all cases where the goal is to decrease or cease environmental pollution that is harmful to human health. Emission licenses mean that acceptable emission levels of certain environmental indicator parameters, which were studied before, are permitted for the polluter's economical activity.

Regulatory Principles

- Maximum permitted emission (e.g., annually emitted polluting material content).
- Minimum required decrease of pollution (e.g., introduction of new processing technology).
- Determination of quality parameters for technologies (e.g., increase of fruit processing quality can only be achieved with the installation of a more modern technology).
- Referring to total production.
- Absolute amount of inputs or their relative ratio (e.g., in case of chemical fruit processing additives).

Subventions are one of the most debated economic policy measures. Based on their principles, the following investments can be differentiated: environmental, resource management, environmental development, and resource-capacity increasing.

Protection-type subventions have the strongest distorting impact on the economy. In certain cases, subventions are reasonable, such as large environmental protection investments. However, subventions supporting utilization can only enable resource exhaustion. If the state supports the costs of water, canal and energy use in consumer prices, which does not enable resource preservation but their excessive utilization. "Pseudosocial policy" measures, like artificially cheap water supply, refuse collection and energy prices, degrade the social value of resources, decrease environmental consciousness, and support everyone regardless of their social status.

On the other hand, the support of nature developing investments is necessary, since they would pay off in the long run (e.g., forest plantation). These developments create positive external impacts. Taxes are imposed, where market mechanisms do not create consensus between those that cause and those that suffer from external costs. If this happens, the state collects incomes, which limits production size to the optimum level. Taxes are proportional with the incomes or with the amount and value of products. However, product fees and penalties take the following factors into consideration: the polluting nature of the activity, amount, and hazardous nature of waste that developed after use.

There are different ways to determine tax base, which can be based upon the following:

- Pollution emission.
- Pollution indicator (e.g., the concentration of a hazardous polluting material).
- Polluting input, the use of polluting ingredients can be decreased by increasing the costs of the economic activity.

In case of nonpolluting resources, this can be used to prevent and moderate excessive use:

- Taxation of finished products and services is recommended, if production is done in more locations and more stages, which makes it difficult to determine the place and indicator of pollution.
- The use of a determined device (e.g., vehicle).

Depending on the tax base and the type of the problem, participants of economic life can show the following reactions to taxes:

- Applying new protection technologies.
- Replacing polluting inputs with less- or nonpolluting ones.
- If substitution is not possible, the amount of the polluting input is decreased by improving the efficiency of its use.
- Total change in technology.
- Change in product structure.
- Increase of reutilization.
- Moving to new plant location, where environmental regulations are less strict.

Mercantile licenses are the most market-friendly solutions. Permitted pollution levels are determined in the form of an objectively measurable parameter for a given area. This pollution level is divided up for pollution (emission) licenses, quotas, which are sold in an artificial market. Those possessing license are entitled to perform economical activity in the given region besides the permitted emission of polluting substances.

If a company declines the size of activity or the extent of emission with a protection technology, it is entitled to sell its remaining quota. This can lead to the development of secondary license market. Consequently, "polluters" operating in the given region are not permitted to exceed the quota jointly. This approach is also called Bubbles Policy.

Main Advantages of Mercantile Licenses

- Protection may be cheaper for companies than the license; thus, it can create income by selling the license; this promotes the aim of environmental politics: enhancing protection.
- By selling the license, companies can get their investment back, when they cease their activity or move into another region.
- The real economic value of licenses can be measured with market mechanisms.
- By determining and dividing permitted pollution levels, there is less uncertainty concerning the total expected pollution of the given region.

Main Environmental Principles in the Treatment of Fruit Processing Waste

Polluter Pays Principle—PPP

In order to ensure acceptable environmental conditions, the costs of decreasing the pollution are paid by the polluter.

This basically follows the Pigou's idea: If market price does not include the costs of environmental damages, then the polluter will pay the environmental external costs. The costs of pollution decrease cannot be covered by state subventions; everyone has to pay the costs of environmental measures.

There may be three basic exceptions:

- Industries, which could face difficulties without subventions.
- Economical and social problems, triggered by the introduction of the environmental program, need to be supported.
- The implementation of this principle would lead to a substantial distortion in international trade.

Environmental information directive defines that increased public access has to be created to environmental information and to the dissemination of such information, which contribute to a greater awareness of environmental matters; a free exchange of views and more effective public participation have to be created in environmental decision making.

Integrated Pollution Prevention Control (IPPC) Directive (Anon 2008) defines the establishment of a uniform procedure for authorizing agricultural and industrial activities and sets minimum requirements to be included in all permits of industrial and agricultural installations. The activity of environment polluting installations, which are under legal control, depends on the permit authorization.

The directive includes the definition of best available technologies (BAT) and the commission level setting and revise of emission limit values as well.

Worldwide Pollution Prevention and Control in Fruit Processing

Reductions in wastewater volumes up to 95% have been reported through implementation of good practices. Where possible, adopt the following measures:

- Use clean raw fruit, reducing the concentration of dirt and organics (including pesticides) in the effluent.
- Use dry methods such as vibration or air jets to clean raw fruit. Dry peeling methods reduce the effluent volume (up to 35%) and pollutant concentration (organic load reduced up to 25%).
- Separate and recirculate processed wastewaters.
- Use countercurrent systems where washing is necessary.
- Use steam instead of hot water to reduce the quantity of wastewater to be treated.
- Remove solid wastes without the use of water.

Table 19.4. Water Usage in the Fruit Processing Industry

Product Category	Water Use (cubic meters per metric ton of Product)
Canned fruit	2.5–4.0
Frozen fruit	5.0–6.0
Fruit juices	6.5
Jams	6.0
Baby food	6.0–9.0

Source: Anon (1998).

- Reuse concentrated wastewaters and solid wastes for production of by-products.

As an example, recirculation of processed water from fruit preparation reduces the organic load by 75% and water consumption by 95%. Similarly, the liquid waste load (in terms of BOD) from apple juice processing can be reduced by 80%.

Good water management should be adopted, where feasible, to achieve the levels of consumption presented in Table 19.4 (Anon 1998).

Target Pollution Loads

Implementation of cleaner production processes and pollution prevention measures can yield both economic and environmental benefits. The target loads per unit of production are shown in Table 19.5 (Anon 1998).

The data refer to the waste loads arising from the production processes before the implementation of pollution-control measures. These levels are derived from the average loads recorded in a major study of the industry and should be used as maximum levels of unit pollution in the design of new plants.

Table 19.5. Target Loads Per Unit of Production, Fruit Processing Industry

	Fruit		
Product	Waste Volume (m^3/U)	BOD (kg/U)	Solid Waste (kg/ton Product)
Apricots	29.0	15.0	
Apples			90
All products	3.7	5.0	
All except juice	5.4	6.4	
Juice	2.9	2.0	
Cranberries	5.8	2.8	10
Citrus	10.0	3.2	
Sweet cherries	7.8	9.6	
Sour cherries	12.0	17.0	
Bing cherries	20.0	22.0	
Dried fruit	13.0	12.0	
Grapefruit			
Canned	72.0	11.0	
Pressed	1.6	1.9	
Olives	38.0	44.0	20
Peaches			180
Canned	13.0	14.0	
Frozen	5.4	12.0	200
Pears	12.0	21.0	
Pineapples	13.0	10.0	
Plums	5.0	4.1	
Raisins	2.8	6.0	
Strawberries	13.0	5.3	60

Source: Anon (1998).

CONCLUSIONS

The latest research and development have resulted in new methods of modern fruit waste management solutions around the world. Biotechnological (bioconversion) procedures (e.g., aerobe composting, biogas production) are outstanding in this respect and can be successfully applied. However, in future, more extensive applications will become necessary, for example, animal feed supplementation, soil conditioning products, and ingredient production.

Ensuring environmental safety and sustainable development through fruit waste utilization aims to ensure that the development needs of the present do not compromise the needs of future generations. It is also important to emphasize that in order for fruit waste utilization to make meaningful impact on developing countries, suitable bioconversion processes need to be developed on a much wider scale, and these countries should begin to pull their meager resources and biological science expertise in a cooperative and integrated manner toward modern, advance genomics and proteomics technologies for identifying novel biological enzymes and engineering enzymes with improved activities suitable for industrial-scale application. In the near future, when global oil stocks have been depleted, cars may have to run on alcohol. Also, the health impacts of new waste management technologies and the increasing use of recycling and composting will require assessment and monitoring.

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20
Microbial Safety and Sanitation of Fruits and Fruit Products

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Abstract: In recent years, there has been an increase in outbreaks of foodborne diseases not only in the developing countries but also in the developed countries. The microbiological safety of food is a dynamic situation that depends on many factors along the food supply chain. Obviously, there is a need to understand their interactions to develop effective prevention and control strategies. This chapter covers outbreaks associated with fruits, critical control points in fruit processing, storage, transportation, and distribution, plant design and safety, effective sanitation programs, sanitation rules and regulations, sanitation chemicals, and microbial biofilms.

INTRODUCTION

In recent years, there has been an increase in outbreaks of foodborne diseases in many countries (WHO 2007). Some of these outbreaks are attributed to foodborne viruses, in particular, noroviruses (NoVs) (Baert et al. 2009). Food safety assurance and quality managers have the difficult task of enacting and observing proper procedures and quality checks to ensure safety of food products (Wilcock et al. 2011). The microbiological safety of food is a dynamic situation that depends on many factors along the food supply chain. There is a need to understand their interactions to develop effective prevention and control strategies (Newell et al. 2010). Some of the factors that have impact on food safety are global trade, socioeconomic changes, technological development, population migration to urban areas, and agricultural land use. Climate changes and variability in weather also have bearing on food safety issues (Tirado et al. 2010). Recently, microbial safety concerns have been raised for potential contamination of fresh whole, cut, and minimally processed fruits and fruit juices (FDA 2001a).

Soil, irrigation and wash water, farm workers, rodents, and other animals can be carriers for spread of pathogenic bacteria. Potential cross-contamination can occur during postharvest handling, processing, transport, and distribution (Brackett 1992). This chapter deals with the characteristics of microbial pathogens associated with fruits, hazard analysis critical control points (HACCPs), and sanitation measures necessary for lowering the incidences of food-poisoning outbreaks involving fruits.

FOODBORNE DISEASE OUTBREAKS ASSOCIATED WITH FRUITS

Fruits and fruit juices are considered relatively safe because of their low pH at which most microorganisms do not grow. However, recent foodborne disease outbreaks have shown that fruits can be carriers of pathogens (CDC 1999). About

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41% of foodborne illnesses in the United States were associated with the consumption of produce (fruits, vegetables, and juices). The outbreaks related to contaminated produce in the United States doubled between 1973–1987 and 1988–1992 (Bean and Griffin 1990; Griffiths 2000). This can be due to increased consumption of "fresh" fruits, increase in import of fruits, and improved surveillance.

Food-poisoning outbreaks are defined as "the occurrence of two or more cases of a disease transmitted by a single food." There are two exceptions, botulism and chemical poisoning in which one case constitutes an outbreak (CDC 1990).

There is little published information about human pathogens in raw and fresh-cut fruits and fruit juices. This is because of a large number of variables (sampling procedure, location of source, number/size of samples, area or portion to be tested, etc.) and lack of optimized methods for pathogen detection and isolation from fruits (FDA 2001a). Fresh whole, cut, and minimally processed fruits and juices are frequently implicated in outbreaks of bacterial food poisoning. *Clostridium botulinum*, *Staphylococcus aureus*, *Campylobacter jejuni*, *Listeria monocytogenes*, *Bacillus cereus*, *Shigella*, *Salmonella*, and *Escherichia coli* have been identified as a food safety concern for fruits. Some of these microorganisms have also been responsible for foodborne outbreaks (Beuchat 1998). Use of fruit peels (Al-Zoreky 2009); chitosan biopolymer films (Kim et al. 2011); bacteriocins (Rocha-Fleming et al. 2010) alone, or in combination with high-intensity pulsed electric fields (PEFs) (Mosqueda-Melgar et al. 2008; McNamee et al. 2010); UV irradiations (Gabriel and Nakano 2009); low concentrations of transcinnamaldehyde (Baskaran et al. 2010); grapefruit limonoids (Vikram et al. 2010); ozone treatment (Patil et al. 2009a); and dynamic high-pressure processing (Tahiri et al. 2006; Brinez et al. 2007) have been investigated as an alternative to thermal processing to inactivate these pathogens while still retaining the maximum amounts of heat-labile nutrients in fruit juices.

C. botulinum is a Gram-positive spore-forming anaerobe that grows well in the absence of oxygen (Farber 1989). The strains of *C. botulinum* can be classified according to the toxin they produce into seven groups designated A through G. *C. botulinum* types A, B, and E are responsible for botulism in humans. Botulism results from the consumption of a neurotoxin that is produced by this microorganism while growing on the food. However, the rate of botulism associated with fruits is very low compared with the foods of animal origin. This is due to the fact that most fruits are sold fresh under aerobic condition, which is not conducive for outgrowth of clostridial spores and toxins. However, safety concerns have been raised about the potential for *C. botulinum* toxin in fresh-cut packaged produce (Austin et al. 1998). The high rate of respiration of both the produce and the microorganisms could create anaerobic conditions for spore outgrowth and toxin production. Thus, it is important to package produce in a high oxygen/carbon dioxide permeable film and store at about 3°C. Larson and Johnson (1999) tested the presence of *C. botulinum* toxin in fresh-cut cantaloupe and honey dew melons artificially inoculated with *C. botulinum*, and subsequently packaged under modified atmosphere packaging and held for 9 days at 12°C.

St. aureus is another major food-poisoning microorganism frequently involved in fruit-associated foodborne illnesses. It is a Gram-positive, facultative anaerobic coccus with a temperature range from 7°C to 45°C (Farber 1989). Food products become contaminated with *St. aureus* from noses, skin, or infected lesions of field workers, handlers, and processing personnel (Bryan 1980). The microorganism is also capable of producing different heat-stable enterotoxins. These enterotoxins are high-molecular-weight proteins and are produced in the lag phase of the bacterial growth (Genigeorgis 1989). High levels of *St. aureus* in fruits indicate poor hygiene and improper storage conditions. This pathogen is a problem in the postharvest processing of fruits because of the widespread hand contact involved in sorting, packing, and repacking of fruits. Nevertheless, this microorganism is a poor competitor and does not grow well in the presence of other microorganisms normally present on fruits. Mukhopadhyay et al. (2002) reported the presence of coagulase-positive *St. aureus* in 17% of sliced papaya samples examined. The authors also reported that despite the risk associated with the presence of this pathogen, the microbiological counts (80–100 CFU/g) were not high enough for toxin production.

C. jejuni has been recognized as the most common cause of bacterial diarrheal disease in humans (Griffiths and Park 1990). It is a Gram-negative, spiral-shaped, microaerophilic bacterium that belongs to the Spirillaceae family (Farber 1989). Foods of animal origin are commonly implicated with *Campylobacter* foodborne illness. Although there are a few reported outbreaks associated with *Campylobacter* in fruits, this pathogen has been isolated from a variety of vegetables and has been shown to survive on sliced watermelon and papaya (Castillo and Escartin 1994; Beuchat 1998). The prevalence of *Campylobacter* in fresh fruits and vegetables at the retail outlets has been reported in the Netherlands and it has been suggested as a risk factor for *Campylobacter* infections if packaged raw fruits and vegetables are consumed (Verhoeff-Bakkenes et al. 2011). Since the infectious dose of *Campylobacter* is low (800 cells), intervention must be put in place to destroy any pathogenic bacteria that may be present on the raw fruit (Black et al. 1988). *C. jejuni* exposed to 20 consecutive cycles of sublethal inactivation by three different techniques, namely, lactic acid (LA), chlorine dioxide, and intense light pulses (ILP), became undetectable after first 2–5 cycles (Rajkovic et al. 2009).

L. monocytogenes is a Gram-positive, rod-shaped, motile bacterium isolated from various foods including cheese, milk, and fresh and processed meats. In accordance with other psychrotrophic bacteria, *L. monocytogenes* exhibits a wide temperature range from 1°C to 45°C with an optimum of

35–37°C (Farber 1989). Listerosis is the disease contracted by the ingestion of contaminated food. Although the minimum infectious dose is still unknown, a high number of viable cells ($>10^6$ CFU/g) are required to cause illness in healthy adults (Farber 1989). High-risk groups including pregnant women and their fetuses, the elderly, and immunocompromised individuals will show clinical symptoms of listerosis at around 10^3–10^4 CFU/g (Farber 1989). The importance of *Listeria* as a causative foodborne agent in fruit stems from the following: (i) the ubiquity of *Listeria* in the environment, (ii) the ability of the microorganism to grow in extended shelf-life refrigerated products at temperatures as low as 1°C, and (iii) high mortality rates as high as 30% (Farber and Losos 1988). Great concerns have been expressed about fruits as major vehicles of transmission of listerosis to humans. Several reports have shown that low temperature is not a hurdle to *Listeria* growth. Conway et al. (2000) reported the growth of *L. monocytogenes* in apples incubated at 5°C. Furthermore, while the pH of most fruits and fruit juices (pH <4) is in the range unsuitable for *Listeria* growth, some fruits such as watermelon (pH 5.2–5.7) and cantaloupe (pH 6.2–6.9) may serve as good substrates for *Listeria* growth. Penteado and Leitao (2004) reported low-acid fruits (melon, watermelon, and papaya) as good substrates for the growth of *L. monocytogenes* at incubation temperatures of 10°C, 20°C, and 30°C. When stored at refrigeration temperatures, the garlic cheese salad and smoked ham salad were able to support the growth of *L. monocytogenes* but shrimp-tomato salad supported the growth least (Skalina and Nikolajeva 2010). *L. monocytogenes* can grow on the peel as well as in the pulp of persimmon (*Diospyros kaki*) fruit at a temperature ranging from 10°C to 30°C, though at much slower rate, the growth is not completely inhibited (Uchima et al. 2008). The orange juice and the minimally processed orange slices can support the growth of acid-adapted cells of *L. monocytogenes* (Caggia et al. 2009). *L. monocytogenes* exposed to 20 consecutive cycles of sublethal inactivation by three different techniques, namely, LA, chlorine dioxide (ClO_2), and ILP, has been studied for change in resistance (Rajkovic et al. 2009). With repeated cycles of LA and ILP treatments (but not ClO_2), produced *L. monocytogenes* culture with higher resistance compared with the original culture. The ability of this pathogen to adapt to mild inactivation treatments would create new challenges in risk assessment and more so in hazard analysis. Canada had experienced one of the most serious outbreaks of foodborne listeriosis in 2008, which has prompted the government to change regulations related to this pathogen, under which the production facilities must implement contact surface testing for *Listeria* spp. and/or *L. monocytogenes* (Farber et al. 2011). A rapid method for the detection of *L. monocytogenes* in foods has been reported that combines the culture enrichment and real-time polymerase chain reaction (PCR) techniques, and this method is 99.44% specific, 96.15% sensitive, and 99.03% accurate than the ISO 11290-1 standard method (O'Grady et al. 2009). Kim and Cho (2010) have recently reported a simple, rapid procedure for the detection of *L. monocytogenes* in unpasteurized fruit juice using real-time PCR without the traditional enrichment culture technique. *L. monocytogenes* has been shown as one of the most PEF-resistant microorganism and it should be considered as a possible target microorganism to define process adequacy with PEF pasteurization (Saldana et al. 2010).

*Bacillus cereus*es are rod-shaped, Gram-positive spore formers that are commonly present in soil, on the surface of plant material, and in many raw and processed foods. Two distinct types of illness have been attributed to the fruits contaminated with *B. cereus*, a diarrheal and an emetic toxin. Fruits incriminated in past outbreaks include orange juice (FDA 2000). *B. cereus* can adapt to changing environments by various mechanisms, such as signal transduction systems (two-component systems, alternative factors), and the environmental factors (temperature, carbon dioxide, redox potential, and pH). The heat resistance of *B. cereus* spore is positively correlated with the sporulation temperature. As a consequence of climate changes that are taking place, surveillance is needed to detect changes in the epidemiology of *B. cereus* foodborne poisoning (Carlin et al. 2010). A new primer-probe set has been developed for the detection and quantification of spoilage and pathogenic *B. cereus* in food products by using real-time PCR technique (Fernandez-No et al. 2011).

Shigella spp. are rod-shaped, Gram-negative, facultative anaerobic bacteria that have been epidemiologically associated with foods or water contaminated with human feces. Shigellosis is the collective term used for the dysentery disease resulting from the infection by a species of *Shigella*. There are four species of *Shigella* known to cause bacillary dysentery. These include *S. dysenteriae*, *S. flexneri*, *S. boydii*, and *S. sonnei*. Shigellosis infections accounted for 3.1% of the total foodborne outbreaks reported from 1988 to 1992 in the United States with most of these outbreaks being attributed to the consumption of contaminated vegetables including parsley, lettuce, and vegetable salads (Davis et al. 1988; Dunn et al. 1995; Bean et al. 1997). The Food and Drug Administration (FDA) conducted an analysis of 151 cantaloupe samples imported to the United States from nine countries; 2% of these imports were positive for *Shigella* (FDA 2001b). This pathogen is of great concern to the fruit industry because of its low infectious dose (10 cells) (Wu et al. 2000).

Nontyphoid *Salmonella* species continue to be the most reported foodborne disease with incidence rates of 17.4 and 187 cases per 100,000 population and an estimated number of 2 million cases per year worldwide (Siliker 1982; D'Aoust 1991). *Salmonella* is a genus of the family Enterobacteriaceae that includes other genera such as *E. coli*, *Shigella*, and *Proteus*. *Salmonella* species are high-temperature mesophiles that grow at temperatures from 5.2°C to 45°C (Farber 1989). These microorganisms are ubiquitous in nature and have been isolated from several sources including irrigation water, sewage, rodents, and dust (Mackenzie and Bains 1976;

Oosterom 1991). Recently, the U.S. Environmental Protection Agency (EPA) scientific advisory board panel specifically identified *Salmonella*, *L. monocytogenes*, and *E. coli* O157:H7 as pathogens of concern for fresh produce. Furthermore, the panel recommended testing five outbreak strains in a cocktail for each pathogen when conducting challenge studies (EPA 1997). Most outbreaks of human *Salmonellosis* have been linked to fresh-cut melons (Tauxe et al. 1997). These fruits are considered as potentially hazardous foods in the FDA Food Code because of their low acidity (pH 5.2–6.7) and high water activity (0.97–0.99). Thus, according to the FDA time/temperature requirements for potentially hazardous foods, melons should be prepared under sanitary conditions and cut melons should be kept at or below 7°C and displayed no longer than 4 hours if they are not refrigerated (Golden et al. 1993). *Salmonella* have also been shown to adapt to reduced pH, and numerous outbreaks related to unpasteurized juices have also been reported (WHO 1998). *Salmonella enteritidis* can grow on the peel as well as in the pulp of persimmon (*Diospyros kaki*) fruit at a temperature ranging from 10°C to 30°C, though slowly with prolonged generation time, the growth is not completely inhibited (Rezende et al. 2009). The PCR assay has been employed successfully to identify various *Salmonella* serogroups based on specific targets obtained by comparative genomics (Liu et al. 2011). Using multiplex PCR, two species, that is, *Salmonella typhi* and *Salmonella typhimurium* have been detected simultaneously in sliced fruits being sold by the hawkers in Malaysia and the estimated quantity ranged from 0 to 19 MPN/g, thus questioning the biosafety of the sliced fruits (Pui et al. 2011). Plant molecules such as carvacrol, transcinnamaldehyde, eugenol, and β-resorcylic acid as a wash treatment could effectively be used to kill the *Salmonella* spp. on tomatoes, but more work is needed to evaluate the sensory and quality characteristics of tomatoes treated with these chemicals (Mattson et al. 2011).

E. coli are rod-shaped, Gram-negative, facultative anaerobic bacteria that are part of the microflora of the intestinal tract of humans and animals. Pathogenic *E. coli* are classified into five major groups based on their virulence properties, mechanism of pathogenicity, clinical symptoms, and antigenic characteristics (Beuchat 1998). These five groups include the following: enterotoxigenic *E. coli* (ETEC), enteroinvasive *E. coli* (EIEC), enteropathogenic *E. coli* (EPEC), enterohemorrhagic *E. coli* (EHEC), and enteroadherent *E. coli* (EAEC). The serotypes of major concern to fruits are the ETEC and EHEC. Sources and the mechanism of contamination are similar to those described for *Shigella* and *Salmonella*. *E. coli* O157:H7 has been commonly associated with outbreaks of unpasteurized apple juice (Besser et al. 1993). Although apple juice and cider are regarded as high acidic foods (pH 3–4), *E. coli* O157:H7 have shown to be acid tolerant and survive in apple juice and cider for weeks in storage (Zhao et al. 1993). *E. coli* O157:H7 has also been shown to survive in stored apple juice for up to 24 days at refrigeration temperatures (Miller and Kasper 1994). The major factor related to unpasteurized fruit juice safety is that these products receive no heat treatment. *E. coli* O157:H7 has been shown to grow on fresh and frozen-cut papayas held at 12°C and it survived for 28 days at 4°C. *E. coli* O157:H7 can survive on frozen-cut mango and papaya for at least 180 days; thus, these fruits are potential vectors for the transmission of this pathogen (Strawn and Danyluk 2010). These numerous outbreaks have led the FDA to take action to improve the safety of fresh and processed juice by requiring processors to use an inactivation step that would result in a 5-log reduction of the target pathogen or else place a warning label on their products (FDA 1998a). Using spectral features with the Fourier transform infrared spectroscopy technique, various bacterial cell components such as nucleic acids, proteins, phospholipids, peptidoglycans, and polysaccharides, from the pure and mixed cultures of *Alicyclobacillus* spp. cells and the pathogenic *E. coli* O157:H7 cells have been detected in apple juice (Al-Qadiri et al. 2006). This Fourier transform infrared spectroscopy technique has also been employed by Al-Holy et al. (2006) to discriminate *E. coli* O157:H7 ATCC 35150 from other bacteria such as *E. coli* ATCC 25522, *B. cereus* ATCC 10876, and *Listeria innocua* ATCC 51742 inoculated in the apple juice. Ultrasound has been suggested as one possible nonthermal technology to inactivate the pathogenic *E. coli* in fruit juices (Patil et al. 2009b).

Raw fruits may also harbor many nonbacterial pathogens of public health concerns including viruses and parasites. These pathogens are usually not part of the natural microflora of fresh produce and are primarily introduced by symptomatic food handlers via fecal-oral route. Secondary modes of parasite and viral transmission to produce include sewage, water-containing untreated sewage, and sludge from primary or secondary municipal water treatment facilities (Beuchat 1998). Fresh produce consumed raw or minimally processed, such as fruits and certain vegetables, can be carriers of pathogenic bacteria and viruses (Newell et al. 2010).

An increasing proportion of fruit-associated foodborne outbreaks have been recently traced to viruses. Hepatitis A virus (HAV) and the small round structured viruses (SRSVs) are the most common viral contaminants of fresh produce. Historically, HAV has been recognized as the major cause of viral foodborne outbreaks. However, more recently, SRSVs have emerged as potential pathogen in fresh produce. O'Brien et al. (2000) reported that SRSVs represented 20% of the total produce (vegetable, fruits, salads) associated outbreaks during 1992–1999 in England and Wales. Hepatitis A and SRSVs have been linked to outbreaks of strawberries and raspberries (Niu et al. 1992; CDC 1996a). Brassard et al. (2011) have developed a method for the simultaneous recovery of bacteria and viruses from contaminated water and spinach using a combination of conventional microbiology, PCR and RT-PCR. This combined method can be applied to identify the responsible agent for the foodborne illnesses. HAV is another foodborne enteric virus that has been

associated with raw fruits such as red berries (Deeboosere et al. 2010). Various RNA-extraction kits with RT-PCR or RT-qPCR are now available for the detection of HAV in food samples (Bianchi et al. 2011). NoVs are now recognized as one of the leading causes of foodborne illnesses. Although efforts have been made to culture this virus, no reliable culture method is available at this time. The detection of this virus in soft red fruits has been evaluated using molecular methods such as RT-PCR (Stals et al. 2011). Cranberry juice and cranberry proanthocyanidins have shown potential for controlling foodborne viral diseases, but their mechanism of action is not known (Su et al. 2010).

Parasites including *Giardia*, *Cryptosporidium parvum*, and *Cyclospora cayetanensis* have been historically associated with waterborne outbreaks (Rose and Slifko 1999). However, in recent years, these pathogens have also emerged as potential risk for foodborne illness and a concern to the fresh produce industry. The CDC reported that these parasites contributed to 2% of the foodborne outbreaks between 1988 and 1992 in the United States (CDC 1996b). However, these numbers could be misleading due to the limitations of improved methods for recovery and detection of parasites in foods. Contamination of fruits with parasites occurs when crop irrigation water becomes contaminated with sewage or untreated wastewater or by runoff from nonpoint sources. Thurston-Enriquez et al. (2002) studied the occurrence of *Giardia* and *Cryptosporidium* in irrigation water in the United States and several Central American countries. They reported that 60% and 36% of irrigation water samples tested positive for *Giardia* and *Cryptosporidium*, respectively. In a survey conducted in Norway, out of 475 fruit and vegetable samples examined, 6% were found to be positive for *Giardia* and *Cryptosporidium*. No *Cyclospora* were detected in any of the samples. Furthermore, water samples were also positive for those two parasites, indicating that irrigation and wash water are the sources of parasite transmission to fruits (Robertson and Gjerde 2001). Outbreaks linked to these protozoan parasites include fruit salad, apple cider, and raspberries (Tauxe et al. 1997; CDC 1997; Anon 2000). An extensive review of various methods for rapid detection of foodborne microbial pathogens in comparison with traditional methods is given by Mandal et al. (2011).

FRUIT PROCESSING

Minimally processed fruits and vegetables (fresh-cut fruits and vegetables) can provide healthier and convenient foods that are generally free of additives (Allende et al. 2006; Artes et al. 2009). Avoiding the contamination of fresh-cut fruits with foodborne pathogens till the point of consumption is extremely essential (Alegre et al. 2010a). A review covering advances for the maintenance of fresh-cut fruit quality with the use of chemical compounds, including calcium for texture improvement, plant natural antimicrobials, and antioxidants, has been published (Oms-Oliu et al. 2010). Raw and minimally processed fruits could be produced in many different ways depending on the type of fruit and the end product. For such products, the techniques most commonly used include whole fruits, fresh cut (peeled/cut/sliced into pieces), and in the form of unpasteurized juices. From a microbiological safety point of view, all critical processing factors should be controlled to minimize risks associated with the contamination of such products. In a fruit processing plant, the major sources of contamination are the plant's environment and the other fruits that transmit both spoilage and pathogenic bacteria. Thus, it is important to ensure the safety of all steps of the fruit processing operations at the plant, in addition to the cleanliness and hygiene of personnel working in the plant.

A number of preservation approaches have been suggested to extend the shelf life of minimally processed as well as the fresh fruits (Rico et al. 2007). Citrus oils (direct oil and vapor form) have been reported to inhibit both the Gram-positive and Gram-negative bacteria (Fisher and Phillips 2008). Minimally processed peaches have been shown to be good medium for the growth of foodborne pathogens, so avoiding contamination and maintaining cold chain is important (Alegre et al. 2010b). Repeated high-pressure homogenization passes at 100 MPa for apricot juice not only enhanced its viscosity but also beneficial in reducing significantly the yeast spoilage (Patrignani et al. 2009). High-pressure processing of orange juice at 600 MPa reduced the microbial load to nondetectable levels, without affecting quality (Bull et al. 2004). A combination of infrared radiation heating with ultraviolet irradiation has been found to be effective for the surface decontamination of fig fruits (Hamanaka et al. 2011). The occurrence of patulin (a mycotoxin) in apple products is a worldwide problem. During the processing of apple puree, various steps such as homogenization, pulping, and pasteurization reduced the patulin levels from 29% to 80% of the original content (Janotova et al. 2011). In case of organic table grapes, the use of sulfur dioxide fumigation to control *Botrytis cinerea* Pers. that causes gray mold is not permitted. As an alternative, fumigation with high concentration of ozone has been shown to reduce the incidence of gray mold during postharvest storage by 50–65% (Gabler et al. 2010). Use of ozone gas has also been recommended for disinfecting processing equipment and storage rooms before the storage of table grapes to control the growth of postharvest pathogenic fungi on fruits (Ozkan et al. 2011).

The deterioration of minimally processed fruits is a complex process involving physicochemical and biochemical changes as well as microbial spoilage. Various chemicals such as *N*-acetyl-L-cysteine, glutathione, calcium lactate, and D-L-malic acid have been suggested for extending the shelf life of fresh-cut apples (Raybaudi-Massilia et al. 2007). Microwave heating of Granny Smith apple puree has been shown to reduce the pathogenic microorganisms in the finished product (Picouet et al. 2009). Edible coatings based on hydroxypropylmethylecellulose (HPMC) and ethanolic

extract of propolis have been developed and applied to table grapes for extending their shelf life. The HPMC-coated product provided health advantages to the consumers due to the beneficial properties of propolis (Pastor et al. 2011). Edible coatings based on water-soluble chitosan, calcium caseinate, and sodium alginate when applied to fresh blueberries with appropriate containers, proper method of applying, extended the shelf-life quality under commercial storage conditions (Duan et al. 2011). The use of a culture of probiotic *Lactobacillus rhamonosus* GG on the minimally processed apples was capable of reducing the growth of *L. monocytogenes*, but the shelf life was limited to 14 days at 5°C to obtain the probiotic effect (Alegre et al., 2011).

Critical Control Points in Fruit Processing

The microbial food safety has emerged as one of the most important concerns for the food industry worldwide. Food safety management system (FSMS) implemented in food industry is based on the good hygienic practices (GHPs) and the HACCP in order to guarantee food safety for the consumers. Jacxsens et al. (2009) have developed a microbial assessment scheme (MAS) as a tool for a systematic analysis of microbial counts in order to evaluate the current microbial performance of an implemented FSMS. Janevska et al. (2010) have described the elements of practical implementation and operation of the HACCP system combined with quantitative microbial risk assessment (QMRA) as well as shelf life predictor (SLP). Critical control points (CCPs) are defined as the location, practice, processing step, or procedure where control must be exercised to prevent one or more of the identified hazards (Baird Parker 1987). This concept underlies the HACCP system. This system provides a structure for anticipating foodborne, microbiological, chemical, and physical hazards depending on their associated risk and on effective measures to prevent these hazards from occurring (Notermans et al. 1994). Since HACCP is regarded as an internationally accepted standard for food safety, regulatory agencies in several countries have recognized the importance of implementing HACCP system in their operations. Various countries have already implemented mandatory HACCP in federally regulated food sectors such as meat and the seafood industry and now require that other products such as fruits be produced under HACCP system. Thus, the industry with the aid of government agencies has taken numerous steps to develop and implement HACCP programs for fruit processing by developing guides to improve the preharvest and postharvest operations. In 1998, the FDA in collaboration with the food industry issued guidance for the industry "*Guide to Minimize Food Safety Hazards for Fresh Fruits and Vegetables*" (FDA 1998b). This guide covers areas such as good agricultural practices (GAPs), good manufacturing practices (GMPs), water quality, manure management, workers training in field and facility, sanitation, and transport. The US industry has also provided farm and processing personnel with codes of practices to improve the washing, handling, distribution, and storage of fruits such as the melon quality assurance program, the strawberry assurance program (US Department of Health 1993; California Strawberry Commission 1997), and the "*Food Safety Guidelines for the Fresh-Cut Produce Industry*" (IFPA 2001). Internationally, the World Health Organization issued a report on surface decontamination of fruits and vegetables that can be eaten raw (WHO 1998).

The first step toward developing an HACCP program for a process is to identify the risks associated with each operation in the process. Because microbial hazards are of major concern in the fruit processing industry, the identification of hazards involves a list of pathogenic bacteria associated with the particular product; the possible sources of contamination; and growth, survival, and death of these microorganisms during processing (Pierson and Corlett 1992). These CCPs must be known before the implementation of additional hygienic practices in the production process. Because raw and fresh-cut fruits usually receive no or a small degree of processing (i.e., no harsh treatment), contamination of fruits can occur. The most important stages to monitor include (i) primary production and harvesting of the fruit; (ii) washing stage; (iii) mechanical operation; and (iv) storage, transport, and distribution.

The primary production and harvesting stage is a crucial stage for limiting the contamination of fruits in the processing plant. Fruits are frequently in contact with the soil that contains a considerable amount of microorganisms, dirt, dust, and feces. Foodborne pathogens such as *C. botulinum*, *B. cereus*, and *L. monocytogenes* are all normal inhabitants of the soil, whereas *Salmonella*, *Shigella*, *E. coli*, and *C. jejuni* could contaminate fruits through contact with the feces, sewage, or irrigation water. Insects, birds, and dust can act as vectors for human pathogens, especially on bruised or injured fruits (Beuchat 1996). Houseflies have been shown to harbor different pathogens (Olsen 1998). Janisiewicz et al. (1999) have also demonstrated that fruit flies carrying a fluorescent-tagged nonpathogenic strain of *E. coli* O157:H7 transmitted the microorganism to apple wounds after 48-hour exposure of the apples to the flies. Another serious worldwide problem is that of increasing antimicrobial resistance, including multidrug resistant microorganisms being transmitted through the food chain (Mozina et al. 2011). Among these, Campylobacteriosis is the leading bacterial foodborne illness reported frequently in humans. Innovative molecular-biological methods provide opportunities for detection of foodborne pathogenic microorganisms in foods produced commercially with fast and reliable technologies (Rossmanith and Wagner 2011). Ensuring the safety of the fruits at the preharvest stage is a very crucial for limiting the presence of pathogenic bacteria on fruits. Once present, these pathogenic microorganisms can be established in the plant and serve as a source of cross-contamination for incoming products that enter the processing line.

Sorting and First Wash Inspection

Most fruit processors depend on wash water sanitizers to lower the microbial load on the produce to improve quality and shelf life (Gil et al. 2009). Treatment of fruits and vegetables with ionizing radiations has been suggested as an alternative to reduce microbial load, but the consumers are still very reluctant to accept irradiated foods (Farkas and Mohacsi-Farkas 2011). Following harvesting, the preparation of fruits for processing involves reducing and/or eliminating external contamination by visual inspection and sorting of the incoming fruits (color, size, maturity), the removal of decayed and/or injured fruits, and packing into containers. Direct hand contact is a common practice during inspection and sorting. In a 1999 survey of production in the United States, 93% of farms that grew fruits harvested fruits by hands (USDA 2001). Furthermore, about 50% of fruit packers only require their employees to wear gloves (USDA 2001). Hand contact of fruits is a problem due to the potential risk of cross-contamination from infected food handlers. Thus, it is necessary to ensure the cleanliness of workers' hands by implementing proper hand-washing techniques or the wearing of gloves.

Containers used to pack whole fruits from the field to the packinghouse and/or processing plant are another sources of microbial contamination. Fruits are usually packed using one container (bags, bins, wooden boxes, buckets, etc.) or exposed to a variety of containers during the postharvest operation. Most of these containers are stored for a long period of time prior to use and are often reused and difficult to clean. Thus, it is necessary to ensure that containers are washed and disinfected regularly to remove gross foreign residue, bird droppings, and rodent nests.

Initial washing of fruits with clean potable water is the next step to remove plant debris, pesticide residues, decomposed products, other extraneous matter, and bacteria. Washing fruits in water will remove the field heat, thereby maintaining its quality and shelf life. Washing of fruits such as strawberries and grapes will impair their quality; therefore, other treatments such as dry cleaning, brushing air blowers, and vacuum have been proposed for their decontamination. For most fruits, the selection of wash equipment depends on the characteristic of the fruit. Soft fruits are washed on conveyer belts using water sprayers. Solid fruits are washed in flume water, while root crops are washed using oscillating brushes. In all cases, the water used for washing should be replaced daily to prevent the buildup of organic material and prevent cross-contamination to other fruits.

The washing stage presents the earliest opportunities for cross-contamination. This is typically the case for fresh-cut and unpasteurized fruit juices (apple cider, orange juice) because external contamination of the skin would be spread to the edible part of the fruit during processing or to other processing equipment. Various reports have demonstrated wash water as the source of pathogen contamination in minimally processed fruits and fruit juices. An outbreak of mangoes was associated with an outbreak containing *Salmonella newport* from wash water during postharvest handling (Sivapalasingam et al. 2003). Similarly, orange juice was linked to *S. typhimurium* originated from wash water that contaminated the peel (Bates 1999). The temperature of the wash water plays an important role in the internalization of pathogens. A common practice of the fruit industry is to wash fruits with cold water to reduce the respiration rate of the fruit and maintain its quality. Merker et al. (1999) reported that potential internalization of pathogens from contaminated water in intact oranges and grapefruit most often occurred when the warm fruits were placed into cold water, so that the resulting pressure differential favors the uptake and internalization of the pathogen into the fruit. Similar results were observed by Buchanan et al. (1999) who reported the internalization of *E. coli* O157:H7 when warm apples were dipped into cold peptone water. Thus, it is recommended that prewashing be conducted at temperatures 10°C above the temperature of the fruit. One method to do that is to use an initial air-cooling step prior to washing to minimize the temperature differential between the fruit and the wash water. Subsequent washing can be conducted in cold water to remove field heat and maintain quality (FSAI 2001). Therefore, the use of sanitary potable pathogen-free water for washing of the rind or surface of the fruit before processing is a critical point in juice processing. The adaptation, modification, and use of ultrasonic technology and devices for testing the material properties of fresh fruits and vegetable tissues, in both the pre- and postharvest applications, has recently been reviewed by Mizrach (2008). It covers the procedures for data processing and correlating the measurements of ultrasound parameters with the important quality indices of fruits and vegetables during various pre- and postharvest operations.

Sanitizers in Fruit Washing

The efficacy of washing and sanitizing treatments to reduce the microbial load on fresh fruits and vegetables has been investigated extensively. Some of these findings are not very useful for the industry because of the extreme doses, use of unauthorized substances, and excessive washing times used (Zhang et al. 2009). A well-documented comparison of various sanitation techniques has been compiled as food safety guidelines for the fresh-cut produce industry (IFPA 2001) and through the Forum on Washing and Decontamination of Fresh Produce (CCFRA 2002–2008). Ölmez and Kretzschmar (2009) have reviewed the efficiency of various chemical and physical methods for achieving the microbiological safety of fresh produce.

Various forms of washing techniques have been adopted by the industry; these include the use of sprays to wash off microorganisms from fruits and prevent risks of recontamination. Another approach uses a double wash technique that involves a preliminary wash treatment to remove field

heat, excess soil, and dirt followed by a more efficient washing/dipping that includes water containing an approved sanitizer for dipping/rinsing application. These sanitizers will only prevent the wash water from being a cross-contaminant to fruit processing. Several researchers have reported that sanitizer washing may enhance the growth of pathogenic microorganisms on fruits, particularly when these products are temperature abused or mishandled after disinfection (Bennik et al. 1996). This is mainly because pathogens hide in cracks and crevices of the fruit and are often protected while the competing epiphytic bacteria are more accessible to sanitizers.

Chlorine-based sanitizers, especially sodium hypochlorite, are the most commonly used chemical sanitizers allowed for the disinfection of fruits (Beuchat et al. 1998). Sodium hypochlorite is allowed at a maximum concentration of 0.2% (2000 ppm) in wash water. However, water containing 50–2000 ppm of chlorine is widely used to sanitize fruits. For example, a concentration of 50–200 ppm of available chlorine is usually used for pome fruits, while a higher concentration of 50–1000 ppm is used for melons and watermelons (Soliva-Fortuny and Martin-Belloso 2003). Residual chlorine on the fruit surface should then be rinsed by potable water after the chlorination treatment and only a residual concentration of 2–7 ppm of chlorine is accepted in the washed fruits. The effect of chlorine dioxide on controlling foodborne pathogens, fungi on blueberries, has been studied by Wu and Kim (2007). According to them, about 15 ppm of chlorine dioxide (ClO_2) was very effective against *St. aureus*, *S. typhimurium*, *Yersinia enterocolitica*, and natural yeasts and molds, but the concentration of ClO_2 decreased over time due to exposure to blueberries. Similar results have been reported by Mahmoud et al. (2007) for the use of ClO_2 against yeast, molds, *E. coli* O157:H7, *L. monocytogenes*, and *Salmonella enterica* on strawberries. Fogging of figs with ClO_2 reduced the total microorganisms, fungal, and bacterial populations during storage without adversely affecting the visual quality and taste of fruit (Karabulut et al. 2009). To avoid the undesirable by-products from chlorine disinfection in fresh-cut apples, many alternative compounds such as carvacrol, vanillin, peroxyacetic acid, hydrogen peroxide, *N*-acetyl-L-cysteine, and Citrox have been used to reduce the *E. coli* O157:H7, *Salmonella* spp., and *Listeria* spp. (Abadias et al. 2011). Among these chemicals, peroxyacetic acid, hydrogen peroxide, and *N*-acetyl-L-cysteine have been suggested as the potential disinfectants for the fresh fruit industry; however, their effect on sensory quality and effectiveness under commercial processing conditions need to be investigated. The effectiveness of most chlorine-based sanitizers is influenced by several factors such as pH, temperature, exposure time, type of pathogen, and the surface morphology of the fruit (FDA 2001a). Hypochlorous acid (HOCl) is formed when these chlorine compounds are mixed with water. The antimicrobial action of chlorine-based sanitizers is due to the formation of HOCl in solution, which is a measure of the available chlorine responsible for the inactivation of microorganisms. At pH 5, nearly all of chlorine is in the form of HOCl; however, at pH 7, 75% of the chlorine is in the form of HOCl. Therefore, the wash water should always be kept at pH 6.0–7.5 for optimum chlorine effect. Furthermore, chlorine-based sanitizers are more effective at low temperatures. Maximum solubility of chlorine in water is achieved at low temperature ($\sim 4^{\circ}C$). However, to prevent microbial infiltration due to temperature-generated pressure differential, the process water is always kept $10^{\circ}C$ higher than that of the fruit. The exposure time is mainly dependent on the product. For some products, long exposure time will have a dramatic impact on the organoleptic quality of the fruit product. Hypochlorites also have different effects on different microorganisms. For example, *L. monocytogenes* are more resistant to chlorine than *E. coli*, *Shigella*, and *Salmonella* (Beuchat 1998). In addition, *L. monocytogenes* will grow better on postchlorine disinfected produce compared with nondisinfected water-rinsed produce (Bennik et al. 1996). The surface of the fruit plays a major role on the effectiveness of the chlorine-based sanitizers. The presence of crevices, creases, pockets, and natural openings in the skin will ultimately reduce the accessibility of chlorine to reach the target pathogens. Pao et al. (1999) reported that immersing inoculated oranges in hot water using 200 ppm chlorine was effective at reducing *E. coli* population by more than 2 logs CFU/cm^2 on the surface of the fruit. However, only 1-log reduction was achieved on the stem scar. Du et al. (2002) reported that treatment with 4 ppm ClO_2 gas resulted in a 5.5-log reduction in *L. monocytogenes* on the skin surface of apples and a 3-log reduction on the stem and calyx cavities. Furthermore, the natural waxy cuticles, which are a barrier to microbial presence on the surface, removed after brushing of hardy fruits are usually replaced by commercial waxes after washing. Kenney et al. (2001) have reported that microorganisms can become enmeshed in the waxy cuticle, making their removal more difficult and thus reducing the effectiveness of chlorine.

Sanitation of fruits with chlorine has shown to have a limited effect at reducing microbial loads. Produce may contain up to 10^6 CFU/g and only 1–2-log reduction is achieved by washing with chlorine (Farber et al. 1998). Parasites and viruses generally exhibit higher resistant to chlorine than bacteria. Several decontamination procedures have been introduced including hot water sanitization, rinsing with organic acids, hydrogen peroxide, irradiation, and ultraviolet radiation (Beuchat 1998; Yuan et al. 2004).

Hot water sanitization has been investigated for various fruits including apples, cherries, lemon, mango, melons, and pears to control insect and plant pathogens (FDA 2001a, 2001b). This treatment has been mainly proposed for fresh-cut fruits and juices where the outer surface of the fruit is removed due to the unacceptable sensory impact of hot water

on intact fruits (Pao and Davis 1999). However, FDA rule 21 CFR part 101.95 (CFR 2000a) considers thermally treated produce as not "fresh."

Organic acids have been one of the most effective treatment methods for the inhibition of pathogens. These acids have been used successfully in spray washing, rinsing, and dipping application for the decontamination of meat/poultry carcasses. These acids include acetic acid, malic acid, sorbic acid, LA, and citric acid. These acids are "generally regarded as safe" (GRAS) food additives and are present naturally in various fruits. These acids act by lowering the pH of the food. In their undissociated form, the acids penetrate the bacterial cell, releasing hydrogen ions, and thus eliminating the proton gradient across the cell membrane. Therefore, they are more effective at acidic pH levels. Several reports have shown the inhibitory effects of organic acids on various pathogens. Treatment of citric acid reduced populations of *S. typhi* inoculated onto cubes of papaya and jacana (Fernandez Escartin et al. 1989). Application of acetic acid (5% for 2 minutes) resulted in more than 3-log reduction of *E. coli* O157:H7 inoculated onto the surface of apples (Wright et al. 2000). Park and Beuchat (1999) showed that a concentration of 40–80 ppm of peracetic acid significantly reduced *Salmonella* and *E. coli* O157:H7 inoculated onto cantaloupe and honeydew melons.

Hydrogen peroxide has been recommended as a replacement to chlorine (Sapers and Simmons 1998). The use of hydrogen peroxide has been recommended for sanitation of fresh-cut melon and cantaloupe fruits. Residual hydrogen peroxide is removed by the action of endogenous catalase or by rinsing with potable water (Soliva-Fortuny and Martin-Belloso 2003). Unfortunately, the application of hydrogen peroxide has shown to have negative effect on strawberries, raspberries, and black berries by causing bleaching of the anthocyanin pigments.

Treatment of fruits with low doses of ionized radiations has been very effective in reducing the number of foodborne pathogens and in extending its shelf life while maintaining the products' nutritive and sensory qualities (Thayer and Reykowski 1999). Food irradiation is currently approved for certain plant and animal products in over 30 countries. In the United States, as an example, products cleared for irradiation include wheat and wheat flour, potatoes, spices and dry vegetable seasonings, dry or dehydrated enzyme preparations, shell eggs, meat, poultry, pork carcasses, and fresh fruits (Morehouse 2001). This process involves exposing the food to an energy source in the form of gamma rays, X-rays, or a beam of high-energy electrons. These rays penetrate the product, damaging the genetic material of all living cells including bacteria, so they cannot survive or multiply (Morehouse 2001).

Irradiation at doses up to 1 kilo gray (kGy) has been shown to be sufficient to eliminate most foodborne pathogens found on fruits (Howard and Gonzalez 2001). However, higher doses (>1 kGy) required to inactivate spores, viruses, and parasites caused sensory defects and/or accelerated senescence (Kader 1986). Only strawberries have shown to withstand higher doses of irradiation and maintain their quality attributes. However, fruits treated at doses higher than 1 kGy cannot be termed as "fresh" according to the Code of Federal Regulation (CFR 2000a). Although this technology produces a microbiologically safe product, consumers' objection to irradiated foods may limit the commercial application of this technology and sale of irradiated fruits.

In addition to the aforementioned antimicrobial agents, novel treatments have been tested and in some instances, approved for dipping application. These include electrolyzed water, ozone, acidified sodium chlorite (ASC), ultraviolet energy, and natural aroma compounds.

Recently, electrolyzed oxidizing (EO) water has emerged as a potential process proposed as an alternative to chlorination to eliminate or substantially reduce bacterial population. EO water is prepared by electrolysis of a dilute salt solution (NaCl) in an electrolysis chamber to produce an acidic fraction and a basic fraction. The acidic fraction of the EO water has shown to be effective in inactivating various foodborne pathogens including *Salmonella*, *L. monocytogenes*, and *E. coli* O157:H7 (Venkitanarayanan et al. 1999; Kim et al. 2000). The antimicrobial effectiveness of acidic EO water is due to its high oxidative-reduction potential (1100 mV), its low pH (pH 2.7), and its production of HOCl. Information on the utilization of EO as a disinfectant for fruits is limited. EO water has several advantages over other processes such as (i) it requires only pure water and sodium chloride to produce EO water, no adverse hazardous chemicals required; (ii) it is produced onsite and on demand with no dilution from concentrated chemicals; and (iii) it has less potential hazard to workers due to lack of need to handle concentrated chemicals for microbial inactivation (Park et al. 2002).

Ozone is a bluish water-soluble gas that has long been used to disinfect, detoxify, and deodorize water in water-treatment plants. Ozone is initially generated by passing air or oxygen through a small chamber charged with high-voltage electricity that converts oxygen (O_2) into ozone (O_3). The water-soluble gas is then bubbled into water, pressurized, and sprayed. Ozone has shown to be an excellent alternative to chlorinated water for materials, equipments, and facilitate cleaning in various process operations because of its superior oxidative potential and low toxicity. Furthermore, since ozone is produced onsite, it requires no storage area (Beuchat 1998). The use of ozone as an alternative to chlorine for the cleaning and disinfection activities in the food industry (Pascual et al. 2007), for the inactivation of acid stressed *L. monocytogenes* and *L. innocua* in orange juice (Patil et al. 2010), and the use of peroxyacetic acid as an alternative to chlorine for reducing microbial load on fresh-cut vegetables (Vandekinderen et al. 2009), bacteriocins (enterocins) for the control of *L. monocytogenes* (Khan et al. 2010), and nanocomposite packaging containing Ag and ZnO for

the inactivation of *Lactobacillus plantarum* in orange juice (Emamifar et al. 2011) has also been investigated.

But the application of ozone for fruit processing is yet another process that is being reevaluated. Recently, an expert panel in the United States affirmed the GRAS status of ozone to be used as a disinfectant or sanitizer in food processing plants (Kim et al. 1999). Bacteria, mold, yeast, and viruses all have been shown to be sensitive to ozone. The biocidal effect of ozone is caused by its high oxidative potential. The antimicrobial effect of ozone is a result of a number of factors including changes in cellular morphology, genetic mechanism, and biochemical reactions (Kim et al. 1999). Several researchers have examined the use of ozone to inactivate microorganisms and to extend the shelf life of various food products. Ozonated water at a concentration of 20 ppm was effective against *S. typhimurium*, *St. aureus*, *L. monocytogenes*, and *Y. enterocolitica* (Restaino et al. 1995). Ozone treatment has been effective for shelf-life extension of oranges, grapes, raspberries, apples, and pears (Beuchat 1998). Dipping apples and strawberries into ozonated water solution (3 ppm) decreased the number of viable *E. coli* O157:H7 and *L. monocytogenes* cells by about 5.6 $\log_{10}$ CFU/g without adversely affecting the sensory qualities of the inoculated apples and strawberries (Rodgers et al. 2004). Disadvantages of ozone use in fruit processing plants include its corrosiveness and concerns regarding workers safety (Howard and Gonzalez 2001).

ASC has long been used as a sterilant for nonporous surfaces and devices in the medical and pharmaceutical industries, as a disinfectant in automobiles air conditioning systems, and as a skin antiseptic in the dairy industry (Kemp et al. 2000). ASC is prepared by mixing an aqueous solution of sodium chlorite with a GRAS acid, usually citric or phosphoric acid. ASC has been approved by the FDA as a pretreatment for raw agricultural commodities or after mechanical operation. The FDA has also approved its use as a dip or spray at a concentration between 500 and 1200 ppm (CFR 2000c). The antimicrobial action of ASC is due to sodium chlorite acidification which when applied to organic matter will produce oxycholorous antimicrobial intermediates (Gordon et al. 1972). These intermediates cause a disruption of oxidative bonds on the cell membrane surface of bacteria (Kross 1984). Park and Beuchat (1999) studied the effect of sodium chlorite on cantaloupe, honeydew melon, and asparagus spears artificially inoculated with *Salmonella*. They reported approximately 3-log reduction following a 5-second exposure to 1200 ppm of ACS.

Ultraviolet energy at a wavelength of 200–280 nm (UVC) is also a promising sanitizer for intact and processed fruits, although it has not been approved for use by the FDA. The antimicrobial action of UVC is due to the penetration of the cell membrane and damaging the DNA and preventing cell replication (Shafiur 1999). Yuan et al. (2004) reported a 3.3-log reduction in *E. coli* O157:H7 on apples after UVC exposure at 24 mW/cm^2. Yuan et al. (2004) reported that UVC has great potential in fruit processing applications because it leaves no residues and is noncorrosive to equipment.

Another promising decontamination treatment of fruits relies on the use of natural essential oils and aroma compounds present in fruits. The primary target of these compounds is the cytoplasmic membrane of sensitive cells, whereby they will disrupt the proton motif force of the sensitive cell and inhibit all energy-dependent cellular processes leading to cell death. Although most of these compounds are GRAS, their use has been often limited because of their detrimental effect on the organoleptic quality of the fruits (Lanciotti et al. 2004).

Mechanical Operations

Several studies have shown that mechanical operations such as cutting, slicing, and peeling play an important role in cross-contamination of the finished product (Brackett 1987; Garg et al. 1990). Fresh-cut fruits are a highly perishable product due to their limited shelf life (5–7 days), high a_w (a_w >0.85), and nutrient content (Soliva-Fortuny and Martin-Belloso 2003). Mechanical operations for minimally processed fruits will provide a source of nutrients for the pathogens as a result of the removal of the protective layer of the fruits or damage to its natural structure (punctures, wounds, cuts). A number of bacteria have the ability to form biofilms on the surface of various food processing equipments, from where these can contaminate the food products. Superior sanitation of food processing plant and equipments is, therefore, a critical component of any successful food processing operations (Scheffler 2009). Use of pulsed UV light has been suggested to be an excellent alternative for the inactivation of foodborne viruses (HAV and NoV) on food-handling surfaces (Jean et al. 2011). *L. monocytogenes* has the ability to adhere to the surfaces of food processing equipments (such as stainless steel, rubber, glass, and polypropylene) and grow there in a biofilm that can survive cleaning and sanitation processes. Chlorine dioxide has been suggested as a very effective sanitizing agent for reducing the counts of *L. monocytogenes* on stainless steel surfaces (Vaid et al. 2010). This bacterium under acid tolerance response (ATR) has the ability to attach on to stainless steel surfaces under low pH conditions, and the ATR of these bacterial cells should be carefully considered when applying acidic sanitation strategies to eliminate *L. monocytogenes* attached to food processing and handling equipments (Chorianopoulos et al. 2011a). The photolytic activity of titanium dioxide (TiO_2) as an alternative means to disinfect *L. monocytogenes* biofilms in food processing equipments has also been investigated by Chorianopoulos et al. (2011b). These authors have also suggested the use of an innovative combination of nanostructured titania and UV irradiation to eliminate *L. monocytogenes* from food equipment surfaces to enhance the food safety as well as to save time and money.

STORAGE, TRANSPORT, AND DISTRIBUTION

Storage and transport are the last stage where the risk of microbial contamination may occur. Once processed, fruits are usually kept for a short period of time prior to transportation. Temperature abuse and cross-contamination as a result of mishandling are fairly common at all stages of storage and transport, and pose a major threat to the safety of these products (Brackett 1992). This is because the safety of these products relies primarily on refrigeration, in addition to the long-term effect of the wash water sanitizer. Optimum temperature for storage and transportation of fruits depends greatly on the respiration rate of the fruit and resistance to chill and freezing injury (FDA 2001a, 2001b). In most cases, a temperature between 1°C and 3°C is regarded as a hurdle to pathogen growth. Minimally processed fruits are usually stored at lower temperatures, preferably 0°C for quality retention (FSAI 2001; FDA 2001a).

Vehicles for transporting fruits should be clean and properly refrigerated. Workers involved in loading and unloading of fruits should be trained on proper hand-washing techniques. Containers and storage facilities should be cleaned, sanitized regularly, and secured from rodents and insects. Thus, truck sanitation and temperature management are critical points during storage, transport, and distribution of fresh fruits (FDA 2001a).

Therefore, an effective traceability and accountability system during storage transport and distribution of food including fruits and vegetables have become a key requirement in most food standards and legislations. In addition, most countries state that ensuring the safety of fruits and vegetables lies within the responsibilities of the food processors and operators (Johannessen and Cudjoe 2009).

PLANT DESIGN AND SAFETY

Processing plants with a poor hygienic design and practices may result in the contamination of final product. Thus, most food processors are now adhering to GMP in their processing operation. In the United States, the FDA code of federal regulation 21 CFR part 110 (CFR 2000b) covers all aspects of a safe and sanitary processing environment. These GMPs include the overall design of the processing plant, construction material selection, processing facilities, water, air, traffic flow, sanitary facilities, water quality program, storage, and distribution.

Location of Processing Plant

The location of the fruit processing plant has an impact on plant sanitation (CFIA 2000). Fruit processing plants should be located in areas away from physical, chemical, or microbial hazards such as industrial activities or environmentally polluted areas (waste disposal areas or areas prone to pest infestation).

Design of Processing Plant

Fruit processing plants should be designed and constructed to minimize contamination, ease of cleaning, and sanitation. A well-designed fruit processing plant should be constructed so that the product flow is "linear" by segregating raw product areas from processing areas and finished product areas to avoid cross-contamination (FDA 2001a). This is a recommended practice especially for minimally processed fruits. Personnel working in such areas are segregated within their area and excluded from entering other areas. In a similar manner to the overall design of the processing facilities, the process water, waste streams, and airflow should be countercurrent to the product flow (FDA 2001a).

Exterior surfaces such as floors, walls, and ceilings should be constructed of approved food grade materials, which are smooth, impervious, and easily cleaned. These surfaces should be constructed in a way to prevent or attract soils, pests, insects, and microorganisms. All floors should be constructed with a slight slope to prevent water accumulation and allow adequate drainage and cleaning. Surfaces that are in direct contact with fruits should be relatively inert to the fruits and nonabsorbent (Schmidt 1997a; FDA 2001a).

The processing facilities should also be designed and constructed to deter the entrance of airborne pathogens and pests (rodents/birds). Ventilation systems should be adequate in a sense that a continuous positive air pressure should be maintained in the production area. In addition, adequate filtration of air entering the processing area using close fitting screens or filters to reduce airborne contamination should always be considered (Schmidt 1997a).

All equipment that comes in direct contact with the fruit should be of stainless steel or plastic because these materials are easily maintained, cleaned, and sanitized. Complex equipments that are not easy to open and dismantle have shown to be a potential source of microbial contamination (Aarnisalo et al. 2006). In particular, this equipment should be designed to have a minimum number of pockets, crevices to prevent bacterial attachment, and biofilm formation, and should not have any loose bolts/knobs or movable parts that may accidentally fall off and contaminate the final product (Marriott 1999a).

Separate storage facilities should be designed for incoming fruits, finished products, and nonfood chemicals (cleaners, sanitizers, etc.) to prevent the risk of cross-contamination. A separate facility should also be considered for the sanitary storage of waste and inedible material prior to their removal from the plant or surroundings (Marriott 1999a).

The sanitary facilities should be designed to be separate from the processing and finished product area. Such facilities should be provided with self-closed doors to prevent the risk of cross-contamination (Marriott 1999a).

The hand-washing facilities should be equipped with a sufficient number of hand-washing sinks, with hot and cold potable water, soap, sanitary hand-drying supplies or devices. It is also imperative that hand-washing sinks should be located adjacent to the toilets to encourage personnel to wash their hands after going to the toilet and should be separate from sinks used for equipment cleaning and other operations (Marriott 1999a).

A potable pathogen-free water supply is crucial for sanitary fruit processing, since water has been demonstrated to be a vector for pathogen transmission to raw/processed fruits. Compliance with appropriate regulations and standards must be verified through testing programs. Water treatments (chlorination, ozonation, filtration) should be routinely monitored by continuous confirmation of the chlorine/ozone concentrations and by the periodic analysis of water to ensure that the water source meets the recognized microbiological criteria for potable water (CFIA 2000).

EFFECTIVENESS OF SANITATION PROGRAM

In general, the facilities and various product and nonproduct contact surfaces and equipment must be evaluated to assess the effectiveness of the sanitation program in place. This is usually carried out by visual inspection and microbiological testing. Visual inspection is usually conducted with the aid of a sanitation evaluation sheet whereby the inspector/sanitarian will use a numerical rating system for each area in the processing plant. Microbiological testing will include swabs and contact plates from processing equipment surfaces and personnel to assess the overall sanitation in the process environment and then the results of such testing are measured against microbiological criteria set by the industry itself, enforcement agencies, or international committees (FSAI 2001). As an example, surface hygiene standards for spoilage bacteria on food contact surfaces have recently been established for food processing plants applying HACCPs–total quality management systems (Lehto et al. 2011).

Sanitation Rules and Regulations

The term *sanitize* for food contact surface is defined as "to adequately treat food contact surfaces by a process that is effective in destroying vegetative cells of microorganisms of public health significance" (CFR 2000b).

Regulatory Considerations for Sanitizer Use

The major regulatory issues concerning chemical sanitizers are their antimicrobial efficacy, the safety of residues on food contact surfaces, and environmental safety (Schmidt 1997b). In the United States, the regulation of chemical sanitizers and antimicrobial agents for use on food and food contact surfaces, and on nonfood contact surfaces, is under the jurisdiction of the EPA. These chemical sanitizers are recognized by the EPA as pesticides (Marriott 1999b). The FDA's responsibility lies in evaluating residues from sanitizer use that may enter the food supply. Thus, any antimicrobial agent and its maximum allowable use concentrations for direct use on food or on food contact surfaces must be approved by the FDA (Schmidt 1997b).

Cleaning and Sanitation of Processing Plants

In a fruit processing plant, processors need to process fruits under hygienic conditions. Fruit processors should always ensure that an appropriate cleaning and sanitation program is in place. A detailed cleaning and sanitation procedures must be developed for all food contact surfaces as well as for nonfood contact surfaces (Marriott 1999a).

The objective of cleaning and sanitizing food contact surfaces is to remove food soils so that microorganisms will not have a suitable environment for survival and multiplication. The correct order of events for cleaning/sanitizing of food contact surface in a processing plant is the removal of gross debris, rinsing, presoaking in cleaning agents, rinsing, and sanitizing. Cleaners, also known as detergents, are used first to remove food soils. The choice of detergent to be used depends on the type of food soil present. Food soils can be classified as those soluble in water (sugars, starches, salts); soluble in acid (limestone and most mineral deposits); soluble in alkali (protein, fat emulsions); soluble in water, alkali, or acid (Schmidt 1997b).

After cleaning and rinsing the food contact surface with water, a sanitizer is usually applied to the surface. The sanitizer is used to destroy the presence of bacteria. The selection of a sanitizer varies with the type of equipment to be sanitized, the hardness of the water, the application equipment available, the effectiveness of the sanitizer under site conditions, and the cost. Sanitizers used in the food include, steam, hot water, and chemical sanitizers. Steam and hot water sanitization are usually carried out through immersion, spraying, or circulating systems. These are easy to apply and readily available, generally effective over a broad range of microorganisms, and relatively noncorrosive. However, they have some disadvantages including film formation, high-energy costs, and safety concerns for employees (Schmidt 1997b).

Chlorine

Chlorine and chlorine dioxide have been approved by the FDA to be used to reduce the number of pathogenic bacteria on the surface of fruits and on food contact and nonfood contact surfaces. Chlorine-based sanitizers are the most commonly used sanitizer in food processing and handling applications. Commonly used chlorine compounds include

liquid chlorine, hypochlorites, inorganic chloramines, and organic chloramines. Recently, safety concerns have been raised about the use of chlorine as a sanitizer and antimicrobial agent for food processing. This concern is based on the reaction of chlorine with the organic matter to produce potential carcinogens such as trihalomethanes (THMs), chloroform, and chlorophenols; thus, other treatments are being considered as a replacement of chlorine (Hurst 1995).

Chlorine Dioxide

Chlorine dioxide (ClO_2) is currently being considered as a replacement for chlorine, since it appears to be more environmentally friendly. Stabilized ClO_2 has FDA approval for most applications in sanitizing equipment or for use as a foam for environmental and nonfood contact surfaces. Approval has also been granted for use in flume waters for uncut fruit operations. ClO_2 has 2.5 times the oxidizing power of chlorine and is less affected by pH and organic matter than chlorine (Dychdala 1991). A maximum concentration of 200 ppm is permitted for processing equipment, while 1–5 ppm has been approved for whole fresh fruits (Cherry 1999).

Iodine

Like chlorine compounds, iodine exists in various forms as mixtures of elemental iodine with a nonionic surfactant as a carrier and is termed as iodophors. Iodophors have a very broad spectrum, being active against bacteria, viruses, yeasts, molds, fungi, and protozoa. However, iodophors have had limited use in the fruit industry as sanitizers because of their corrosiveness, reduced efficacy at low temperature, staining effect on plastic surfaces, and their reaction with starch-containing food commodities to form a bluish purple-colored complex, thus restricting their use to nonstarch fruit commodities. Iodophors are also not approved for direct food contact. The general recommended usage for iodophors for food contact surfaces and equipment is 10–100 ppm (Cherry 1999).

Quaternary Ammonium Compounds

Quaternary ammonium compounds (QACs) are mainly used as sanitizers of walls, ceilings, food contact surfaces, and equipment used for fruit processing. Since QACs are positively charged cationic surface-active sanitizers, their mode of action is related to the disruption of protein membrane function of bacterial cells. Unlike chlorine, QACs are noncorrosive to metals, are active and stable over a broad temperature range, and are less affected by organic matter. However, QACs are generally more active against Gram-positive than Gram-negative bacteria and their effectiveness could be improved by the incorporation of chelating agents such as ethylenediaminetetraacetic acid (EDTA). Disadvantages of QACs include limited activity under alkaline conditions; excessive foaming, especially for clean-in-place (CIP) applications; and incompatibility with certain detergents after cleaning operation (Schmidt 1997b).

Microbial Biofilms

Microbial biofilms are defined as "functional consortium of microorganisms attached to a surface and embedded in the extra cellular polymeric substance (EPS) produced by microorganisms" (Costerton et al. 1987). EPS will help the proper colonization of microorganisms by trapping nutrients and protecting pathogens from the action of sanitizers. The resistance of biofilms to sanitizers has caused severe problems such as fouling of water transport systems, and contamination of dental caries and medical implant devices (Carpenter and Cerf 1993).

Microbial biofilms constitute a major problem in the fruit processing industry. Pathogenic and spoilage microorganisms can attach firmly to food contact surfaces, and thus become a source of postprocessing contamination. LeChevallier et al. (1988) reported that biofilms once formed are 150–3,000 times more resistant to the chlorine effect. Sanitation programs have had limited success in the removal of biofilms from processing lines and equipments. Efforts to remove biofilms include identifying the high-risk production areas and the critical sites of production in a plant where biofilms may occur and then expose these critical sites to frequent sanitation and special treatments. Special treatments such as scrubbing or brushing have shown to be effective in removing bacterial biofilms (Gibson et al. 1999). Recently, the prevention of bacterial adhesion has become the more favorable option for the food industry than treating biofilm formation (Simões et al. 2009). In addition to regular cleaning and disinfection, the surface preconditioning agents such as surfactants have been used to prevent biofilm formation (Simões et al. 2010).

FUTURE RESEARCH NEEDS

Future needs for assuring the safety of fruits and fruit products include increased surveillance; reporting and research on the presence of foodborne pathogens in imported and domestic fruits; and development of reliable, fast, and sensitive methods for their isolation and detection. Safety issues that need to be addressed include better understanding of the interaction between plant pathogens and human pathogens; investigation on factors affecting pathogen infiltration into fruits and their significance to fruit safety; and development of new treatments/technologies to reduce/eliminate these pathogens from fruits and studies on the behavior of these pathogenic bacteria in the presence/absence of the natural microflora on fruits.

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21
Fresh and Processed Fruits: Safety and Regulations

Muhammad Siddiq, Nirmal K. Sinha, and Nanda P. Joshi

Abstract: Food safety is a major consumer, industry, and regulatory concern. Unsafe and inferior quality products can have serious health and economic consequences. A growing demand for fruits and expansion of international trade in fresh and minimally processed produce coupled with concerns about foods allergens and harmful chemicals found in foods have created additional concerns. The coverage in this chapter discusses important safety and regulatory issues; global food safety initiatives, including role of Codex Alimentarius and International Center for Excellence aimed at food risk communications; food safety concerns of fresh and processed fruits; safety across supply chain; critical food safety violations; good manufacturing practices (GMPs); hazard analysis, critical control points (HACCP); and traceability. A number of regulations/acts are also covered: Food, Drug & Cosmetics (FD & C) Act; Perishable Agricultural Commodity Act (PACA); Nutritional Labeling and Education Act (NLEA); Food Allergen, Labeling and Consumer Protection Act (FALCPA); Organic Labeling Regulations; Occupational Safety and Hazard Act (OSHA); and Food Bioterrorism Act.

INTRODUCTION

The US Center for Disease Control and Prevention (CDC) indicated that "most people do not think about foodborne illness until they become ill from unknowingly eating contaminated food." While the food supply in the United States is one of the safest in the world, according to CDC, "each year about 1 out of 6 Americans (or 48 million people) get sick, 128,000 are hospitalized, and 3,000 die of foodborne illness." The CDC online database (www.cdc.gov/foodborneburden) of foodborne disease outbreak in the United States listed fruits salad, berries, cantaloupe, watermelon, unpasteurized apple cider, and applesauce as sources of foodborne illnesses due to *Escherichia coli* O157:H7, *Salmonella*, *Cyclospora*, and *Norovirus*.

The food safety is an industry, consumer, and regulatory concern. A "Reportable Food Registry (RFR)" monitored by the Food and Drug Administration (FDA) was established in 2007 covering most foods except infant formula and dietary supplements. "The RFR requires a responsible party to file a report within 24 hours through the RFR electronic portal when there is reasonable probability that the use of, or exposure to, an article of food will cause serious adverse health consequences or death to humans or animals." The first

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annual report of the RFR by the FDA in January 2011 showed *Salmonella* (37.6%), *Listeria monocytogenes* (14.4%), *E. coli* (2.6%), and undeclared allergen/intolerances (34.9%) as major food safety hazards. More information on this is available at http://www.fda.gov/ReportableFoodRegistry.

A growing demand for fruits and fruit products and expansion of international trade in fresh and minimally processed foods coupled with concerns about foods allergens and harmful chemicals found in foods have created additional concerns. Further, in a globalized food trade, "no country is an island" and the food safety issues cannot be fully addressed by nations working in isolation. This chapter briefly reviews important safety procedures, guidelines, and regulations related to production, processing, and marketing of safe and nutritious fresh and processed fruit products.

FOOD SAFETY

Unsafe and inferior quality products can have serious health and economic consequences. For example, an outbreak of foodborne illness in the United States and Canada from consumption of raspberries containing *Cyclospora* parasite imported from Guatemala had a negative impact on raspberry production in that country. Similarly, a recent *Salmonella* outbreak, believed initially due to consumption of contaminated tomatoes, sickened many people in different parts of the United States and severely affected the tomato industry. The presence of *Salmonella* was later determined due to Serrano peppers from Mexico used in the contaminated tomato products. These incidences often involve a wide geographic footprints and cause erosion of consumer confidence in the food industry.

The safety of fruits and fruit products begins with practices followed at various farms and orchards. The conditions and environment at the farms and specifically the use of production inputs such as insecticides, pesticides, fertilizers, (chemical risk factors), sanitation, quality of water and workers health (biological risk factors), postharvest handling (precooling, use of sanitizers), and storage (refrigeration and freezing facilities) and shipment practices as these relate to good agricultural practices (GAPs; see Table 21.1) are critical to ensure food safety. Similarly, at fruit processing plant, safe and sanitary manufacture and handling of food for human consumption require adherence to current good

Table 21.1. Important Parameters for Good Agricultural Practices (GAPs) to Minimize Microbial Food Safety Hazards

Parameters	Key Consideration
1. Water quality	• As water can be a potential carrier of microorganisms and pathogens, identify the source and distribution of water to be used • Regularly test and maintain a record of water quality • The quality of water in direct contact with edible portion of produce should be of potable quality • GAPs include protecting surface waters, wells, and pump areas from uncontrolled livestock or wildlife access to prevent fecal contamination that can be the source of pathogens • Use of polluted water should not be permitted
2. Worker health and hygiene	• Infected and sick workers can contaminate fresh produce, water supply, and other workers and transmit foodborne illness • Workers and other food handling employees should be trained in various aspects of good hygienic practices, importance of sanitation, and proper hand washing
3. Sanitary facilities	• It is important to maintain a clean sanitary work place • The toilet and washroom facilities, production and other areas should be provided with facilities such as tissue papers, soaps, etc., and properly cleaned on a regular basis, as per applicable regulations • The sewage and waste should be properly disposed off
4. Field and packing house sanitation	• Maintain sanitary and clean facilities including buildings, fixtures, other physical facilities, and equipment • Prevent and control pest infestations
5. Manure and municipal biosolids	• Manure and animal waste can be a potential source of contamination and should be disposed off carefully
6. Transportation	• Microbial cross-contamination from other foods and nonfood sources and contaminated surfaces may occur during loading, unloading, storage, and transportation operations • Keep transportation vehicles clean • Maintain proper temperature
7. Trace back	• Maintain records of dates of production, area of production, packing, etc., to be able to trace back each step in the supply chain

manufacturing practices (cGMPs) and good hygienic practices (GHPs) which are important foundations and prerequisites for process-specific food safety control programs such as hazard analysis critical control points (HACCP).

Global Food Safety Initiative

Global food safety initiative (GFSI), launched in 2000, has three broad objectives (Swientek 2009):

a. Harmonization of food safety standards
b. Improving cost-efficiency through a common acceptance of recognized standards
c. Providing stakeholders a platform for sharing best food safety practices

An International Center of Excellence (ICE) (www.foodriskcommunications.org) aimed at food risk communications was established in 2011. This is a collaborative initiative and an international resource for communicating food-specific risk made up of key global food and health organizations, academic institutions, and important nonprofit agencies. In case of events such as earthquake and tsunami in Japan on March 11, there was a serious effect and damage to nuclear power plants in Japan. There is a fear of radiation entering food supply and trade. The ICE is taking a lead in communicating the risk associated with radiation to global food supply chain.

Codex Alimentarius Commission

The Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO) established Codex Alimentarius Commission (Latin for "food code" or law) in 1963 to develop a set of uniform standards, guidelines, and codes of practices for foods entering trade. The objective was to "protect the health of consumers and ensure fair practices in food trade" by promoting uniform regulatory systems and standards across the food supply chain based on scientific principles. An effective food safety is undermined by "fragmented legislation, multiple jurisdiction and weakness in surveillance, monitoring and enforcements." There is a need to create uniform set of guidelines, standards of identity, and practices to be followed in production, processing, and marketing of various foods. The program supports training and risk analysis of food safety. Official Codex standards related to use of pesticides, hygienic practices, raw, canned, frozen, dried, and juice products can be obtained from Codex Web site: http://www.codexalimentarius.net.

Sanitation and Phytosanitation Measures

In order to minimize risks associated with consumption of fresh produce produced through a diversity of agricultural practices from different countries entering international trade, common sanitation and phytosanitation (SPS) measures were established by the General Agreement on Tariffs and Trade (GATT) in 1994. The GATT has now been replaced by the World Trade Organization (WTO). The SPS measures are aimed "to protect animal or plant life or health within the territory of the member countries from risks arising from entry, establishment or spread of pests, disease, disease-carrying organisms, or disease-causing organisms." The establishment, recognition, and application of common sanitary and phytosanitary measures by different members include "relevant laws, decrees, regulations, requirements, and procedures including *inter alia* end product criteria; process and production methods; testing; inspection; certification and approval procedures; quarantine treatments including relevant requirements associated with the transport of animals and plants, or with materials necessary for survival during transport; provisions on relevant statistical methods; sampling procedures and methods of risk assessments; and packaging and labeling requirements directly related to food safety." The SPS follows the standards, guidelines, and recommendations established by the Codex Alimentarius Commission relating to food additives, veterinary drug and pesticide residues, contaminants, methods of analysis and sampling codes, and guidelines for hygienic practices. In 1986, provisions on rules of origin (country of origin) and agreement on pre-shipment inspection were added to increase the responsiveness of GATT to the evolving international economic environment.

In the United States, a food safety modernization act was enacted in 2011 to prevent foodborne illness from reaching consumers by requiring food processing plants to upgrade the frequency and thoroughness of their safety inspections. The bill requires the Health and Human Services (HHS) Department and Agriculture Department to jointly develop a national plan to improve food safety. It grants HHS a greater authority to order recalls of suspected tainted foods. It also seeks to improve inspections of foreign foods imported to the United States.

International Standards Organization

International Standards Organization (ISO) (www.iso.org) is a network of national standards institutes of 163 countries, one member per country with a Central Secretariat in Geneva, Switzerland. It is a nongovernmental organization that forms a bridge between public and private sector. ISO standards ensure desirable characteristics of products and services such as quality, environmental responsiveness, and safety. They support the requirements of businesses and broader needs of society. ISO-approved companies practice structured quality management to ensure safety.

Since major retailers source produce and processed products from local and other sources, including abroad, they follow supplier certification, inspections, and quality control measures to ensure safe quality food (SQF) on their shelves. The leading practices for safety and quality in the supply chain are HACCPs, ISO 22000, and food safety management

systems (FSMS). HACCP identifies hazards within FSMS and their control through prerequisite programs (PRPs) and critical control points (CCPs) in the food production handling and processing. ISO 22000 guides the HACCP process and incorporates it into standard, and SQF incorporates both HACCP and ISO processes into certification standard (Anon 2010). It is important to account for when and where the product is produced, processed, packed, quality tested, storage temperature and time, shipment, and distribution in order to create lot traceability. Each shipment received should have a certificate of analysis (COA) including an estimated shelf life and storage recommendations.

Food Safety Fundamentals

According to Taylor (2002), the fundamentals of food safety should have the following elements:

a. *Prevention*: It requires food producers, processors, and marketers to identify potential physical, biological, and chemical hazards in their food supply chain and implement controls to prevent or minimize the hazards. Programs such as HACCP and ISO certifications emphasize prevention as their primary approach.
b. *Accountability*: The principle of accountability is well established for use of certain chemicals. For example, there is limit on use of insecticides, etc., in produce and processed products. Similarly, there are regulations for use of additives, preservatives, color, flavors, and ingredients that have allergenic potentials. However, the testing and requirements for pathogens that are major sources of foodborne illness is not so well followed.
c. *Risk-based resource allocation*: There is a growing realization to understand and manage food safety risks instead of simply depending on the hazard-based approach to food safety. This requires that the food safety system makes the optimum uses of its resources to reduce foodborne illness, for example, by training employees about food safety issues, good hygienic and manufacturing practices, and increasing the level of inspections both domestically and abroad.
d. *Integration*: An integrated and coordinated approach by agencies such as FDA, USDA, and CDC would enable better utilization of resources to avert major foodborne outbreaks.
e. *Regulatory framework*: Regular inspection and enforcement of rule of law are required to ensure food safety across the supply chain.

FRESH/RETAIL USE FRUITS

Good Agricultural Practices

Fruits and vegetables, in addition to being low in fat and high in fiber, are also rich in antioxidants, which have been shown to benefit health. In the past two decades, there has been a greater emphasis by the USDA and public health officials on increasing the consumption of fruits and vegetable for healthy living. With increased consumption of produce in the United States, the outbreaks of human gastroenteritis associated with consumption of fresh produce contaminated with pathogenic bacteria, parasites, and viruses have occurred with increased frequency since early 1990s (NACMCF 1999; Beuchat 2006). The growth in production, marketing, and trade resulting from increased demand and consumption of fruits and vegetables has also heightened consumers concerns with respect to food-related disease outbreaks (Rangarajan et al. 2000).

Production and marketing of safe food (from chemical, biological, and microbial contamination perspectives) entail a number of inputs and operations in the field or orchard and postharvest value chain (Rangarajan et al. 2000). These researchers asserted that the highly mechanized and diverse agricultural production practices together with increased international trade have expanded options to consumers.

Sources of potential contaminations can be divided into pre- and postharvest types, as shown in Box 21.1 (Rangarajan et al. 2000).

Food safety is a complex issue that requires a thorough understanding of the mechanisms of food contamination. Figure 21.1 shows the basic food supply chain and possible ways in which produce can be contaminated/cross-contaminated or intentionally contaminated (Beuchat 1996).

Box 21.1 Potential Sources of Contamination

Preharvest:

- Soil
- Irrigation water
- Animal manure
- Inadequately composted manure
- Wild and domestic animals
- Inadequate field worker hygiene
- Harvesting equipment

Postharvest:

- Transport containers (field to packing facility)
- Wash and rinse water
- Unsanitary handling during sorting and packaging
- Equipment used to soak, pack, or cut produce
- Ice, for cooling produce
- Cooling units (hydrocoolers)
- Transport vehicles
- Improper storage temperature
- Improper packaging
- Cross-contamination in storage, display, and preparation

Source: Rangarajan et al. (2000).

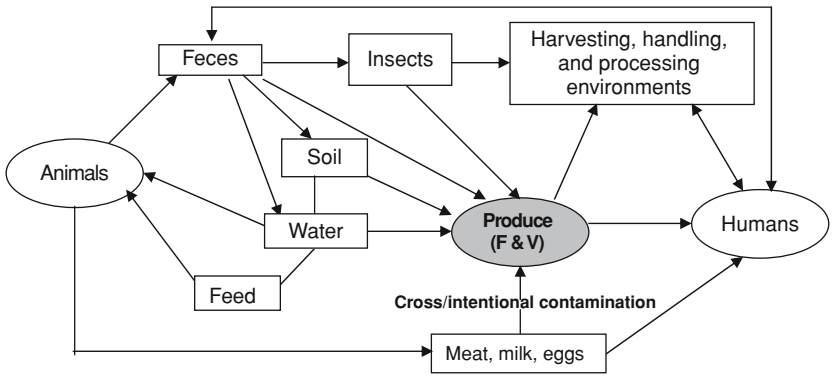

Figure 21.1. Food contamination cycle of produce—fruits and vegetables. (Adapted from Beuchat 1996.)

To minimize food safety and public health problems, it is important to produce fruits not only in a safe manner by following GAPs but also to maintain a safe supply chain throughout marketing channels. While it is impossible to completely avoid the risk of microbial contamination, nonetheless, carefully adopted preventative measures can certainly reduce such risks. In 1998, the U.S. Department of Health and Human Services (HHS), FDA, and Center for Food Safety and Applied Nutrition (CFSAN) issued *"Guidance for Industry–Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables,"* which addressed microbial food safety hazards and GAPs and Good Manufacturing Practices (GMPs) (FDA 1998). These guidelines covered measures common to the growing, harvesting, cleaning/washing, sorting, packing, and transporting of most produce sold to consumers in an unprocessed or minimally processed raw form. Calvin (2003) noted that FDA emphasizes the fact that GAPs only reduce the risk of microbial contamination and cannot eliminate the risk.

The guidance identifies eight principles of microbial food safety that can be applied to production, harvesting, packing, and transportation of fresh produce; these principles are based on certain basic principles and practices associated with minimizing microbial food safety hazards from the field through distribution of fresh produce (FDA 1998). These principles emphasize: (1) Prevention of microbial contamination of fresh produce over reliance on corrective actions once contamination has occurred; (2) Minimization of microbial food safety hazards in fresh produce, growers, packers, or shippers should use good agricultural and management practices in those areas over which they have control; (3) That fresh produce can become microbiologically contaminated at any point along the farm-to-table food chain. The major source of microbial contamination with fresh produce is associated with human or animal feces; (4) Whenever water comes in contact with the produce, its source and quality dictates the potential for contamination. Minimize the potential of microbial contamination from water used with fresh fruits and vegetables; (5) Practices using animal manure or municipal biosolid wastes should be managed closely to minimize the potential for microbial contamination of fresh produce; (6) Worker hygiene and sanitation practices during production, harvesting, sorting, packing, and transport play a critical role in minimizing the potential for microbial contamination of fresh produce; (7) Following all applicable local, state, and Federal laws and regulations, or corresponding or similar laws, regulations, or standards for operators outside the United States, for agricultural practices; and (8) Accountability at all levels of the agricultural environment (farm, packing facility, distribution center, and transport operation) is important to a successful food safety program.

Packaging, Transport, and Retailing

Food safety requires that fruits should be handled in safe manner at all steps of food value chain. O'Beirne (2007) suggested the following important considerations at various stages of value chain:

Production and harvesting: (a) producer awareness of role in food safety, (b) training and facilities for workers, (c) avoiding animal manure/sewage/flooded land, (d) irrigating with clean water, (e) cleaning and sanitizing harvesting equipment, (f) excluding wild birds and animals from packinghouse, (g) minimizing bruising and cutting, and (h) avoiding cross-contamination during delivery to processor.

Fresh-cut processing: (a) program for sanitizing surfaces and machines, (b) good preliminary decontamination and inspection, (c) avoiding severe peeling/cutting techniques that result in higher tissue injury, (d) eliminating/minimizing human contact with processed product, (e) deploying effective washing/antimicrobial dipping, and (f) avoiding postdipping contamination.

Packaging/Distribution/Retail: (a) careful selection of packaging material, (b) monitoring microbial quality of packaged product, (c) ensuring a temperature of $<4^{\circ}$C, (d) process

Table 21.2. Maintaining the Cold Chain for Perishables

Value-Chain Stage	Suggested Actions
Harvest	• Protect the product from the sun • Transport quickly to the packinghouse
Cooling	• Minimize delays before cooling • Cool the product thoroughly as soon as possible
Temporary storage	• Store the product at its optimum temperature • Practice "first-in-first-out" rotation • Ship to market as soon as possible
Transport to market	• Use refrigerated loading area • Cool truck before loading • Load pellets toward the center of the truck • Put insulating plastic strips inside door of reefer if truck makes multiple stops • Avoid delays during transport • Monitor product temperature during transport
Handling at destination	• Use a refrigerated unloading area • Measure product temperature • Move product quickly to the proper storage area • Transport to retail markets or foodservice operations in refrigerated trucks • Display at proper temperature range
Handling at foodservice outlet or home	• Monitor product temperature during transport • Store product at proper temperature • Use the product as soon as possible

Source: Adapted from Kader (2003).

at low temperature, (e) suitably designed vehicles, (f) proper vehicle loading practices, including chill cabinet loading, (g) modest shelf life labeling, and (h) education of retailer and consumer.

Maintaining a desired cold chain throughout marketing channels not only extends the shelf life of perishable commodities, including fresh fruits, but it also minimizes risks of microbial growth due to temperature abuse. Kader (2003) suggested a number of actions needed to maintain the cold chain throughout the postharvest handling system for perishable horticultural crops; these actions are summarized in Table 21.2.

Quality and Shelf Life

For quality and shelf life of intact and fresh-cut fruits, selection of best quality fruits, temperature, and relative humidity (RH) control are important factors (Gross et al. 2002; Kader 2002). Kader (2003) reported that there is a continuing trend toward increased precision in temperature and RH management to provide the optimum environment for fresh produce during cooling, storage, and transport; precision temperature control and management tools, including time–temperature monitors, are becoming more common in cooling/storage facilities and during transportation and shipping (Figure 21.2).

In addition, edible coatings, waxing, sanitizers, innovative packaging, etc., can further enhance the postharvest safety and shelf life of fruits.

Kader (2003) noted that the emphasis of continuing research on produce safety is on developing reliable and quick detection methods for human pathogens, improving efficacy of water disinfection techniques, and developing methods for reducing microbial load on intact and fresh-cut fruit. Other aspects of produce safety included ensuring that the pesticides residues are within the legal limits and avoiding handling conditions that lead to contamination with mycotoxins.

Critical Food Safety Violations

As compared with vegetables, the critical food safety violations reported for fresh fruits are relatively few. The low pH or high acidity of fruits plays an important role in the overall safety of fresh fruits. Food safety violations/recalls are reported comprehensively by FoodHACCP.com (Anon 2011), which also publishes monthly "Food Safety" magazine, and USDA's Food Safety and Inspection Service (FSIS 2011). The violations/recall reported at both of these sites cover food-borne illnesses.

Other types of violations, such as related to pesticide application/residue, are spelled out in state food and agricultural codes. California Food and Agricultural Code (CFAC 2011), section 12671–12674, lists regulations related to such violations. For example, section 12671 says "It is unlawful for any person to pack, ship, or sell any produce that carries pesticide residue in excess of the permissible tolerance which is established by the director."

Organic Fruits

The general GAPs guidelines for produce safety can be used for the production of organic fruits. However, it must be noted that there are specific regulations with respect to organic foods production, handling, and marketing (USDA-AMS 2011).

According to USDA-AMS (2011), "organic production is a system that is managed in accordance with the Organic Foods Production Act (OFPA) of 1990 and regulations in Title 7, Part 205 of the Code of Federal Regulations to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity. The National Organic Program (NOP) develops, implements, and administers national production, handling, and labeling standards." Title 7, Section 205 regulations are available online

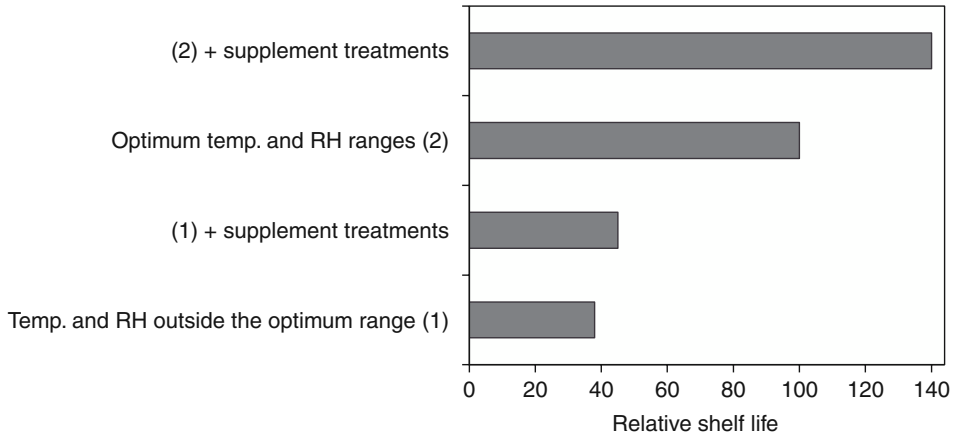

Figure 21.2. Relative postharvest shelf life of perishable commodities. (Adapted from Kader 2003.)

(e-CFR 2011). Readers are also referred to NOP Web site for detailed information on many aspects of organic food production (USDA-AMS 2011).

PROCESSED FRUIT PRODUCTS

Current Good Manufacturing Practices

Processed fruit products, an important category in many countries, are globally traded and certain branded processed fruit products are considered premium because of their good quality and safety records. The manufacturers of these products have adopted strong cGMPs, prevention, quality control, certification, and audit measures to ensure safe food quality. Table 21.3 describes the important aspects of cGMP. Adherence to GMP practices also minimizes the risk of adulteration and misbranding.

Hazard Analysis Critical Control Points

In 1959, Pillsbury Company (now owned by General Mills) developed HACCP plan for food for the manned space program. Subsequently, HACCP principles have been incorporated into low acid canned food, seafood, and juice processing. The practice of testing finished product to ensure product quality, although important, can often be too late and costly to identify sources of food safety problems. The HACCP concept underscores building food safety in the manufacture of product. It identifies potential safety hazards and establishes control steps to correct and prevent them from entering into the food chain. However, HACCP often does not provide acceptable limits about hazards. Nonetheless, the HACCP is not simply an in-house preventive food safety program, but procedures and records created under this system can be verified by third-party auditors and regulators. It also helps to ensure that standard operating, quality control, and use of auditable procedures for procurement of raw materials, etc., are being followed.

The five steps and seven principles of HACCP (FDA 1997; LaBorde 2011) are as follows:

Five steps:

- Create an HACCP team and identify a point person.
- Describe the product and its supply chain.
- Describe end use.
- Describe processing steps through a flow diagram.
- Validate flow diagram.

Seven principles:

- Determine significant hazards and do a hazard and risk analysis.
- Determine CCPs. The CCPs are control steps to be monitored in the flow diagram.
- Establish critical limits in each step of the process.
- Establish monitoring procedures.
- Establish corrective actions.
- Establish verification procedures.
- Establish record keeping and documentation procedures.

Application of a decision tree for determination of CCPs, as shown in Figure 21.3, can be a very helpful tool in developing a successful HACCP program.

Audit

Third-party audits have become central to ensure that products are being manufactured hygienically following GMP guidelines. The auditing bodies such as AIB (American Institute of Baking), BRC (British Retail Consortium), IFS (International Food Standards), SQF (Safe Food Quality) each have their separate scoring methods and would walk though

Table 21.3. Important Aspects of Good Manufacturing Practices (GMPs)

Parameters	Key Consideration
1. Building, water supply, and sewage disposal	• Building should be of adequate size, construction, and design • Floors, walls, and ceilings are properly maintained for safe operation • Lighting, ventilation, ducts, and pipes are maintained and routinely replaced to minimize safety violations • Water supply system, washing and toilet facilities, drainage, and sewage disposal systems are well maintained to support quality
2. Equipment	• Equipment used in processing should be of sanitary design and quality • A proper record of plant cleanup procedure and its frequency should be maintained
3. Personnel	• The employees should have proper training in jobs to be performed and follow safe handling of food protocols; wear appropriate clothing, hairnet, etc.; and personnel hygiene so as to avoid any potential contamination of products
4. Incoming ingredients	• Raw materials and ingredients used in the processing should be obtained from certified and approved venders • Raw materials should be maintained at proper storage conditions under sanitary conditions • Raw materials not meeting quality standards should not be used
5. Production	• Production should follow HACCP principles and standard operating procedures to minimize risk of contamination and quality defects
6. Quality control (QC)	• Proper quality control testing setup should be followed for incoming material and finished product to be able to issue a certificate of analysis (COA) • The QC should maintain proper records of quality procedures and data including certification, audits, and compliance to customer complaints • The QC should have proper protocols on recalls • The QC should have retain samples and maintain traceability program
7. Labeling	• The products should have proper labels indicating date of manufacture, ingredients, nutritional information, storage requirements, etc.

HACCP, hazard analysis critical control points.

the facility to review: plant and personnel (uniform, use of hairnets, safety glass, and other safe and sanitary handling procedures), conditions of building, premises including rest room, equipment, storage and shipping area, allergen control, pest control, hold–release programs, etc. They would check whether the facility follows HACCP and would review records. These audits are typically done annually and are often unannounced.

Hold–Release Procedure

Each production facility should have a positive "hold–release" guidelines. Typically, a work-in-progress (WIP) and a finished product (FP) undergoing testing, especially for the presence of pathogens, pesticides, etc., should be placed under hold until the testing confirms no safety risk. Further a product under hold can have some defect, can be cross-contaminated, or fail to properly list all the ingredients used in the processing. Such products are isolated and stored with clear "hold" sign so that other products are not affected. The quality assurance department is the custodian for "hold–release" process. They would keep proper record of how the product under "hold" is disposed off.

Traceability and Recall

In the wake of many food safety incidences, product-based traceability would create a better handle on the cause of problems and actions for product retrieval or recall. The traceability encompasses both trace-back and trace-forward routes of the supply chain to identify origin of product, processing plant and personnel involved, process details, ingredients used, quality and shelf-life tests, storage time and temperature, transport, and sale to the consumers. Typically, manufacturers create lot codes and universal product codes (UPCs) that can identify sources of raw materials and ingredients used in the process and date of processing and packaging. The uses of bar codes and radio frequency identification (RFID) electronic devices have improved the traceability vis-à-vis simple tags that are still in use.

FOOD SAFETY REGULATIONS

Perishable Agricultural Commodity Act

The Perishable Agricultural Commodity Act (PACA) regulations (USDA-AMS 2011) came into force in 1930. It

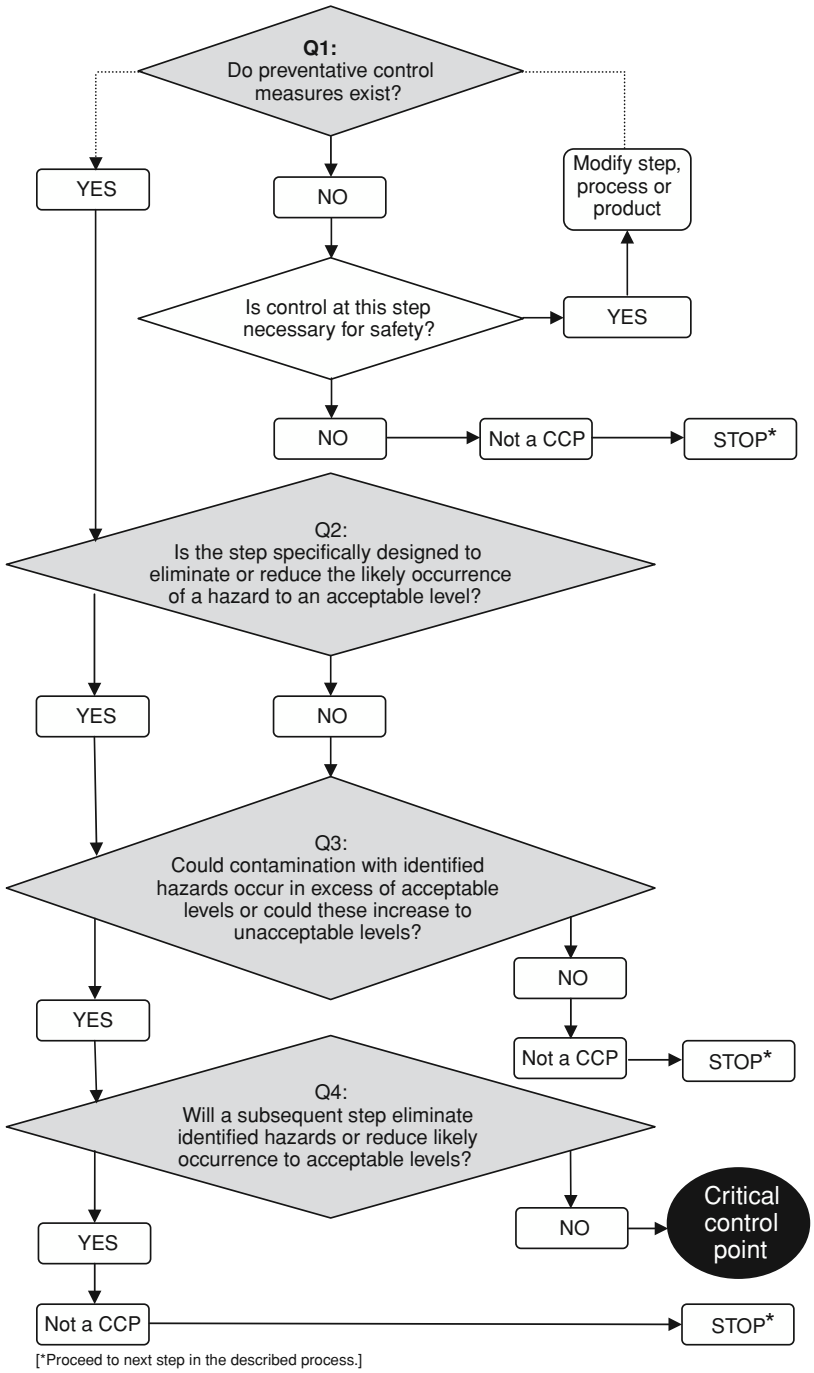

Figure 21.3. Application of decision tree toward CCP identification. (Adapted from FDA 1997.)

protects businesses dealing in fresh and frozen (not canned or cooked) fruits and vegetables "by establishing and enforcing a code of fair business practices and helping companies resolve business disputes." The country of origin labeling (COOL) program shall apply to imported and domestic perishable agricultural products (including fresh fruits and vegetables).

Food, Drug, and Cosmetics Act

The Food, Drug, and Cosmetics Act (FD&C) passed by the US Congress in 1938 "authorized the FDA to demand evidence of safety of new drugs, issue standards for food, and conduct factory inspections." The FDA ensures safety of all food except meat, poultry, and some egg products. The safety

of additives, including color additives, preservatives, etc., falls under FDA which issues list of generally recognized as safe (GRAS) list.

Nutritional Labeling and Education Act

The Nutritional Labeling and Education Act (NLEA) (www.fda.gov) was passed by the U.S. Congress in 1990. However, the regulations for nutritional labeling and other provisions became effective in August 1994. The law "provides FDA with specific authority to require nutrition labeling of most foods regulated by the agency; and to require that all nutrient content claims (i.e., high fiber, low fat, etc.) and health claims be consistent with agency regulations." The FDA has been issuing warning letters as part of broader efforts to improve enforcement and truthful labeling to food manufacturers including juice-making companies for misleading and false health and other claims on product labels.

Food Allergen Labeling and Consumer Protection Act

The Food Allergen Labeling and Consumer Protection Act (FALCPA) was enacted in 2004. It became effective in January 2006. It is an amendment to Federal Food, Drug, and Cosmetics Act and requires that "the label of a food that contains an ingredient that is or contains proteins from a 'major food allergen' declare the presence of the allergen in the manner described by law." The eight major food allergens—milk, egg, fish (e.g., bass, flounder, cod), crustacean shellfish (e.g., crab, lobster, shrimp), tree nuts (e.g., almonds, walnuts, pecans), peanuts, wheat and soy—are believed to account for over 90% of all food allergens in the United States.

Organic Labeling Regulation

The Organic Foods Production Act (NOP) of 1990 became fully implemented in 2002. The NOP sets rules and regulations for

- National standards for interstate marketing of organic agricultural products.
- Products to be sold or labeled as an organically produced product; an agricultural product should be produced and handled without the use of synthetic chemical, antibiotics, germicides, radiations, or genetic modification.
- In order for a farm to produce organic foods, the land must be free of any harmful pesticides and fertilizers for a minimum of 3 years prior to start of organic production.
- A product to be labeled organic must contain over 95% organic materials. A "made with organic" product must contain at least 70% certified organic agricultural products. The remaining 30% may include conventionally produced product excluding products using genetic modification and radiation, but can include natural and synthetic ingredients or processing aids.

Kosher (Jewish) and Halal (Muslim) Certifications

Kosher (meaning "fit' or "proper") and Halal (meaning "lawful" or "permitted") certifications may be necessary for marketing fruits and fruit products in a specific target market (Jackson 2000). These certifications are made by recognized agencies. They certify to the fact that religious guidelines for production and handling of foods are being followed.

Occupational Safety and Hazard Act

With Occupational Safety and Hazard Act (OSHA) enacted in 1970, Congress created the Occupational Safety and Health Administration within the Department of Labor. Under this law, there is a "Standard Industrial Classification Code" for each employer. The OSHA "standards are rule that employers must use to protect their employees from hazards." Under the OSHA rules, employees are required to use personal protective equipment (respiratory protection, eye protection, and protection against excessive noise level) and follow safety precaution while using hazardous waste and chemicals. The basic goal is to prevent workplace injury, illness, and fatality. Typically, a food processing facility should have a safety committee. It should have announcement or sirens in case of fire (code red for fire) to evacuate the building and should conduct periodic fire drills. It should also have emergency alert system for hazardous chemicals (code blue for chemical hazard, no evacuation needed but an emergence support team attends to injured and the affected area is isolated) and weather (code white). It also creates group of emergency respondents trained in first aid and cardiopulmonary resuscitation (CPR).

Bioterrorism Act

In the wake of 2001 terrorist attacks in the United States, Congress passed the Public Health Security and Bioterrorism Preparedness Act 2002 (PL107-188). Among other provisions, the Act aims to protect safety and security of drinking water, food, and drug supply. The Act requires the "owner, operator, or agent in charge of a domestic or foreign facility (exporting to United States) that manufacture/process, pack, or hold food (subject to FDA's jurisdiction) for human or animal consumption to register with the FDA." "Facilities are defined as any factory, warehouse, or establishment, including importers. Domestic facilities are required to register (the registration is one-time, not annual and does not require fee) whether or not food from the facility enters interstate commerce. The requirement applies to each covered

facility, not to firms or companies as a whole." The examples of FDA-regulated foods include the following:

- Fruits and vegetables.
- Canned and frozen foods.
- Beverages (including alcoholic beverages and bottled water).

Farms, restaurants, retail food establishment, and nonprofit food establishments are exempt from registration.

The Act requires creation and maintenance of records to determine the source and receipt of foods (i.e., one up, one down) to allow FDA to address credible and serious threats.

In case of imported foods, the Act requires prior notice of food shipments describing the article, country of origin, grower, manufacturer, and shipper. The FDA and Customs and Border Protection (CBP) can issue civil monetary penalties against the violators importing food with no prior notice.

CONSUMER'S RESPONSIBILITY

After all the necessary steps have been taken by the producer, processor, and marketer to ensure food safety aspects, it is the consumer's responsibility to handle, prepare, and store a food product in a safe manner to avoid food safety issue. The USDA and FDA have resources available online for education of consumers on latest information in food safety issues.

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Part 5
Commodity Processing

22
Apples and Pears: Production, Physicochemical and Nutritional Quality, and Major Products

Nirmal K. Sinha

Abstract: This chapter reviews important aspects of apple and pear production, quality, processing, and major products. Apples (*Malus domestica*) are the second leading fruits produced in the world. They are good sources of natural plant flavonoids having antioxidant properties. On average, about 46% of the polyphenolic compounds found in apples are concentrated in the skin and apples with the peel have higher antioxidant capacity than without the peel. Apples contain natural sugars, organic acids, dietary fiber, minerals, and vitamins. Regular consumption of one or more apples a day is suggested to reduce risks of lung and colon cancer.

Similar to apples in production, postharvest handling and processing, pears (European pears: *Pyrus communis* L.; Asian pears: *Pyrus serotina* L.) are sweet, fleshy, dessert-type fruit. Fructose is the primary sugar in European pears and they contain more sorbitol than glucose and sucrose. Pears are good sources of fiber and micronutrients. The skin/peel of pears contains higher concentration of chlorogenic acid, flavonols, and arbutin than the flesh.

SECTION 1: APPLES: PRODUCTION, QUALITY, AND PROCESSING

INTRODUCTION

The apple (*Mauls domestica*), a climacteric fruit, is grown primarily in the temperate regions of the world. Apples are consumed and traded worldwide. Naturally present phenolic constituents in fruits and vegetables have antioxidant properties and are suggested to protect lipids, proteins, DNA, and other biomolecules in our body from oxidative stress. Apples contribute to a greater intake of natural phenolic constituents compared with other fruits because of their relatively higher per capita consumption. This section describes production, consumption, storage, processing, physicochemical, phytochemical, and nutritional qualities of apples.

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

PRODUCTION AND CONSUMPTION

The apple tree belongs to the Rosaceae (rose) family (Anon 2004). It adapts well to temperate climates where the average winter temperature is near freezing for at least 2 months. Newly planted apple trees start producing fruits in about 6–8 years. The fruit production begins in late spring when trees bear white blossoms. The blossoms (flowers) produce pollen and nectar to attract bees and other insects that pollinate the blossoms, which grow into fruits in about 140–170 days.

According to the Food and Agricultural Organization (FAO 2011), estimated world production of apples in 2009 was over 70 million metric ton (MMT). Next to bananas, apples are the second leading fruit (Table 22.1) produced in the world. China and the United States contribute to more than 50% of the world apple production (Table 22.2). The apple production in China has grown significantly during the last 20 years. In 2008, about 5 million hectares were estimated to be devoted to apple production in the world of which China accounted for a little over 2 million hectares. The land under apple production in the United States has declined from 166,810 ha in 1980 to 141,676 ha in 2008. In 2008, the estimated yield of apples in the world was about 14 MT/ha. The yield in the United States (31 MT/ha) was more than twice that of China (14.9 MT/ha). The yields of apples in India (7 MT/ha) and Russia (6 MT/Ha) were half of China.

Table 22.1. Leading Fruits and Leading Producing Countries—2009

Leading Fruits	World Production [Metric Ton (MT)]	Leading Producing Countries Production (MT)
1. Banana	97,378,272	India (26,996,600)
2. Apples	71,286,632	China (31,684,445)
3. Oranges	68,445,267	Brazil (17,618,500)
4. Grapes	67,557,199	Italy (8,242,500)
5. Mango, mangosteen, guava	35,124,127	India (13,557,100)

Source: FAO (2011).

Next to bananas, apples are the most consumed fruit in the United States, with a per capita fresh consumption of approximately 16.0 lbs (Table 22.3). The consumption of fresh apple has declined from a high of about 19.0 lbs in 1980 to 16.0 lbs in 2008. However, the consumption of apple juice has doubled from 13 lbs [fresh weight (FW) equivalent] to 26.0 lbs (Table 22.4). In the United States, about 33% of

Table 22.2. Apple Production—Leading Countries and World Aggregate (MT)

Country	1980	1990	2000	2005	2008	2009
1. China	2,382,996	4,331,922	20,437,065	24,016,882	29,851,163	31,684,445
2. United States	4,000,000	4,380,000	4,681,980	4,408,870	4,358,710	4,514,880
3. Poland	844,106	812,340	1,450,376	2,074,951	2,830,870	2,626,270
4. Iran	600,000	1,523,980	2,141,655	2,661,901	2,718,775	2,431,990
5. Turkey	1,430,000	1,900,000	2,400,000	2,570,000	2,504,490	2,782,370
6. Italy	1,936,700	2,050,070	2,232,100	2,192,000	2,210,100	2,313,600
7. India	658,000	1,093,900	1,050,000	1,739,000	1,985,000	1,795,200
8. France	2,902,000	2,326,000	2,156,900	2,241,480	1,940,200	1,953,600
9. Russia	5,090,000[a]	6,034,000[a]	1,832,000	1,779,000	1,467,000	1,596,000
10. Chile	245,000	700,000	805,000	1,400,000	1,280,000	1,090,000
World	33,942,609	41,046,903	59,059,783	62,517,903	69,304,442	71,286,632

Source: FAO (2011).
[a]USSR.

Table 22.3. Per Capita Consumption of Fresh Fruits in the United States (lb)

Fruit	1980	1990	2000	2005	2008
1. Apple	19.20	19.56	17.46	16.67	16.17
2. Banana	20.77	24.34	28.45	25.20	25.06
3. Orange	14.28	12.36	11.74	11.43	9.93
4. Grapes	3.97	7.81	7.44	8.60	8.53
5. Peach and nectarine	7.08	5.54	5.30	4.83	5.07
6. Pears	2.60	3.21	3.40	2.91	3.12
7. Strawberries	1.97	3.24	4.86	5.83	6.45
8. Pineapples	1.49	2.05	3.22	4.91	5.08

Source: USDA (2008a).

Table 22.4. Per Capita Consumption of Apple and Apple Products in United States (lb, Fresh Weight Equivalent)

	Fresh	Canned	Juice	Frozen	Dried	Others	All
1980	19.20	5.27	13.01	0.79	0.82	0.72	39.81
1990	19.56	5.50	20.66	1.12	0.76	0.29	47.88
2000	17.46	4.36	21.37	0.92	0.77	0.33	45.21
2005	16.67	4.19	22.28	0.86	0.73	0.54	45.26
2008	16.17	4.41	25.68	0.70	0.90	0.78	48.62

Source: USDA (2008a).

apples are utilized as fresh; the remaining 67% are processed into products. Of the processed apples, juice and cider make up about 53%; canned apples (mostly as applesauce) about 9%; frozen, dried, and other items (apple jam, apple butter, etc.) are less than 2% each (Table 22.4).

HARVEST, POSTHARVEST, AND STORAGE

Harvest

Premature harvesting of apples affects fruit size, skin color, firmness, taste and flavor, Brix, and acidity. It also increases susceptibility to storage disorders such as bitter pit and storage scald. Harvesting too late can produce softer, mealy fruits with shorter storage life.

Early maturing varieties can be ready for harvest in August or early September; however, most apples in the United States are harvested by late September through October. Growers use "days after full bloom (DAFB)" for maturity. For Gala and Fuji apples, DAFB are 110–120 days and 170–185 days, respectively.

Objective tests to determine harvest date include pressure tests (for firmness) using an Effigi tester or a Magness–Taylor pressure recorders (Anon 2003). Apples for storage and processing typically have pressures above 15 lbs. However, pressures in the range of about 13 lbs per square inch (psi) are suitable for fresh consumption. Other maturity indicators are size, skin color, Brix, acidity, and starch (starch is converted to sugars during ripening process) and ethylene measurements. A starch reading of 1–2 on a scale of 1–8 indicates that the fruit is immature; 5–6 indicates the fruit is suitable for consumption. Starch is estimated by applying iodine solution to cut apple surfaces; high starch content gives a complete blue–black reaction with a reading of 1.

Preharvest foliar spray of calcium has been suggested to maintain fruit firmness and decrease the incidences of physiological disorders such as water core, bitter pit, and internal breakdown in apples. Treatment with bioregulators such as ethephon is suggested to improve fruit quality and storability (Drake et al. 2002). Similarly, treatment with 1-methylcyclopropene (1-MCP) is reported to improve postharvest quality of apples by regulating ethylene biosynthesis. Lurie et al. (2002) reported 50% and 95% inhibition of ethylene by treatment with 0.1 μL/L and 1.0 μL/L 1-MCP. This compound has also been shown to improve flavor and quality of apples during storage (Defilippi et al. 2004, 2005).

Postharvest Handling and Storage

Typical postharvest treatments for apples include washing, hydrocooling, sorting, grading, testing, waxing, and packing. Shellac- and wax-based fruit coatings having high permeability to carbon dioxide (CO_2) and oxygen (O_2), and relatively low permeability to water vapor and fruit volatiles have been reported to improve the shelf life of apples (Saftner 1999).

Apples are stored at 0°C to −1°C with 92–95% humidity in regular cold storage for a short duration. Prompt cooling after the harvest minimizes softness in stored apples. Controlled atmosphere (CA) storage has extended the marketing season of apples. This type of storage involves storing apples at approximately 0°C in a facility with 1–3% O_2 and 1–3% CO_2 to slow the respiration rates of fruits. The relative humidity in storage is maintained at 92–95%. Under CA, apples can be stored for about a year without any appreciable loss of quality. The CA storage requires airtight refrigerated rooms that are sealed after apples are placed inside (and must not be opened for at least 90 days after the seal is affixed). The O_2 content is reduced from atmospheric 21% to 1–3% and CO_2 content is increased from atmospheric 0.25% to 1–3%. Storage disorders such as "corky" flesh browning, bitter pit, firmness loss, chilling injury, superficial scald, water core, etc., are not uncommon, and stem from inconsistent storage protocols and questionable fruit quality entering CA storage (Anon 2003). Lavilla et al. (1999) showed that low oxygen (1.8–2% O_2/1.8–2% CO_2) and ultra-low oxygen (0.8–1% O_2/0.8–1% CO_2) CA had better effect on sensory qualities of stored apples than a standard low oxygen (2.8–3.0% O_2/2.8–3% CO_2) CA storage.

APPLE BIOCHEMISTRY (FLAVOR, COLOR, TEXTURE, PLANT FLAVONOIDS, ANTIOXIDANT CAPACITY) AND HEALTH BENEFITS

Desirable apple quality is based on simple attributes, such as fresh appearance, a balance between sweetness (Brix) and tartness (acidity), fresh fruit aroma, and firm juicy texture. Table 22.5 shows characteristics of selected commercial apple varieties. The Brix and acidity of two popular apple

Table 22.5. Characteristics and Uses of Selected Apple Varieties

Variety	Characteristics	Use
1. Braeburn	Originated in New Zealand; harvested, mid to late October; appearance, pale pink over a yellow-green background; yellow flesh; sweet taste with moderate tartness	An all-purpose apple for fresh eating and processing as sauce, pie and baked, juice, and cider
2. Empire	A cross between McIntosh and Red Delicious; harvested, late September to early October; dark red appearance; size, small to medium; sweet with mild tartness; flesh is creamy white	A good apple for fresh eating and for salad but can be used in other applications as well
3. Fuji	A cross between Ralls Janet and Red Delicious; bred in Japan; popular apple in Japan and China; introduced in United States in 1980s; harvested, September to late October (in some regions, late October to mid-November); appearance, golden hued to red; round shape; large to extra large in size ($1\frac{1}{2}''$ to $4''$); sweet and aromatic; crisp texture; flesh is whitish yellow; good storage apple	For multiuse; holds texture after processing
4. Gala	Originated in New Zealand from "Kidd's Orange Red × Golden Delicious"; harvested, mid to late August; appearance, orange-red strips over creamy yellow; mild sweet flavor; flesh is yellow, firm, and juicy. Good aroma apple	For fresh eating and salad
5. Golden Delicious	Genetically not related to Red Delicious; a famous apple from West Virginia; parentage is believed to be Golden Reinette and Grimes Golden; harvested, mid-September to early October; small to medium size ($2\frac{3}{8}''$ to $3''$) pale greenish-yellow appearance; sweet apple with excellent flavor; juicy yellow flesh; aromatic apple	This is an all-purpose apple used in fresh apple cider; produces cream colored applesauce
6. Granny Smith	Raised by chance from a seed thrown out by an Australian grand mother Maria Ann Smith; a long season fruit, may not ripen before frost; harvested, October to early November; appearance, signature green; size, large ($2\frac{1}{2}''$ to $3\frac{1}{2}''$); a slightly tart apple with a crisp texture and white flesh	This apple has good eating and cooking qualities; excellent for applesauce, salad, and apple juice
7. Ida Red	Developed from Jonathan and Wagener; harvested, mid to late October; large apple ($2\frac{1}{2}''$ to $3\frac{1}{4}''$); appearance, bright red; flavor, tangy and tart; flesh is white, firm, and juicy	Used as fresh, frozen, canned, sauces, and pies
8. Jonagold	A cross between Jonathan and Golden Delicious; harvested, mid-October; size, medium large ($2\frac{1}{2}''$ to $3''$); appearance is orange red; well-flavored greenish white flesh; fine taste; crisp and juicy	Excellent fresh eating and cooking (pie and baked) quality apple
9. Jonathan	Discovered as a chance seedling in 1820s on a farm in Woodstock, New York; named after the man who promoted it; harvested, mid-September to mid-October; crimson color with touches of green; flavorful with small to medium slices; flesh is off-white, sweet and juicy; blends well with other varieties in sauces and cider; stays firm during cooking	Crimson color with touches of green; flavorful with small to medium slices; flesh is off-white, sweet and juicy; blends well with other varieties in sauces and cider; stays firm during cooking
10. McIntosh	An important commercial variety; harvested, early to mid-September. Appearance, red striped; white juicy flesh, tender skin; medium large fruit ($2\frac{1}{2}''$ to $3''$); good aroma apple	Mainstay of fresh cider, for eating out of hand and sauce making
11. Mutsu (Crispin)	Origin, Japan; a cross between Golden delicious and Japanese variety Indo; one of the later variety apple with mid-October harvest; light green to yellow; very large fruit ($1\frac{1}{2}''$ to $3\frac{3}{3}''$); moderately sweet; creamy flesh	Preferred use: fresh, pies, and baked
12. Northern Spy	Harvested, mid-October; large size ($2\frac{1}{2}''$ to $3\frac{1}{4}''$); yellow-green skin and creamy white flesh; crisp and juicy; spicy, aromatic flavor	Can be used in various processing, including, slices, sauces, and pie
13. Red Delicious	Believed to be the most popular variety in the world and in the United States; discovered as a chance seedling on a farm of a nonapple region—central Iowa, glossy red with a distinctive "typey" five-pointed elongated shape. Sweet and flavorful; harvested, late August; can generally be found in market in fall and early winter; good aroma apple	Fresh and salad use
14. Rome	Discovered in Rome township, Ohio; harvested, mid to late October; size, large ($2\frac{1}{2}''$ to $3\frac{1}{4}''$) bright red skin; sweet, juicy, white flesh; somewhat neutral in flavor	Good processing apple for pies, sauce, and baked

Sources: www.michiganapple.com; www.applejournal.com; www.paapples.org/varieties.htm; www.raa.nsw.gov.au; Peterson Farm Inc. Michigan.

Table 22.6. Characteristics of Golden Delicious and Granny Smith Apples

	Golden Delicious		Granny Smith	
Characteristics	1993–1994	1994–1995	1993–1994	1994–1995
Brix (soluble solids)	12.2 ± 0.2	11.8 ± 0.2	11.8 ± 0.2	10.3 ± 0.3
Acidity (% malic acid)	0.39 ± 0.1	0.45 ± 0.7	0.93 ± 0.7	1.0 ± 0.13
Texture (kg/cm^2)	6.7 ± 0.1	6.5 ± 0.3	7.3 ± 0.4	7.8 ± 0.3

Source: Lopez et al. (1998).

varieties, Golden Delicious and Granny Smith, at harvest for two growing seasons are given in Table 22.6. These two varieties have similar Brix, but the acidity of Granny Smith is almost three times that of Golden Delicious. The Brix to acid (Brix/acid) ratio shows relative sweetness to tartness profile of a fruit. For example, Golden Delicious and Granny Smith's Brix/acid values (Table 22.6) are 26–31 and 11.8–12.7, respectively. Thus, Golden Delicious apples would be perceived twice as sweet as Granny Smith.

Apples contain approximately 85% water, 12–14% carbohydrate, about 0.3% protein, less than 0.10% lipids, minerals, and vitamins (Table 22.7). Variation in these values can be expected due to differences in growing location, variety, maturity, agronomical, and environmental conditions.

Table 22.7. Proximate Composition of Apples (Raw, with Peel)

Component	Values/ 100 g	Values/Serving (154 g)
Water (g)	85.56	131.76
Protein (g)	0.26	0.40
Total lipids (g)	0.17	0.26
Ash (g)	0.19	0.29
Total carbohydrate (by difference) (g)	13.81	21.27
Sugars (total) (g)	10.39	16.00
Sucrose (g)	2.07	3.19
Glucose (g)	2.43	3.74
Fructose (g)	5.90	9.09
Starch (g)	0.05	0.08
Dietary fiber (g)	2.40	3.70
Calcium (mg)	6.00	9.00
Iron (mg)	0.12	0.18
Magnesium (mg)	5.0	8.0
Phosphorus (mg)	11.0	17.0
Potassium (mg)	107.0	165.0
Sodium (mg)	1.0	2.0
Zinc (mg)	0.04	0.06
Vitamin C (mg)	4.60	7.10
Vitamin A (IU)	54.0	83.0
Cholesterol (mg)	0.0	0.0
Calorie (kcal)	52.0	80.0

Source: USDA (2008b).

Approximately 80% of carbohydrates present in apples are soluble sugars, sucrose (about 2%), glucose (2.4%), and fructose (6.0%). The total fiber content is about 2%; 0.2% sorbitol has also been reported in apple juice (Van Gorsel et al. 1992). Malic acid is the primary organic acid (0.3–1.0%), which can vary due to variety, maturity, environmental conditions during growth, and storage (Ackermann et al. 1992). Lopez et al. (2000) reported changes in firmness, acidity, soluble solids, and skin color of Golden Delicious apples during storage with fruits in normal cold storage maturing more quickly than fruits stored under CA.

Flavor

Flavor and aroma of apple are a function of composition, variety and maturity, environmental conditions during growth, biochemical and metabolic processes regulating ripening, and storage conditions. Defilippi et al. (2005) reported role of ethylene, amino acids (branched chain amino acids, isoleucine, leucine, and valine), fatty acids (palmitic, stearic, oleic, linoleic, and linolenic), precursors and aroma-related enzymes, alcohol acyltransferase, alcohol dehydrogenase, and lipoxygenase on biosynthesis of volatiles in apples. According to these researchers, volatile profile of apples investigated was dominated by aldehydes at harvest, esters, and alcohols after 13 days of storage at 20°C. They also observed higher levels of esters and alcohols in the peel tissue than flesh. Lurie et al. (2002) reported the presence of aldehydes and alcohols at the harvest, with some acetate esters as well as 2-methylbutyl acetate and β-damascenone. They showed that during ripening, acetate and butyrate esters increased and alcohols and aldehydes decreased. However, Lopez et al. (2000) reported that at harvest, the fruit is at an early preclimacteric stage of ethylene (0.7 μL/kg/h) production and esters comprised more than 185 μg/kg of total volatile compounds. Ethyl acetate, ethyl propionate, and propyl acetate accounted for 73 μg of the total volatile fractions and 2-methylbutyl acetate accounted for 8.0 μg/kg. Cunningham et al. (1986) showed that β-damascenone (sweet, perfumy, and fruity odor), butyl isoamyl, and hexyl hexanoates, along with ethyl, propyl, and hexyl butanoates, are important to flavor of most apple cultivars. Ester compounds such as ethyl propionate and butyl acetate give the characteristic "apple"

Table 22.8. Concentration of Flavor Volatiles (μg/kg)[a]

Compound	Concentration (μg/kg)
Methyl acetate	178.5 ± 78.5
Hexyl acetate	70.5 ± 18.9
2-Methylbutyl acetate	81 ± 2.8
Ethyl propionate	120.0 ± 69.3
Ethyl butyrate	147.5 ± 48.8
Hexyl butyrate	25.5 ± 0.7
Ethyl 2-methylbutyrate	167.0 ± 19.8
Hexyl 3-methylbutyrate	35.0 ± 5.7
Ethyl hexanoate	169.0 ± 67.9
1-Propanol	56.5 ± 7.8

Source: Lavilla et al. (1999).
[a]In Granny Smith apples after 1 day at 20°C followed by 3 months under CA (2% O_2/2% CO_2) storage.

flavor; hexyl acetate, "sweet-fruity"; and 1-butanol, "sweetish sensation". Compounds responsible for undesirable flavors such as acetaldehyde (piquancy), *trans*-2-hexanal and butyl propionate (bitter), and 3-methylbutylbutyrate and butyl 3-methylbutarate (rotten) were not found in apple varieties analyzed by Lopez et al. (1998).

The flavor volatiles responsible for characteristic apple flavor are reported to be maintained even after 3 months of CA storage (Table 22.8).

Plant Flavonoids

Apples are good sources of natural polyphenol and other phytochemicals such as hydroxycinnamic acids, dihydrochacones, flanols, catechins and oligomeric procyanidins, triterpenoids (in apple peel), and anthocyanins (in red apples). These secondary plant metabolites with antioxidant properties have been shown to minimize effects of free radical induced degenerative and chronic diseases. Gerhauser (2008) reviewed cancer preventive potential of apples and indicated that regular consumption of one or more apples a day may reduce the risk of lung and colon cancer. Apple varieties differ in their flavonoid concentration. Jonagold was shown to have relatively higher concentration of flavonoids than Golden Delicious, Elstar, and Cox's orange (Table 22.9). Flavonols are present more in peel than in flesh, while hydroxycinnamics such as chlorogenic acid is present more in flesh than in peel (Table 22.10).

McGhie et al. (2005) studied effect of cultivar and growing region on polyphenolic concentration and composition of apples grown in New Zealand. They showed that on average, 46% of the polyphenolic concentrations in apples were in skin. Lata and Tomala (2007) reported flavonols (~40%), ascorbate (~30%), and total phenolics (~20%) in apple peel. Apple juice varies in phenolic content; fresh apple juice has greater phenolics than stored juice (Table 22.11). Wu et al. (2004) reported total antioxidant capacity

Table 22.9. Concentration of Flavonoids in Selected Apple Varieties[a] (μg/g of Fresh Weight)

Compound	Jonagold	Golden Delicious	Cox's Orange	Elstar
Total Q-glycosides[b]	95 ± 11	67 ± 11	64 ± 12	63 ± 12
Total catechins[c]	145 ± 37	121 ± 29	106 ± 47	152 ± 42
All compounds[d]	467 ± 86	385 ± 108	265 ± 98	326 ± 100

Source: Sluis et al. (2001).
[a]Mean (± SD).
[b]Total quercetin glycosides.
[c]Catechin and epicatechin.
[d]Sum of all phenolic compounds analyzed.

Table 22.10. Average Concentration (μg/g Fresh Weight) of Phenolic Compounds in Peel and Flesh of Apples[a]

Compound	Peel	Flesh
Total hydroxycinnamics[b]	148.5	193.0
Total procyanidins[c]	958.2	267.7
Total flavonols[d]	288.2	1.3
Total dihydrochalcones[e]	123.7	19.3
Total polyphenolics (HPLC)[f]	1604.4	481.3
Total phenolic content (F-C)[g]	1323.6	429.6

Source: Tsao et al. (2003).
[a]Based on eight apple varieties.
[b]Chlorogenic and p-coumaroylquinic acid.
[c]Catechin, epicatechin, and other procyanidins.
[d]Quercetin-3-galactoside, glucoside, xyloside, arabinocide, rhamnoside.
[e]Phloridzin and ploreitin.
[f]Calculated on the basis of total phenolics calculated by HPLC.
[g]Phenolic content measured by Folin–Ciocalten method.

(TAC) of apple varieties to range from 3578 to 5900 μmol of Trolox equivalent (TE)/serving of apple (Table 22.12). Apples with peel had higher TAC values than without peel. Among the varieties analyzed, Red Delicious had the highest TAC (5900 μmol) followed by Granny Smith (5381 μmol), Gala (3903 μmol), Golden Delicious (3685 μmol), and Fuji (3578 μmol).

Nutritional Quality

Besides plant flavonoids, apple contains natural sugars, organic acids, dietary fiber (80% of which are soluble fibers), minerals, and vitamins (Table 22.7). Fresh eating apples are considered a natural dessert with little fat and cholesterol, and less than 100 calories per serving size. Apples are also a good source of potassium, which have beneficial role in blood pressure regulation. Nutrient profile of various apple products is given in Table 22.13.

Table 22.11. Concentration of Phenolic Acids, Flavonoids, and Total Polyphenols (mg/L) in Fresh and Stored Apple Juice

Component	Fresh Juice	Stored Juice
Phenolic acids	43.54 ± 0.45 to 93.07 ± 0.39	34.44 ± 0.17 to 84.46 ± 0.09
Flavonoids[a]	20.30 ± 0.31 to 92.11 ± 3.19	17.55 ± 0.17 to 74.77 ± 0.39
Total polyphenols	63.84 ± 0.71 to 163.35 ± 3.62	51.99 ± 0.18 to 139.43 ± 0.36

Source: Gliszczynska-Swiglo and Tyrakowska (2003).
[a]Quercetin glucosides, phloridin, and kaempferol.

PROCESSED APPLE PRODUCTS

Processed apple products such as juice, cider, applesauce, jam, and jelly are universally consumed. Frozen, diced, and sliced apples are typically used in pies and other baked applications. Recent advances in minimal processing have allowed use of fresh, mostly peeled apple slices with a refrigerated shelf life of about 1 week. Intermediate moisture and infused-dried apples are used as ingredients in bakery, dairy products, cereals, snack bars, confection, etc. Infused-frozen and stabilized-frozen apples are used in dairy and bakery products. Dried apple fiber (based on apple pomace obtained from juice operations) is available as a source of fruit-based dietary fiber for use in various foods. This section describes processing of selected apple products.

Apple Juice and Cider

Apple juice can be frozen concentrate, canned, pasteurized, or aseptically processed. In the United States, apple juice leads consumption of all apple products (Table 22.4). Apple juice making involves milling/mashing of apples into smaller pieces and pressing with a hydraulic filter press to express juice. Thus, the apple juice and cider are extracted liquids containing soluble solids primarily fruit sugars and acids. Cider is cloudy because of pulp (solids), amber golden in appearance, and often unfiltered and unpasteurized with potentials for food-borne illness. Cider processors use pasteurization (heating to 60–65°C with 30 minutes hold time) to achieve 5-log reduction in pathogenic microorganisms. As pasteurization can affect flavor, color and viscosity alternate processes such as use of electron beam radiation have been suggested (Boylston et al. 2003). Chikthimmah et al. (2003) reported a 5-log cycle reduction in *Escherichia coli* O157:H7 in cider by adding fumaric acid (0.15% w/v) and sodium benzoate (0.05% w/v) to the product. The use of these preservatives lowered the natural pH of cider from 3.40–3.87 to 3.19–3.41 and inactivated *E. coli*.

Unlike "hard ciders," which contain alcohol, regular ciders are not fermented. The characteristic cider flavor varies from region to region and is based on types of apples used in the manufacturing process. Blanco-gomis et al. (2002) characterized cider apples based on fatty acids composition. The unsaturated oleic and linoleic acids and saturated caprylic, capric, stearic, and palmitic acids were related to the sweet apple cider category, while pentadecanoic acid was related to sharp category. The fatty acids contribute to flavor as precursors of volatile aldehydes and alcohols by the action of oxygen and a multienzymatic system made up of lipoxygenase, hydroperoxide lyase, and alcohol dehydrogenase.

Apples used in juice making can be culled from fresh packing lines. In the traditional milling–pressing operations, the juice yields can vary from 70% to 80% (w/w), and about 65% for stored apples (Cliff et al. 1991). However, through use of enzyme liquefaction and membrane filtration, the apple juice yields can be as high as 98%.

Typical juice-making steps are given in Figure 22.1. The process follows hazard analysis critical control point (HACCP) to identify potential hazards; determine critical control points; establish control limits; and proper monitoring systems for verifications, audits, and tracebility. The apple used should be from certified growers who follow good agricultural practices and maintain records of phytosanitary practices during production. Fruit receiving operation includes cleaning, washing with chlorinated water, grading and inspection (to remove defective, rotten, and moldy fruits), and quality checks (weighing, Brix, acidity, microbial tests, etc.). Subsequently, apples are milled/sliced (using bars/knives) before pressing/extraction. Treatments with enzyme or use of fining agents, or both, are practiced to remove suspended solids from the pressed juice (Kilara and VanBuren 1989). The apple juice is then microfiltered and pasteurized before packaging into hermetically sealed cans or bottles or aseptically packaged.

Typically, a blend of several apples is used to provide flavorful apple juice and cider. A batch hydraulic (a traditional rack and frame) press where milled apples are placed on thick fabrics separated by wooden racks and hydraulic pressure is applied from the top of the rack to release the juice, and various types of continuous pressing equipment are used. The latter are often employed in commercial operations because of efficiencies in yield, quality, and process controls. It also permits low residual moisture in the pressed cake or pomace.

Commercial juice press designs include a belt press where milled apple pulp is held between belts and juice is released through pressure from rollers, and a screw press made up

Table 22.12. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity, and Total Phenolics of Selected Apple Varieties

Apple	Moisture (%)	L-ORAC$_{FL}$ (μmol of TE/g)	H-ORAC$_{FL}$ (μmol of TE/g)	TAC[a] (μmol of TE/g)	TP[b] (mg GAE per/g)	Serving Size (g)	TAC/s[c] (μmol of TE)
Fuji	84.2	0.21 ± 0.11	25.72 ± 6.96	25.93	2.11 ± 0.32	138 g (1 fruit)	3578
Gala	85.8	0.35 ± 0.08	27.93 ± 1.42	28.28	2.62 ± 0.29	138 g (1 fruit)	3909
Golden Delicious (with peel)	86.1	0.26 ± 0.06	26.44 ± 1.61	26.70	2.48 ± 0.18	138 g (1 fruit)	3685
Golden Delicious (no peel)	86.9	0.05	22.05	22.10	2.17	128 g (1 fruit)	2829
Red Delicious (with peel)	85.5	0.41 ± 0.02	42.34 ± 4.08	42.75	3.47 ± 0.38	138 g (1 fruit)	5900
Red Delicious (no peel)	86.7	0.07	29.29	29.36	2.32	128 g (1 fruit)	3758
Granny Smith	85.7	0.39 ± 0.11	38.60 ± 4.69	38.99	3.41 ± 0.38	138 g (1 fruit)	5381

Source: Wu et al. (2004).
TE, Trolox equivalent.
[a]TAC = Total antioxidant capacity (L-ORAC$_{FL}$ + H-ORAC$_{FL}$) as Trolox equivalent/g.
[b]TP = Total phenolics as milligram of gallic acid equivalent/g.
[c]TAC/s = Total antioxidant capacity per serving size.

Table 22.13. Nutritional Values of Selected Apple Products

Nutrients/100 g	Apple Juice[a]	Apple Juice Concentrate[b]	Apple Sliced, Canned[c]	Apple Sauce[d]	Dehydrated Apple[e]	Infused-Dried Apple[f]
Calories (kcal)	47.0	166.0	67	43	346.0	336.0
Total fat (g)	0.11	0.37	0.43	0.05	0.58	1.93
Saturated fat (g)	0.019	0.06	0.07	0.008	0.095	0.20
Polyunsaturated fat (g)	0.033	0.108	0.126	0.014	0.171	0.30
Monounsaturated fat (g)	0.005	0.015	0.017	0.002	0.024	1.4
Cholesterol (mg)	0.00	0.0	0.0	0.0	0.0	0.0
Sodium (mg)	3.0	25	3.0	2.0	124.0	31.0
Potassium (mg)	119.0	448	70.0	75.0	640.0	64.0
Total carbohydrate (g)	11.68	41.0	16.84	11.29	93.53	81.7
Total fiber (g)	0.1	0.4	2.0	1.2	12.4	6.3
Total sugar (g)	10.90	38.83	14.84	10.09	81.13	75.5
Sucrose (g)	1.70	NA	NA	NA	NA	NA
Glucose (g)	2.50	NA	NA	NA	NA	NA
Fructose (g)	5.60	NA	NA	NA	NA	NA
Protein (g)	0.06	0.51	0.18	0.17	1.32	2.26
Calcium (mg)	7.0	20.0	4.0	3.0	19.0	65.0
Iron (mg)	0.37	0.91	0.24	0.12	2.00	0.42
Vitamin C (mg)	0.9	2.1	0.2	1.2	2.2	372.0
Vitamin A (IU)	1.0	0.0	56.0	29.0	81.0	20.0
Water (g)	87.93	57.0	82.28	88.35	3.0	12.7

Source: USDA (2008b).
NA, not available.
[a]Canned or bottled, unsweetened, without added ascorbic acid.
[b]Frozen concentrate without added ascorbic acid.
[c]Canned, sweetened sliced apple: Drained and heated.
[d]Canned unsweetened apple sauce without added ascorbic acid.
[e]Low moisture dehydrated, sulfured apples.
[f]Data of commercial product, courtesy Graceland Fruit Inc, Frankfort, MI: Infused with sugar prior to drying, contains ascorbic acid and high oleic sunflower oil.

of tapered screws to convey and squeeze juice against close fitting screens. Juice extraction can also be done using a centrifuge. In a countercurrent extraction process, juice is extracted with water. The extracted water is then depectinized and passed through membrane filtration systems (microfilter and revesrse osmosis) to generate about 10°–12°Brix juice, which can be further concentrated to about 67°Brix using multistage evaporators.

The presence of colloidal pectic substances such as starch, cellulose, hemicelluloses, pectins, etc., cause haze, cloudiness, and sedimentation in apple juice. Therefore, after extraction, apple juice is treated with enzymes, fining agents (diatomaceous earth, gelatin, etc.), or both to remove suspended solids and clarified using membrane filtration. Two pectinase enzymes are usually employed in juice-making operations. Polygalacturonases (an endoform: EC 3.2.1.15 and two exoforms: EC 3.2.1.67 and EC 3.2.1.82), which act on glycosidic linkage, are responsible for fruit softening. These enzymes can be used as a press aid, that is, can be added to milled/crushed apples before the juice extraction step. Pectin lyase (EC 4.2.2.10) degrades the pectin chain by acting on glycosidic linkage through β-elimination. A combination of endo- and exolyases can be used to depectinize juice and as a clarification and membrane filtration aid. The enzyme doses, time, and temperature would depend upon specific enzymes. Clarification time is inversely proportional to the enzyme concentration.

The presence of amino acid proline is linked with haze formation. A protein–polyphenol haze is due to interactions between a protein fraction capable of binding polyphenols (haze active protein) and a polyphenol fraction (haze active polyphenol) that can form a bridge between two protein molecules. Stabilization steps for manufacturing a clear apple juice are designed to reduce the levels of either protein or polyphenol or both (Siebert and Lynn 1997; Siebert and Lynn 2000).

Following the enzymatic treatment and membrane filtration, the juice is pasteurized (88°C/1 min) and packaged. In 2001, the Food and Drug Administration (FDA) promulgated rules requiring juice processors to use HACCP principles and sanitary standard operating procedures (SSOPs) because of the risk of food-borne illness from consumption of unpasteurized juice products. Under the federal "Juice HACCP" rule, juice processors must comply with the following: (1) HACCP

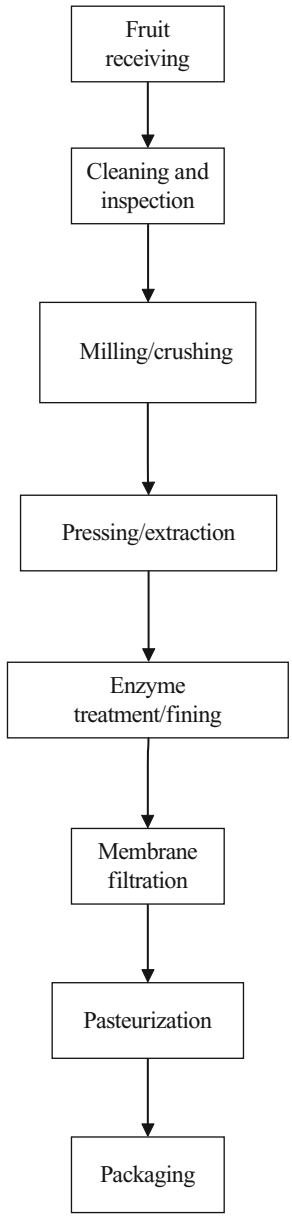

Figure 22.1. Process for apple juice.

principles and systems; (2) reduce a theoretical population of "pertinent" microorganisms in the juice by 5-log cycles. The "pertinent" microorganism is defined as the most resistant microorganism of public health concern that is likely to occur in juice. *E. coli* O157:H7 and *Cryptosporidium parvum* are regarded as "pertinent" organisms for apple juice.

In 1996, *E. coli* O157:H7 contamination of apple juice was responsible for over 70 illnesses and 1 death in the United States. This organism due to its acid tolerance and low infectious dose (10–2000 CFU/g) is of concern in unpasteurized juices and ciders. Patulin, a mycotoxin (one of the microbial hazard to be controlled under HAACP regulation) produced by certain species of *Penicillium*, *Aspergillus*, and *Byssochylamys* molds that may grow on harvested apple, is also a regulatory concern. The regulations typically limit Patulin content in apple juice to be no more than 50 ppm (μg/kg) (Kryger 2001).

Apple Slices

A number of techniques are used to maintain flesh color, flavor, and crisp texture of apple slices. The softening of apple tissue due to loss of cell fluids and enzymatic browning are subject of many investigations including modified atmosphere packaging, low temperature storage, and addition of preservatives (Soliva-Fortuny et al. 2001).

Polyphenol oxidase (PPO) catalyzed oxidation of phenolic compounds (enzymatic browning) that results in dark brown color when cut apple are exposed to air is undesirable. The role of oxygen in enzymatic browning and cellular damage was evident from lower firmness values and greater amount of cell fluid loss in apples packed in a 2.5% O_2 and 7% CO_2 atmosphere package than in 100% N_2 atmosphere package (Soliva-Fortuny et al. 2003). Commonly used effective inhibitors of PPO are sodium metabisulfite and ascorbic acid. However, sulfites have been linked to allergic reaction, especially in asthmatic individuals. In the United States, FDA regulates the use of sulfites in foods, and sulfite content $\geq$10 ppm is required to be shown on the labels. The alternatives to sulfites are based on ascorbic acid, citric acid, and calcium salts. Santerre et al. (1988) reported that application of ascorbic acid or ascorbic acid–citric acid combination has beneficial effects on quality of frozen apple slices. Calcium ascorbate or calcium erythorbate and ascorbic acid applications and storage at -7°C to 20°C have been claimed to extend shelf life of fresh-cut fruits including apples (Chen et al. 1999; U.S. patent 5,939,117). Powrie and Hui (1999; U.S. patent 5,922,382) described a method of preserving fresh apple by immersing apple pieces in an acid solution containing 5–15% ascorbic acid and erythorbic acid (pH 2.2–2.7) for up to 3 minutes, followed by removal of excess solution from fruit surfaces, quick chilling, and storing at 0°C–10°C.

Use of edible coating containing prebiotics such as inulin on fresh-cut apple wedges has been reported (Roble et al. 2011) to provide 1–3 g of prebiotics per 100 g of apples. The sensory quality of apples was stable throughout the 14 days.

Applesauce

Applesauce contains apple, sugar and other sweeteners, honey, acidulants, salt, flavorings, spices, preservatives, etc. The desirable characteristics of applesauce are golden creamy color, a balance of sweetness and tartness, and glossy texture, which is not soft and mushy. The United States Standards for Canned Applesauce Grades effective since 1982 (http://www.ams.usda.gov/AMSv1.0/) give details of

natural, spice flavored, artificially colored, regular, and chunky canned apple sauce. The Brix of unsweetened and sweetened applesauce is minimum 9.0 and 15.5, respectively. Applesauce has a pH of approximately 3.4–4.0. The typical processing steps are as follows:

- Dice/chop wash apples (a blend of several apple varieties, in peeled or unpeeled forms can be used).
- Heat apple pieces (similar to blanching, this step is important for consistency and color of the finished product).
- Pass through a pulper/finisher (screen size: 0.16–0.32 cm; for coarse grainy sauce: 0.25–0.32 cm) to remove seeds, peels, etc.
- Fill and seal in containers (the fill weight is 90% of the container's capacity and allow for a head space of about 0.6 cm upon cooling).
- Heat process (if the fill temperature is $\leq 88^{\circ}$C, heat containers in boiling water for 10–15 minutes in an open container to ensure microbiological safety; a high pressure processing ensures product safety and longer shelf life by destroying spoilage organisms).
- Invert containers and cool.

Infused Frozen Apple

Apple can be infused in sugar and other types of sweeteners and pasteurized (65°C with 5 minutes hold) for use in frozen desserts such as ice cream, frozen yogurt, etc., or for addition into baked good. The water content of apple is stabilized by infusion with sweeteners or by incorporating stabilizer (pectins, carrageenan, gums, and modified starches). The fruits thus processed are not icy and crystalized when frozen. As the products are pasteurized, they are a ready to use ingredients in frozen desserts. The process maintains fruit piece identity, natural color, texture, and flavor (Sinha 1998).

Dried Apples

Drying as a method of food preservation has been practiced since the earliest recorded history. A number of drying techniques are available (sun drying, atmospheric drying using heated air, vacuum, and freeze drying, etc.), but they all must take into consideration the economics and efficiencies of operation. Prior to the advent of freezing and canning, drying was used to conserve surplus quantities of produce. However, as drying was more or less a salvage operation then, little emphasis was placed on optimizing important parameters (variety, maturity, postharvest handling, size, shape, etc.) that are required for obtaining good quality dried products. In the current market where consumers demand quality and are willing to pay for it, the aim of drying is to preserve quality and provide shelf stability.

For a given type of dryer, the drying rate at a given temperature would depend on pretreatments (blanching, etc.), type of product (fresh or frozen) with or without skin, composition, size and geometry (sliced, diced, etc.), and drying load or feed rate. In general, the drying profile can be divided into (i) a short period of quick water evaporation per unit time. Initially, the fruit contains relatively high amounts of free moisture not tightly bound to the constituents of the fruit cell and this free moisture can be evaporated fairly quickly; (ii) followed by a steady or constant drying rate; and (iii) a falling or declining rate of water evaporation toward the end of cycle, because the remaining water is tightly held by fruit components and is difficult to dislodge.

Moisture content of dried fruit is important. The completion of drying is determined by monitoring water activity (a_w). The cutoff a_w of shelf stable dried fruit is below 0.65; above this, a_w mold can grow on the dried fruits (Beuchat 1981) if it does not contain any antimycotic agents.

The color of dried apple is often of concern. About 20% of the nonenzymatic browning reaction occurring during storage have been attributed to nonoxidative, or Maillard reaction and about 70% to oxidation. Cysteine, which is helpful in preventing nonenzymatic browning, did not reduce browning during storage (Bolin and Steele 1987). Pineapple juice was an effective browning inhibitor in both fresh and dried apples. In this case, the inhibitor(s) was not a high-molecular-weight protein such as bromelain, but a neutral compound of low molecular weight (Lozano-de-Gonzalez et al. 1993).

Most dried foods with reduced moisture are partly or completely amorphous. There is a glass transition (T_g) theory, which is based on the concept that a glass (amorphous material) is changed into a supercooled melt or liquid during heating, or to reverse transformation during cooling. The glass transition phenomena have implications for textural transformation in sugar-containing dried fruits. Mobility of water is high in glassy food systems; a heterogeneous distribution of water is often desired to provide soft dried texture. In foods, plasticization (T_g decreases) is mainly due to water, but other solutes such as glycerin may also act as plasticizers to enable soft textured dried products (Le Meste et al. 2002).

The T_g of freeze-dried apples has been reported to be $33.8^{\circ}\text{C} \pm 3.4^{\circ}\text{C}$. The T_g is shown to increase with the temperature of drying. The glass transition represents the thermal limit between a state where the molecular mobility is rather low (no reaction) and a state of increased molecular mobility, which favors diffusion and other reactions. Thus, a freeze-dried strawberry with a T_g of $45.4^{\circ}\text{C} \pm 2.2^{\circ}\text{C}$ would be less susceptible to color changes than freeze-dried apples (T_g of $33.8^{\circ}\text{C} \pm 3.4^{\circ}\text{C}$) or pear ($T_g$ of $24^{\circ}\text{C} \pm 2.6^{\circ}\text{C}$). However, other factors (besides T_g) such as internal fruit structure, porosity, thermal conductivity, matrix elasticity, temperature within the product, and rate of heat transfers during drying can affect fruit quality (Khalloufi and Ratti 2003).

The hygroscopic properties of dried apple chips are mainly due to their composition of sugars and pectins, in combination with their porous structure. At a_w below 0.12, apple chips demonstrated excellent crispness (Konopacka et al.

2002). During air-drying of apple rings, nonuniform moisture and/or temperature distribution can cause varying degree of shrinkage. Apples dried at 60–65°C showed higher cellular collapse than those dried at 40–45°C and 20–25°C (Bai et al. 2002).

Infused-Dried Apple

Infused-dried apples retain their shape, texture, and color much better than traditionally dried apples. A range of texture from chewy to crisp can be achieved by controlling the water activity of infused-dried apples. The infusion drying process (Fig. 22.2) consists of infusing diced or sliced apples in a sweetener or juice solution (polyols such as glycerin and sorbitol can also be used in infusion) to a desired Brix range, separating the infused fruit from the infusion solution and drying to generally about 0.40–0.60 water activity (about 8–14% moisture). High-stability oils such as high oleic sunflower (<1%) are sprayed on dried apples to enable nonsticky, free-flowing texture. The residual/spent syrup can be concentrated and reused.

Infused-dried apple is a value-added ingredient for various foods or snacks. Unlike other dried apples, infused-dried apples can be diced for application. With infusion-drying, use of sulfites is not necessitated (Sinha 1998). The infused-dried apples are also not high in calorie (Table 22.13), besides noncaloric sweeteners can be used for infusion. Infusion process allows incorporation of desirable vitamins and other nutrients of interest.

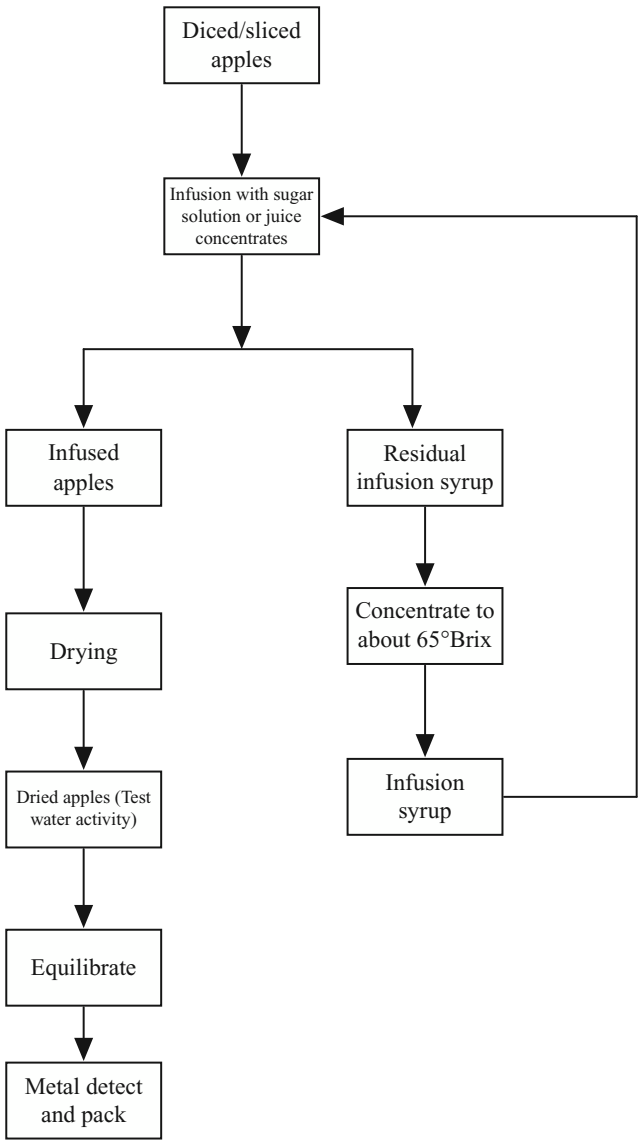

Figure 22.2. Typical infusion-drying process for apples.

Apple Fiber

Apple fiber is a by-product of apple juice processing. Following extraction of juice, the residual apple pomace is properly washed, dried (~2% moisture), and milled to specific screen size for use as source of dietary fiber. Chen et al. (1988) compared the chemical, physical, and baking properties of apple fiber with wheat and oat bran. On a dry weight basis, the apple fiber contained about 62% total dietary fiber (TDF). The wheat bran and oat bran had 38.0% and 26.4% TDF, respectively. Furthermore, about 67% of TDF in apple fiber composed of insoluble (cellulose: ~40%; lignin: 15%, pectin: ~9%, hemicellulose: 4%) fiber. The researchers showed that apple fiber had superior water binding to wheat and oat brans and can be added to cookies and muffins at a replacement level of at least 4% without affecting their qualities.

SECTION 2: PEARS: PRODUCTION, QUALITY, AND PROCESSING

INTRODUCTION

Similar to apples in production, postharvest handling, and processing, pears are sweet, fleshy, dessert-type fruits. European pears (*Pyrus communis* L.) and Asian pears (*Pyrus serotina* L.) are two categories grown in various parts of the world. This chapter provides a brief overview of their production, quality, and processing.

PRODUCTION AND CONSUMPTION

Production

The estimated world production of pears in 2008 was 21.0 MMT. China was the top pear producer (65.0% of the world production and 72.6% of area harvested), followed by the United States, Italy, Spain, and Argentina (Table 22.14). In

Table 22.14. Pear Production (Million Metric Ton, MMT) in Leading Countries and World

Country	1980	1990	2000	2009
1. China	1.58	2.48	8.52	14.41
2. United States	0.81	0.87	0.86	0.84
3. Italy	1.32	0.96	0.89	0.84
4. Spain	0.43	0.44	0.66	0.43
5. Argentina	0.15	0.23	0.51	0.70
6. S. Korea	0.05	0.15	0.32	0.47
7. Turkey	0.33	0.41	0.38	0.38
8. S. Africa	0.13	0.19	0.30	0.43
9. Japan	0.49	0.44	0.39	0.35
10. France	0.44	0.35	0.26	0.18
World (Total)	8.58	9.59	16.25	22.00

Source: FAO (2011).

the United States, the three Pacific Coast states, Washington, California, and Oregon, account for most of the pear cultivation.

The European pear varieties popular in the United States are Bartlett, Bosc, d'Anjou, Comice, Concorde, Forelle, Seckel, and Starkrimson. The Asian pears (also known as apple pears, Japanese or Chinese pears, or Oriental pears) are crisp, firm, and juicy. Some important Asian pear varieties are Ya Li, Hosui, Nijisseiki, Shinko, and Shhinseiki. All major varieties of pear were released about two centuries ago, and as is the case with apples, there seems to be little new pear variety trials (Kupferman 2007).

Consumption

The per capita consumption of fresh and canned pears in the United States in 2008 was 3.12 and 2.24 lbs, respectively. While the consumption of fresh pear has increased, canned pear consumption in the United States has been declining over the years.

HARVEST AND POSTHARVEST HANDLING

Harvest

Like apple, peach, plums, banana, and avocados, pears are picked unripe and before the commencement of climacteric, that is, when the internal ethylene concentration is low. However, most European pears, unlike other climacteric fruits, require a period of chilling and/or ethylene exposure to ripen properly (Villalobos-Acuna and Mitcham 2008). A proper understanding of effects of variety, agro-climatic conditions, seasonality, etc., on maturity indices such as skin color, seed color, size, flesh firmness, starch, soluble solids, and ethylene concentration is helpful in harvesting decisions. Kader (1999) indicated California's minimum maturity index for Bartlett pears as follows: color, yellow-green; firmness, $\leq$23 lb; soluble solids, $\geq$13°Brix. Like other characteristics, pear varieties differ in their flesh firmness. Gorny et al. (2000) reported flesh firmness of Anjou, Bartlett, and Bosc pears as 6.07–10.11 lbs (or 27–45 Newton), and for Red Anjou, 12.6–16.6 lbs. Kupferman and Dasgupta (2001) measured pressure of soft and firm Anjou pears as 3.90 and 9.15 lbs, respectively, by an Effegi pressure tester.

Postharvest Handling

Romani and French (1977) reported that Bartlett pears held continually at 40°C remained green and hard and developed an off-flavor indicative of abnormal metabolic reactions. Villalobos-Acuna and Mitcham (2008) reviewed ripening of European pears which, unlike other climacteric fruits, require a period of chilling and/or ethylene exposure to ripen properly, and the postharvest storage life of Bartlett and d'Anjou pears was better when stored at -1°C than at 0°C. Gorny et al. (2000) showed that pears held at -1°C in a CA (2% O_2 + 98% N_2) had a longer postcutting shelf life than those held in air at -1°C. Kader (1989) reported that the respiration rates of "Bartlett" pears were 35.0, 15.0, 4.0, and 3.0 mL CO_2/kg/h, respectively, for fruits kept in air (control), air + 20% carbon dioxide (CO_2), 1.5% oxygen (O_2), and 1.5% O_2 + 20% CO_2 atmosphere. The lowest ethylene production (3 μL/kg/h) was observed in 1.5% O_2 + 20% CO_2 atmosphere. This condition also showed higher flesh firmness. However, use of CA storage to extend the shelf life of pears can cause core browning, brown heart, and cavities (Rizzolo et al. 2005). Application of 0.42 μmol/m^3 1-MCP, which reduces ethylene synthesis 1 day after the harvest, was reported to prevent ripening of d'Anjou pear stored at 1°C for 4 months. Furthermore, the threshold concentration of 1-MCP to maintain firmness and inhibit senescent and disorders such as scald, core browning, and senescent scald at 1°C for 8 months was 4.2 μmol/m^3 (Argenta et al. 2003).

PHYSICOCHEMICAL AND NUTRITIONAL QUALITY

European pears have smooth texture; in contrast, Asian pears are crisp. Pears are sweet and not as acidic as apples or pineapples. Fructose is the main sugar in European pears and they contain more sorbitol than glucose and sucrose. Drake and Eisele (1999) reported that the source of the fruit influenced Brix (8.4°–11.2°) sugars and acid content of "Bartlett" (similar to European "Williams") pears at harvest. The predominant acid was citric acid (305.9–319.3 mg/100 mL). Table 22.15 shows sugar and acids data measured in pear juice and TAC and total phenolics of green pears. The green pears have slightly more (0.56 μmol TE/g) lipophilic oxygen radical absorbance capacity (L-ORAC) than most apples (0.21–0.41 μmol TE/g), but their hydrophilic ORAC value (18.56 μmol) is slightly lower than apples (25.71–42.34

Table 22.15. Sugar, Organic Acids, Total Antioxidant Capacity, and Total Phenolics in Pears

Sucrose (g/100 mL pear juice)	0.55 ± 0.12
Glucose (g/100 mL pear juice)	1.68 ± 0.36
Fructose (g/100 mL pear juice)	8.12 ± 1.56
Sorbitol (g/100 mL pear juice)	4.08 ± 0.70
Malic acid (mg/100 mL pear juice)	371 ± 16
Quinic acid (mg/100 mL pear juice)	220 ± 2
Total antioxidant capacity (μmol Trolox equivalent/100 g green pear cultivars)	1911
Total Phenolics (mg gallic acid equivalent/100 g green pear cultivars)	220

Sources: Pear juice data: Van Gorsel et al. (1992). Pear data: Wu et al. (2004).

μmol TE/g). A serving size (one fruit, weight 166 grams) of pears would provide approximately 3000 μmol TE (Wu et al. 2004). The total phenolics content of green pears [2.20 mg/g gallic acid equivalent (GAE)] is comparable with Fuji apples (2.11 mg GAE/g).

Colaric et al. (2006) reported chlorogenic acid (280.86–357.34 mg/kg FW) as the predominant phenolic acid, followed by syringic acid (95.46–131.32), epicatechin (46.55–83.09), catechin (25.67–44.81), vanillic acid (1.87–3.48), sinapic acid (0.83–1.72), and caffeic acid (0.72–1.04). Sanchez et al. (2003) reported that the skin/peel of the pears contained higher concentrations of chlorogenic acid, flavonols, and arbutin than the flesh, where only chlorogenic acid was detected. The total phenolics ranged from 1235 to 2005 mg/kg in the peel and from 28 to 81 mg/kg in the flesh. The ranges of vitamin C content were 116–228 mg/kg in the peel and from 28 to 53 mg/kg in the flesh.

Cui et al. (2005) reported arbutin that can be used as a specific marker for identity of pear products and chlorogenic acid as the major phenolic constituents in oriental pears. According to their research, the concentration of the two compounds in Yali pears was the greatest in young fruit (9.92 mg/g FW of arbutin and 3.72 mg/g FW of chlorogenic acid). The mean concentration of arbutin in the Oriental (Asian) pear cultivars was 0.164 mg/g FW; this was greater than the 0.083 mg/g FW in Occidental or European pear cultivars. However, the mean concentration of chlorogenic acid in the Oriental pear was 0.163 mg/g FW, less than 0.309 mg/g FW found in Occidental pear.

Asian pears contain more water than European pears and as a result are lower in calories. Table 22.16 gives nutritional data of pears. Like other fruits, pears can be source of fruit fiber and micronutrients.

Pear Aroma and Sensory Quality

Riu-Aumatell et al. (2005) reported compounds responsible for pear flavor as hexanal, cinnamaldehyde, methyl and ethyl decadienoates, and farnesenes. According to Jaeger et al. (2003), consumers described an ideal pear as sweet and juicy and preferred ripe pears over nonripe pears which appeared as too firm and devoid of pear flavor. Heinz et al. (1965) showed rise in aroma producing ester, 2,4-decadienoate, which coincided with optimum eating quality of Bartlett pears held for 8–9 days at 20°C.

Table 22.16. Nutritional Value of Selected Pears and Products

Nutrients	European	Asian	Prickly	Canned, Juice Pack, Drained
Calories (kcal)	58.0	42.0	41.0	51.0
Water (g)	83.7	88.3	87.5	86.3
Total fat (g)	0.12	0.23	0.51	0.19
Protein (g)	0.38	0.50	0.73	0.34
Carbohydrate (g)	15.46	10.65	9.57	12.91
Dietary fiber (g)	3.1	3.6	3.6	2.2
Sugars (g)	9.80	7.05	NA	8.27
Sucrose (g)	0.78	NA	NA	0.67
Fructose (g)	6.23	NA	NA	5.40
Glucose (g)	2.76	NA	NA	2.01
Vitamin C (mg)	4.2	3.8	14.0	0.30
Vitamin A (IU)	23.0	0.0	43.0	NA
Calcium (mg)	9.0	4.0	56.0	9.0
Potassium (mg)	119.0	121	220.0	99.0
Sodium (mg)	1.0	0.0	5.0	4.0
Iron (mg)	0.17	0.0	0.30	0.34

Source: USDA (2008b).

Pear Polyphenol Oxidase

As in the case of apples and other fruits and vegetables, PPO enzyme can cause browning of pears during cutting, pealing, and other operations. Siddiq et al. (1994) showed that *Red* pears had higher PPO activity, total phenolics, and chlorogenic acid concentration than *Bosc* pears. The temperature and pH optima for *Bosc* and *Red* pears were 20°C and 23°C, and 5.0 and 5.5, respectively. The PPO enzyme was inhibited by heating to 75°C for 30 minutes and by ascorbic acid, L-cysteine, and sodium metabisulfite.

MAJOR PROCESSED PRODUCTS

Fresh-cut slices, canned pears, pear juice and concentrates, and dried pears are some of the important pear products briefly discussed here.

Fresh-Cut Pears

The minimal processing and mechanical cutting and peeling operations to develop fresh-cut pears are aimed at retaining fresh-like color, flavor, and texture. Pear cultivars vary with

respect to the shelf life of their fresh-cut slices. Ripeness, fruit size, and the length of storage time after harvest can have effect on shelf life of pear slices. Fresh-cut pear slices from partially ripened *Bartlett* pears were shown to perform better than *Bosc*, *Anjou*, and *Red Anjou* pears (Gorny et al. 2000). Rosen and Kader (1989) observed increased CO_2 but not C_2H_4 production relative to whole fruit during slicing of pears, and slicing caused browning and loss of firmness. They showed that a combination of 1% calcium chloride dip and storage at 0.5% O_2 atmosphere maintained firmness of pears for 8 days. Oms-oliy et al. (2006) reported browning inhibition of fresh-cut pears for up to 28 days at 4°C by use of 0.75% N-acetyl-L-cysteine. Dipping for 2 minutes in a combination of 0.01% 4-hexylresorcinol, 0.5% ascorbic acid, and 1% calcium lactate and partial vacuum packaging provided 15–30 days shelf life to *Anjou*, *Bartlett*, and *Bosc* pear slices. Arias et al. (2008) showed that Conference pear was the most suitable variety for fresh-cut processing. In their research, treatment with a combination of 2% ascorbic acid + 0.01% 4-hexylresorcinol + 1% $CaCl_2$ was effective against browning. According to Dong et al. (2000), initial whole pear firmness of 45–67 N (1–15 lbs) for *Bartlett*, 27–45 N (6–10 lbs) for *Bosc*, and 36–45 N (8–10 lbs) for *Anjou* were important for slicing and color and firmness retention of fresh-cut pears.

Pear Juice and Concentrates

Akhavan and Wrolstad (1980) noted that surplus pears, including culls, are used to make about 70°Brix concentrate for use in beverages, canning syrup, vinegar, and wine.

The process to make single strength (~11°Brix) pear juice and concentrate (~70°Brix) is similar to what is described for apple juice in Section 1: Apple. Hsu et al. (1990) had also provided the detailed steps for making a single strength juice and concentrate from three pear varieties. According to these researchers, the higher pH of Bartlett (4.4) versus Comice and d'Anjou (4.0 and 3.9) and also its higher amino acids content contributed to higher degree of browning in juice and concentrates from Bartlett pears. Earlier, Montgomery (1983) had shown that treatment of pear juice with cysteine prior to concentration decreased the browning of pear juice concentrates. Ajlouni and Iyer (2003) used polymeric adsorbent (XAD 16) and weak-based anion (IRA 95) resins to improve quality of UF-clarified pear juice. The treated juice showed 85% reduction in both color and titrable acidity, besides significant reduction of polyphenolics and organic acids. Loez-Nicolas and Garcia-Carmona (2007) investigated the use of cyclodextrin as secondary antioxidants to improve color of fresh pear juice.

Canned Pears

Canning of pears like other fruits involves sorting, grading, and washing followed by peeling, coring, trimming, and dicing. The pears are then steam blanched for about 1 minute to inhibit PPO enzyme and filled into specific size tin cans. Following this, hot syrup or hot water is added. The cans are then exhausted at about 180–190°F; the contents temperature typically would reach about 160°F. Following exhausting, lids are placed and the cans are sealed. As, unlike vegetables, the pH of pears is less than 4.6, the time temperature requirement for canning is not as severe and pears can be sterilized at the boiling point of water (212°F) for about 15 minutes. The sterilized cans are then cooled immediately to avoid stack burning and corrosion of cans.

In the United States, standards for grades of canned pears as given by the USDA (2004) and the Code of Federal Regulations (21 CFR 145.175 and CFR 145.176) describe the various requirements for commercially traded canned pears. The canned products are prepared from properly mature, peeled, and cored pears. There are various grades (U.S. Grade A or U.S. Fancy; U.S. Grade B or U.S. Choice; U.S. Grade C or Standard; and Substandard) based on color, flavor, character, and freedom from defects and styles of different size and cuts (whole, halves, quarters, slices, dices, pieces, or irregular pieces) of canned pears. Although, there is no requirement for liquid media in canned pears, as they are not a factor of quality, there is a cut-off Brix for syrup in the can. For example, canned pears with extra heavy syrup or fruit juice has a range of 22°–35°Brix, heavy syrup has a range of 18°–22°Brix, light syrup should be of 14°–18°Brix, and slightly sweetened should be of less than 14°Brix.

Investigations into shelf-life evaluation of Bartlett pears in retort pouches for military use by Klutter et al. (1996) showed that pears processed at temperature 190.4°F for 3–4 minutes in a pH 4.0 sugar syrup scored better in terms of sensory tests than pears processed at temperature 204.8°F in pH 3.5 syrup over 36 months of study at 39°F and 70°F.

Dried Pears

As is described for apples, dried pears can be a good product for direct consumption and as ingredients in various foods. The main concern is loss of quality in terms of shrinkage, color, flavor, and texture during the drying process. The sulfur added dried products to preserve color are not as acceptable because many individuals are allergic to sulfur. In the author's company, sugar and fruit juice based infused dried 3/8″–1/2″ diced pears with less than 0.60 water activity and without any sulfur or artificial flavor and color have been developed for use as snack item, trails mix, or ingredients in various baked goods and cereals. The process consists of infusing individually quick frozen (IQF) 3/8″–1/2″ diced pear pieces to about 35°–45°Brix in sugar or clear juice concentrates prior to drying at 60°C (140°F) to 80°C (176°F). A combination of 0.2–0.5% ascorbic acid and citric acid may be added to retain color and improve flavor.

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23
Apricots Production, Processing, and Nutrition

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Abstract: Apricots (*Prunus armeniaca*) are produced in more than 50 countries, with Turkey, Iran, Uzbekistan, Pakistan, and Algeria as the major producers. This chapter covers the following topics on apricot fruit: world distribution and production, main cultivars, harvesting, postharvest handling and storage, packaging, physiological and pathological disorders, postharvest treatments to improve shelf life, storage technologies, processing, and processed products. The coverage also includes apricot nutrition and bioactive compounds. Applications of innovative technologies such as high pressure processing (HPP) and pulsed electric field (PEF) with respect to apricot processing are also discussed.

INTRODUCTION

Apricots (*Prunus armeniaca)* are categorized under "stone fruits," along with peaches, plums, almonds, and cherries, due to its seed being enclosed in a hard, stone-like endocarp. Apricot (from Latin meaning early ripe) tree belongs to genus *Prunus* in the Rosaceae (rose) family (Anon 2007). This fruit is native to temperate Asia, first discovered growing wild on the mountain slopes of China, and long cultivated in Armenia later. Early Spanish explorers are credited with introducing apricots to California. The apricot tree is of medium size, usually held under 18 ft by pruning. The fruit is generally globose to slightly oblong, 1.25–2.5 inch in diameter; the fruit flesh is yellow and the skin is yellow or blushed red. The early apricot bloom is susceptible to injury by frost. Also, the fruit is subject to cracking in humid climates, thus making commercial production in the United States primarily limited to states west of the Rocky Mountains (Magness et al. 1971; Anon. 2007). Apricot, like most stone fruits, thrives in a Mediterranean climate of long, hot summers and cool, wet winters; the fruit matures primarily in early summer making them one of the earliest available summer fruits (Boriss et al. 2006).

Apricot production, from 2004 to 2008, is shown in Figure 23.1. The 2008 total world production of 3.76 million metric tons was an increase of 31% over 2004 figures. Turkey is the leading apricot producing country followed by Iran and Pakistan; these three countries accounted for 40.7% share of the total world production in 2008 (Table 23.1). Apricot

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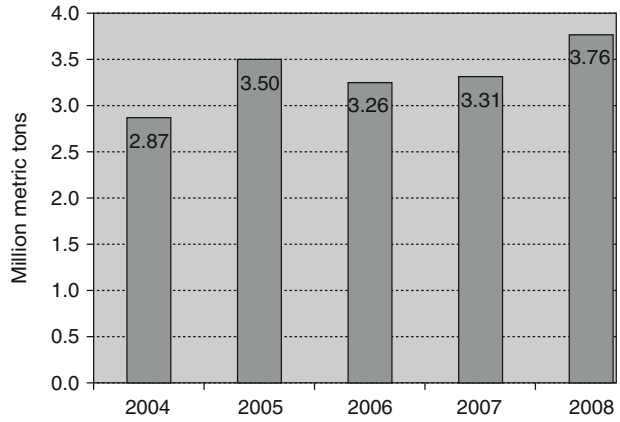

Figure 23.1. World apricot production (2004–2008). (Adapted from FAO 2010 data.)

production in Turkey more than doubled during the 5-year span (2004–2008). Turkey, Iran, Uzbekistan, Pakistan, and Algeria are the top-five countries with respect to the area under apricot cultivation (Table 23.2). On yield per hectare basis, Austria, Malta, the United States, Greece, and Turkey are the leading five countries. There are wide variations in the yield per hectare, with the countries employing good agricultural practices (GAPs) leading in this category. Major apricot exporting countries in 2008 (by quantity) were Spain, France, Afghanistan, Turkey, and Kyrgyzstan; these five countries accounted for 61.3% share of exports among top-20 apricot exporting countries (FAO 2010). Russia, Germany, Pakistan, France, and Italy were the major importing countries in 2008; their import share was 70.7% of the top 20 importers (FAO 2010).

Table 23.1. Apricot Production in Leading Countries (2004–2008)

	Production (1000 metric tons)				
Country	2004	2005	2006	2007	2008
Turkey	350.0	860.0	460.2	557.6	716.4
Iran	166.4	275.6	346.0	416.0	487.3
Pakistan	214.8	197.2	177.3	240.2	325.8
Uzbekistan	162.0	170.0	235.6	230.0	265.0
Italy	213.4	232.9	222.0	214.6	205.5
Algeria	88.0	145.1	167.0	116.4	172.4
Japan	113.6	123.0	119.7	120.6	120.6
Morocco	85.0	103.6	129.4	105.2	113.2
Egypt	72.5	73.0	100.8	101.1	106.2
Spain	121.5	137.2	156.9	89.0	103.4
Syrian Arab Republic	75.7	65.5	98.5	112.7	100.9
France	166.1	177.0	179.8	126.4	94.5

Source: FAO (2010).

Table 23.2. Apricot: Area Harvested in Leading Countries (2004–2008)

	Area Harvested (1000 ha)				
Country	2004	2005	2006	2007	2008
Turkey	57.5	60.0	53.4	55.2	58.0
Iran	45.9	49.4	50.0	52.0	54.0
Uzbekistan	26.0	24.0	34.6	36.0	36.0
Pakistan	29.0	28.9	29.2	31.3	33.4
Algeria	19.4	22.9	27.4	31.1	32.8
China	18.0	18.6	19.1	19.7	20.5
Spain	19.9	19.2	18.2	18.3	18.8
Japan	17.3	17.8	18.0	17.5	17.5
Italy	15.6	17.3	17.7	16.3	17.4
Egypt	7.5	7.5	17.4	15.3	15.6
France	15.3	13.9	14.0	14.2	14.0
Syria	13.1	13.3	13.9	13.7	13.6

Source: FAO (2010).

In the United States, the first major production of apricots was recorded in California in 1792. California continues to be the leading apricot producing state in the United States. Over 90% of the apricots in the United States are produced in California, with much smaller production operations in Washington and Utah. The per capita consumption of fresh apricots and its processed products in the United States is shown in Table 23.3. More than half of per capita consumption of apricots is in the dried form. Some facts about California apricot industry are as follows (APC 2010): California produces about 95% of the apricots grown in the United States; there are over 200 plus growers producing apricots from orchards covering 17,000 acres in the San Joaquin Valley, with the leading production area being Stanislaus County; Patterson variety apricots are the most prevalent variety for all usages, except dried which uses the Blenheim variety. The harvest period typically begins in May and ends in early July. Apricot is utilized as canned (59%), frozen (12%), dried (8%), and fresh consumption (20%).

Table 23.3. US Per Capita Consumption of Apricots, in Pounds (2004–2008)

			Processed			
	Total (All Uses)	Fresh	Canned	Dried	Frozen	Total
2004	0.93	0.12	0.21	0.53	0.07	0.81
2005	1.11	0.13	0.15	0.76	0.06	0.98
2006	0.91	0.08	0.10	0.70	0.03	0.83
2007	1.04	0.15	0.16	0.68	0.05	0.89
2008	0.92	0.13	0.14	0.58	0.06	0.79

Source: Adapted from USDA-ERS (2010).

PRODUCTION AND POSTHARVEST PHYSIOLOGY

Plant Breeding

Apricot cultivation is most successful in mild, Mediterranean-type climates, where danger of spring frost is minimal. Deep, fertile, well-drained soils are best suited to produce tall and healthy trees. Apricot trees exhibit moderate tolerance to high pH soils and salinity but are intolerant to water logging. Most American cultivars are self-pollinating and do not require cross-pollination, exceptions being 'Riland' and 'Perfection' that are self-incompatible. Apricots are pruned fairly heavily as they bear too many fruits. In general, most new growth and interfering wood is removed each year, exposing the spurs to maximal sunlight (Westwood 1993; Rieger 2004). Perez-Gonzales (1992) reported that the most important morphological traits of the apricot trees that correlated with fruit weight were tree growth habit, apical and basal diameter of fruiting spurs, and bud and leaf size. Timing and type of fertilizer application is known to improve external and internal fruit quality and storage ability, reduce production costs, maintain soil fertility, avoid nutrient deficiency or excess, and control tree vigor (Tagliavini and Marangoni 2002).

Varieties

A list of apricot varieties grown in California along with their maturity dates, size, and flavor characteristics is shown in Table 23.4. 'Patterson' continues to be the most widely grown apricot variety in California. It has firm texture, good flavor, and an excellent shelf life. Some other varieties include the following: *Perfection*—a mid-to-late season variety that is oval, oblong in shape with excellent flavor, its skin is clear yellow/orange with a blush, and its flesh is firm and yellow/orange in color; *Rival*—a mid-season variety that is oval in shape, and it has sweet/tart flavor with firm texture; the skin is light orange with a red blush; *Moorpark*—large fruit with red blush, yellow flesh, sweet, and juicy, with excellent flavor, and it is good for canning and eating fresh; *Moongold*—soft golden colored fruits are of medium size, attractive orange yellow flesh, firm and sweet with excellent flavor, and good for eating fresh or making preserves; *Sungold*—medium sized, brightly colored clear gold with attractive orange blush, nearly round, and tender skinned, good for eating fresh or making preserves (CLC 2000; Anon. 2010a).

Maturity and Fruit Quality

The maturity and harvest date in California is determined based on the changes in the skin ground color from green to yellow; the exact yellowish-green color is cultivar dependent. Since apricots are susceptible to high bruising when fully ripe and soft, picking is recommended when the fruit is still firm. Important quality criteria include fruit size, shape, and freedom from defects (such as gel breakdown and pit burn) and decay. Soluble solids contents of over 10% and a moderate titratable acidity of 0.7–1.0% are critical for consumer acceptance. Fruit with flesh firmness of 2–3 lb force (8.9–13.3 N) is ready for fresh consumption (Crisosto and Kader 2004). Femenia et al. (1998) studied the ripening-related changes in the cell wall of apricot fruit and concluded that the decrease in the pectic galactans and inhibition of cross-linking within

Table 23.4. Maturity Dates and Quality Characteristics of Apricot Varieties Grown in California

Apricot Variety	Average Maturity Date	General Size Trend	Profile/Flavor
Poppy	7-May	Medium/large	Solid orange/good flavor
Earlicot	11-May	Large	Firm/high color
Lorna	12-May	Large	Deep orange/juicy
Robada	17-May	Medium	Red blush/high sugar
Ambercot	25-May	Medium	Firm/sweet
Jordanne	25-May	Large	High color/flavor
Castlebrite	28-May	Medium	Firm/full flavor
Katy	5-June	Large	Firm/good flavor
Helena	8-June	Large	Firm/juicy
Tri Gem	11-June	Large	Firm/good flavor
Goldbar	15-June	Medium	Firm/deep red blush
Patterson	15-June	Medium	Firm/good flavor
Tomcot	15-June	Large	Orange/sweet
Blenheim	19-June	Medium	Intense flavor
Tilton	25-June	Large	Firm/tart flavor

Source: Anon (2010a).

the pectic backbone was related to the softening process that occurs during apricot fruit ripening. During postharvest storage of apricots, increase in β-galactosidase activity results in lower total pectin and hence the loss of fruit firmness (Kovacs and Nemeth-Szerdahelyi 2002).

Harvest and Storage

Apricots for fresh consumption and processing are mostly picked by hand, and trees are usually picked over two to three times each when fruit are firm. It must be noted that full flavor never develops when apricots are ripened off the tree (Gomez and Ledbetter 1997). Apricots are generally handled in half bins, tray-packed in single/double layers, and shipped in shallow containers to prevent crushing and bruising. Apricots should be uniform in size, and by count, no more than 5% apricots in each container may vary more than 6 mm when measured at the widest part of the cross section.

Apricots, though not stored in large quantities like apples, keep well for 1–2 weeks (or even 3–4 weeks for some cultivars) at −0.5 to 0°C with RH of 90–95%. Susceptibility to freezing injury depends on soluble solid contents, which varies from 10% to 14%. Cultivars that are sensitive to chilling develop and express chilling injury symptoms (gel breakdown, flesh browning), and loss of flavor, more rapidly at 5°C than at 0°C. In order to minimize the incidence and severity of chilling injury on susceptible cultivars, storage at 0°C is recommended. Controlled atmosphere (CA) storage conditions of 2–3% O_2 + 2–3% CO_2 are suggested to retain fruit firmness and ground color. The development of off-flavors may hasten at O_2 exposure of <1% and CO_2 exposure in excess of 5% for over 2 weeks can cause flesh browning and loss of flavor. Prestorage treatment with 20% CO_2 for 2 days may reduce incidence of decay during subsequent transport and/or storage in CA or air. As compared with 0°C, respiration rate more than doubles at 10°C. Ethylene production rate increases significantly with temperature increase; from <0.1 μL/kg/h at 0°C to 4–6 μL/kg/h at 20°C for firm-ripe apricots and even higher for soft-ripe apricots. The greatest hazard in handling and shipping apricots is decay, mainly brown rot and rhizopus rot, and accelerated ethylene production can hasten the development of such decay. In order to retard ripening, softening, and decay, quick cooling to temperatures of 4°C or lower and keeping them as near to 0°C as possible is recommended (Crisosto and Kader 2004).

A variety of methods and treatments have been investigated to extend the shelf life and preserve flavor, firmness, and other quality attributes of apricots. In recent years, the use of ethylene inhibitor 1-methylcyclopropene (1-MCP) to delay ripening and prolong storage life of apricots has shown good results for ethylene inhibition, decline in pectin methylesterase activity, and preserving fruit firmness and flavor (Fan et al. 2000; Botondi et al. 2003). Zhang et al. (2009) studied the effects of 1-MCP treatment (1 mg/kg for 24 hours) on the postharvest quality deterioration of fresh apricots stored at 22°C and 4°C. Evaluation of respiration rate, ethylene release, and weight loss showed that 1-MCP was effective in delaying ripening and maintaining quality.

DeMartino et al. (2002) examined interactions between temperature, ethylene generation, and impact injury symptoms in apricots. Martinez-Romero et al. (2002) studied the effects of postharvest putrescine treatment on the physicochemical properties and physiological response to mechanical damage of apricots (cv. 'Mauricio') during storage. Apricots harvested at the commercial ripening stage were treated with 1 mM putrescine by pressure infiltration, then mechanically damaged with a 25 N force and stored at 10°C for 6 days. Putrescine treatment increased fruit firmness and reduced the bruising due to mechanical damage. Color changes, weight loss, ethylene emission, and respiration rates were reduced in putrescine-treated fruits.

Physiological Disorders

Chilling injury, also termed as "gel breakdown," and pit burn are the two main physiological disorders in apricots. Chilling injury, which is characterized by the formation of water-soaked pockets that subsequently turn brown, develops usually at 2.2–7.6°C during extended cold storage (Crisosto and Kader 2004). Breakdown of tissue is sometimes accompanied by sponginess and gel formation. In addition to a short market life, fruit stored at elevated temperatures loses flavor. "Pit burn" occurs as a result of softening of the flesh that turns brown around the stone when apricots are exposed to temperatures above 38°C before harvest. Tagliavini and Marangoni (2002) recommended early diagnosis of bitter pit for guiding applications of calcium sprays. Bussi et al. (2003) evaluated the effects of N and K fertilization on incidence of pitburn defect (PD), yields, and fruit quality of apricot (cv. Bergeron). They reported that fruit N increased with N fertilization level; high fruit N was shown to be a predisposing factor for PD, whereas higher Ca contents tended to reduce PD during storage. Matsumoto et al. (2008) reported that the Japanese apricot (cv. 'Benisashi') fruits are prone to the physiological disorder of a gumming syndrome; the accumulated gum becomes a solid gel during processing, thereby reducing the commercial value of the finished products.

PROCESSED PRODUCTS

About 20% of apricots produced are consumed fresh and the rest are processed as dried, canned, frozen, jam, juice, and puree (APC 2010). Haciseferogullari et al. (2007) indicated that physical properties such as length and diameter of fruit, mass, volume of fruit, geometric mean diameter, sphericity, bulk density, fruit density, porosity, projected area, and static and dynamic coefficient of friction are important in designing processing equipment. The processing information in this

section mainly relates to apricots produced and processed in the United States, unless noted otherwise. In California, about half of apricots produced are canned and the rest processed as frozen, dried, and used for juice production.

Dried Apricots

Dried apricots are the halved and pitted fruit of the apricot tree (*P. armeniaca*) from which the greater portion of moisture has been removed. Before packing, the dried fruit is processed to cleanse the fruit and may be treated with SO_2 to retain a characteristic color. Federal inspection certificates shall indicate the moisture content of the finished product which should not be more than 26% by weight for sizes No. 1, No. 2, and No. 3, and for slabs, and not more than 25% by weight for other sizes (USDA-AMS 1967). Description of dried apricot sizes is given later under "U.S. Standards of Quality and Sizes of Dried Apricots."

Processing

Turkey produces almost half of the world's total dried apricots, where apricots are traditionally sun-dried after pretreatment with SO_2 (obtained by burning sulfur in specially constructed rooms) to moisture content of 23–28%. Sun-drying produces (Fig. 23.2) a product with a rich orange color, translucent appearance, and desirable texture. However, the long drying time, dependence on weather, and manual labor requirements are some of its disadvantages (Abdelhaq and Labuza 1987; Mahmutoglu et al. 1996).

In the United States, almost all of dried apricots are produced in California. Cultivars that retain their color and flavor during processing and storage are best suited for drying. Ledbetter et al. (2002) studied the effects of fruit maturity at harvest on dried 'Patterson' apricot quality with regard to color changes during 8 months of storage. While dried fruits of the immature class were of low quality at the end of storage period, both medium and most mature dry fruits were of sufficient quality to warrant marketing even after 8 months of cold storage.

Apricots are harvested at fully ripe stage and treated with SO_2 to preserve the color of the finished product. Drying is either natural, in the sun, or in large dehydrators used for prunes (Rieger 2004; see Chapter 31 "Plums and Prunes" for more detail). California apricots are sun-dried in halves, while Turkish (Mediterranean) dried apricots are whole with the pit squeezed out (APC 2010). For drying apricots in a single layer, the use of a solar energized rotary dryer was reported by Akpinar et al. (2004).

Sulfites are the most widely used chemicals in the production of dried apricots, mostly to preserve the color quality during storage. Traditionally, sulfited apricots can have SO_2 contents from 1000 to 6000 ppm. However, maximum legal limit allowed in most countries is 2000 ppm. Various methods of desulfiting apricots, with the objective to meet legal limits for SO_2, have been reported by Ozakan and Cemeroglu (2002a, 2002b). Piga et al. (2004) reported that the sufiting pretreatment can reduce ascorbic acid contents in the dried apricot. Nisar-Alizai and Ahmad (1997) reported that apricot products treated with polyphenol oxidase (PPO) inhibitors prior to dehydration were of better color and textural quality than those prepared with sulfite treatment alone. However, shelf life after drying was restricted, suggesting that PPO inhibitors usually do not provide the same extent of protection as sulfiting does. In a storage study of 17 different dried fruits, Winus (2000) showed that sulfite content of the dried fruit decreased during 3-month storage; the greatest decrease (∼80%) was detected in dried salted Japanese apricot, while the smallest decrease (∼11%) occurred in dried apples.

Figure 23.2. Sun drying of apricots in open fields in Turkey.

U.S. Standards of Quality and Sizes of Dried Apricots

More details on quality standards of dried apricots can be found on the Web site of Agricultural Marketing Service of the USDA (USDA-AMS 1967). The various sizes of dried apricots, except for slabs, as per USDA-AMS (1967), are as follows: No. 1 (jumbo size): 1–3/8 inches, or larger in diameter; No. 2 (extra fancy): 1–1/4 to 1–3/8 inches in diameter; No. 3 (fancy size): 1–1/8 to 1–1/4 inches in diameter; No. 4 (extra choice size): 1 to 1–1/8 inches in diameter; No. 5 (choice size): 13/16 to 1 inch in diameter; and No. 6 (standard size): less than 13/16 inch in diameter.

Canned Apricots

Canned apricots are convenient and easy to use in recipes such as baked goods, salads, and sauces. For quick ways to add flavor and nutrients, canned apricots can be added to plain oatmeal, cottage cheese, yogurt, or ice cream. Research has

shown that, nutritionally, canned apricots are fairly comparable with the fresh fruit with added convenience of year-round availability (APC 2010).

Processing

Apricots for canning are harvested at the peak of ripeness, to retain quality and nutrients. The optimum harvesting period is very short; if the fruit is green, the flavor is astringent and if it is over ripe, it is too soft to handle during processing. Apricots are canned within 24 hours of delivery to the processing plant, which ensures that the processed fruit maintains nutritional value and flavor (CLC 2000; Rieger 2004). A brief description of processing steps for canning apricots is given as follows (Lopez 1981a):

- *Grading and Washing:* Since the fruit is received at the cannery with wide range of sizes, the first operation is to grade for size by running them over screens of 40/32, 48/32, 56/32, 64/32 and 68/32 inches. After grading, apricots are washed under spray water and bad, smutty spots are trimmed.
- *Pitting and Cutting:* Apricots are then split into halves (or other styles) and pitted using mechanical pitters and cutters; splitting is done on the natural dividing line in order to make symmetrical pieces and to have the pit come out easily. The pitters make a preliminary sorting by placing the prime fruit in one receptacle, the hard and irregular in another, and the soft in a third one.
- *Filling:* The filling of cut apricots is done by hand or by hand pack fillers. Standard of identity requires a minimum cutout Brix (detail given later). Therefore, in order to estimate the strength of the syrup to use, it is important to know soluble solids of fruit, and also how much fruit goes into each can. The syrup is added hot by means of rotary and straight-line syrupers or by prevacuumizing syrupers.
- *Exhausting:* Apricots contain considerable trapped air, which presents a danger of can pin holing if not driven out. Cans must be either thoroughly exhausted prior to closing or closed in a steam-flow machine. Depending on the texture of fruit, exhaust procedure of up to 10 minutes at 180–190°F is used. If necessary, additional syrup is added before the cans are closed.
- *Processing and Cooling:* To attain a commercially sterile product, canned apricots should be processed sufficiently long for the center temperature of the product to reach a minimum of 190°F or 195°F for air and water cooling, respectively. Most canned apricots are processed in continuous reel cookers at 212°F for 17–30 minutes, depending on the size of the cans and the texture of the fruit. The cans are partially cooled in water and then air-cooled on trays.

The most important quality attribute of canned apricots is texture or firmness; if the texture is too soft, the product acceptability is low even if color and flavor are of acceptable quality. Textural quality of canned apricots has been researched extensively (Luh et al. 1978; Brecht et al. 1982; Sharma et al. 1992; Mallidis and Katsaboxakis 2002). Chitarra et al. (1989) studied fruit softening and cell wall pectin solubilization in canned 'Patterson' apricots and reported that canning of slightly immature fruit led to immediate softening of the halves, to the extent that many were of unacceptable texture. The results showed that such softening occurred in conjunction with a substantial solubilization of (presumably pectic) polysaccarides, rich in uronic acid, arabinose and galactose, into the canning liquid. Since this solubilization was not accompanied by pectin depolymerization, it was suggested that some process interactions other than acid-catalyzed polymer hydrolysis were responsible for fruit softening during processing.

Generally, canning apricots are not peeled. However, the lye peeling method, the same as for peaches, is employed for those that are peeled before canning. Toker and Bayindirli (2003) investigated enzymatic peeling of apricots at 20°C, 35°C, and 50°C. They concluded that enzymatic peeling could be an alternative to chemical or mechanical peeling of stone fruits due to (1) better quality, as fruit retained their structural integrity and fresh fruit properties; (2) reduced heat treatment; and (3) less industrial waste.

U.S. Standards of Quality and Styles of Canned Apricots

The Standard of Quality for canned apricots has strict requirements regarding minimum size, uniformity of size, trimming, blemishes, and texture, which must be met. The U.S. Standards for Grade require uniformity of color, a minimum drained weight, and certain numbers of units in the usual sizes of cans. The standard for "Fill of Container" must always be reached or exceeded. The amount of fruit in each can is also highly important with respect to the strength of syrup that must be used to justify the label statement. Altogether, the filling of the cans is a critical part of the canning. The canned apricots may be seasoned with one or more of the optional ingredients permitted in the Food and Drug Administration Standards of Identity (Lopez 1981a). Complete detail on quality standards of canned apricots can be found on the Web site of Agricultural Marketing Service of the USDA (USDA-AMS 1976).

Styles of canned apricot are as follows: (a) *Halves*—pitted apricots cut approximately in half along the suture from stem to apex; (b) *Slices*—pitted apricots cut into thin sectors or strips; (c) *Whole*—unpitted apricots with stems removed; (d) *Pieces or irregular pieces*—cut apricot units that are predominantly irregular in size and shape, which do not conform to a single style, or which are a mixture of two or more of such styles; (e) When the apricots are unpeeled, the name of the style is preceded or followed by the word "unpeeled"; and (f) When the apricots are peeled, the name of the style is preceded or followed by the word "peeled" (USDA-AMS 1976).

Frozen Apricots

Apricots to be processed as frozen should have even ripening, good color and flavor, low browning tendency, a tender and smooth skin, and firm texture. In California, the principal variety is 'Patterson,' followed by Blenheim, Tilton, and Modesto, which are processed on a smaller scale. Apricot halves are preferred to sliced fruit and can be processed with or without peeling. Halves and slices are sold to bakers, ice cream makers, and frozen dessert makers, whereas multiple-scored apricots (called machine pitted) are primarily used for jam, jelly, and preserve making (Boyle et al. 1977; Scorza and Hui 1996). Most of the frozen apricots are bulk packed for use in food applications listed earlier. Retail marketing of frozen apricots has not gained popularity on a scale similar to some other frozen fruits.

Processing

Apricot freezing method based on Boyle et al. (1977) and Scorza and Hui (1996) is described briefly here. Upon arrival at the processing plant, apricots are graded and inspected on a conveyor belt and then passed through a halving and pitting machine. Apricots to be processed as "machine-pitted" (for jam, jelly, and preserve) are pitted using Elliott pitters. After separation of the pits, halves, slices, or dices are inspected and washed to remove small fruit pieces or skin. They are then treated to prevent browning before they are syruped, packed, and frozen. One of the following two methods are used for browning control: (1) the fruit may be blanched in hot water or steam or (2) treated with an antibrowning agent, like ascorbic acid. Blanching is done in a single layer on a mesh belt for 3 to 4 minutes in steam to give satisfactory results for firm fruit. In case of softer fruit batch, it is best to treat it with ascorbic acid or other antibrowning agents at a level of 0.05% or more into the syrup used for packing. The packing medium can vary from 15°Brix syrup to dry sugar (fruit to sugar ratio is usually 3:1), which may be sprinkled on the fruit as it is filled into the containers or can be distributed evenly by light mixing.

Another process for frozen apricots, "Osmodehydrofreezing" (osmotic dehydration followed by air drying and freezing), has been proposed for the production of intermediate moisture apricot ingredients without SO_2 application, with natural and agreeable color (Forni et al. 1997). Ten-millimeter apricot cubes were osmodeyhydrated in sucrose, maltose, or sorbitol syrups at 56% and 3-to-1 fruit:syrup ratio. Ascorbic acid (1%) and sodium chloride (0.1%) were added as antioxidants. Osmodehydration was carried out at 25°C for 15 minutes under vacuum (700 mm Hg) and for 45 and 120 minutes at atmospheric pressure. Drying was conducted in an upward air-circulated drier, at the dry-bulb temperature of 65°C and an air speed of 1.5 m/s, to achieve a soluble solids content corresponding to a_w of 0.86. Osmo-air-dehydrated apricot cubes were then frozen in an air-blast tunnel at −40°C and an air speed of 4 m/s. Results showed that incorporation of different sugars into the apricot cubes affected their low-temperature phase transitions and the percentage distribution of the sugars. Ascorbic acid retention during air-drying was affected by the composition of the syrup. Maltose exhibited the greatest protective effect on color stability during subsequent 8-month frozen storage. Giangiacomo et al. (1994) and Erba et al. (1994) also studied the feasibility of osmodehydrofreezing apricots.

U.S. Standards of Quality and Styles of Frozen Apricots

Complete detail on quality standards of frozen apricots can be found on the Web site of Agricultural Marketing Service of the USDA (USDA-AMS 1963). Styles of frozen apricots are as follows: (a) *Halves*—cut approximately in half along the suture from stem to apex and from which the pit has been removed; (b) *Quarters*—apricot halves cut into two approximately equal parts; (c) *Slices*—apricot halves cut into sectors smaller than quarters; (d) *Diced*—are apricots cut into approximate cubes; (e) *Cuts*—apricots that are cut in such a manner as to change the original conformation and do not meet any of the foregoing styles; and (f) *Machine pitted*—mechanically pitted in such a manner as to substantially destroy the conformation of the fruit in removing the pit (USDA-AMS 1963).

Apricot Juice and Concentrate

Apricot juice and puree are used mainly in baby foods. Apricot juice production method is the same as for peaches (see Chapter 30 "Peaches and Nectarines"). The use of pectinolytic enzymes (pectinesterase and polygalacturonase) aids in the liquefaction of apricot pulp and juice extraction (Chauhan et al. 2001). Juices thus obtained had higher total soluble solids, total sugars, and acidity, but lower crude fiber and vitamin C. Apricot juice can be processed into concentrate; a typical design for apricot cryoconcentrated juice production is shown in Figure 23.3. The use of apricot juice in juice blends/cocktails is also becoming popular. Zhang and Xing (2004) reported on the development of juice blends using juices from Japanese apricot, grapes, Russian olives, and dates. Juice blends were evaluated for optimum formula, stability, and flavor.

The use of appropriate enzymes (pectinase and cellulase) during juice extraction is critical for maximizing yields. Effect of two pectinolytic enzymes treatment on the volatile compounds composition of apricot, peach, and pear juices were investigated by Riu-Aumatell et al. (2005). Over 80 compounds were detected, representing a wide range of volatiles (alcohols, aldehydes, ketones, terpenoids, esters, norisoprenoids, etc.). This study identified theaspirane and alpha-isophoron for the first time in apricot. Enzyme treatment during juice processing enhanced the juice content of terpenes and norisoprenoids, which are aroma compounds.

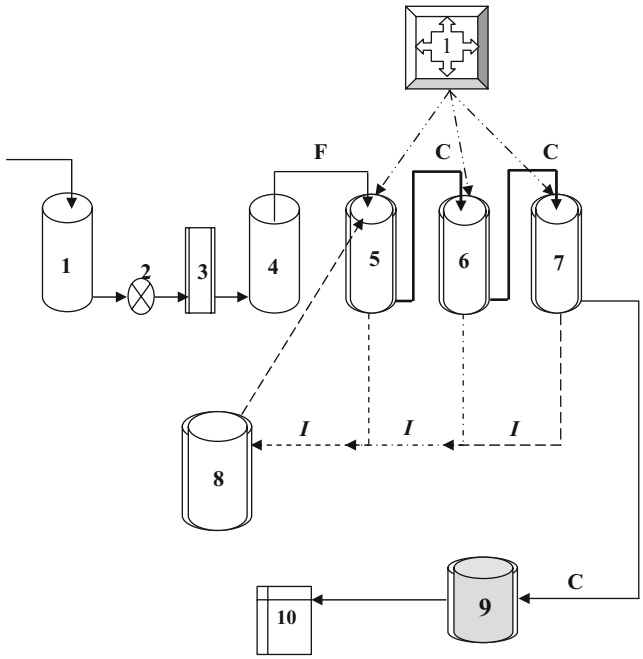

Figure 23.3. Technological design for apricot and cherry cryoconcentrated juice production. The technological process includes the following apparatus: reservoir-1 for the feed solution; a centrifugal pump-2; filtration system-3; reservoir-4 for the filtered feed juice; cryoconcentration modules-5, 6, 7; reservoir-8 for the recuperated ice fraction and ice recycling; reservoir-9 for the cryoconcentrated juice; and packaging machine-10. (*Source*: Aider and Halleux (2008).)

Versari et al. (2008) characterized 26 Italian commercial apricot juices (obtained from organic, integrated, and conventional agriculture) by analyzing carbohydrates, organic acids, amino acids, phenolic compounds, and furanic compounds by high-performance liquid chromatography (HPLC). The principal component (PC) analysis on chemical composition of apricot juices resulted in two PCs that accounted for 66% of the total variance. The study further showed that organic apricot juices showed some separation from the other juices, while a lack of distinction between integrated and conventional juices was observed.

Apricot Puree

The production and use of apricot puree is gaining popularity as a new substitute for oil or water in many high-calorie, high-fat recipes. Unlike prunes, which can darken the color of some baked goods, or applesauce, which may cause recipes to be watered down, apricot puree reduces the fat content and adds a touch of flavor without any negative effect (APC 2010). McHugh et al. (1996) investigated the use of apricot puree as an edible film and concluded that fruit puree edible barriers may be used in food system, not only for favorable sensory characteristics but also to control mass transfer, improve product quality, and extend shelf life. Fruit barrier films, which are good oxygen barrier, can be used for low to intermediate moisture food systems such as nuts, confections, and baked goods.

In pilot plant filtration (Fig. 23.4) tests that used a ceramic microfilter, Hart et al. (1994) showed that pectinase

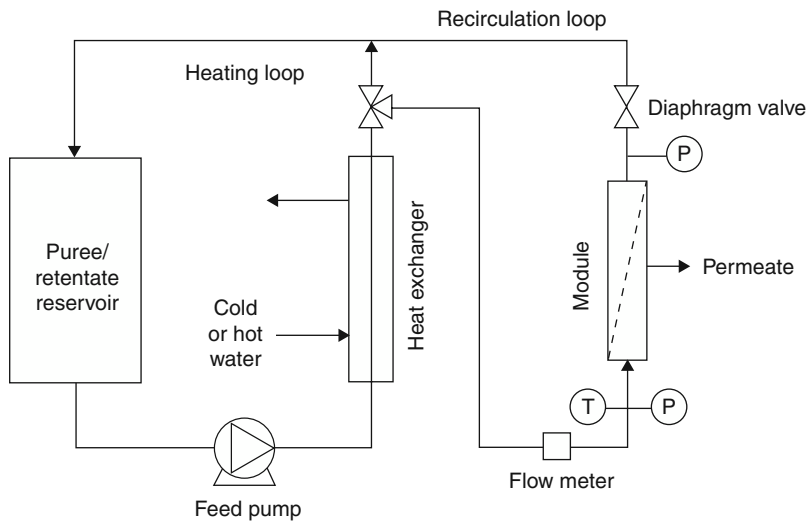

Figure 23.4. Schematic representation of a pilot-scale microfiltration unit. (*Source*: Hart et al. (1994).)

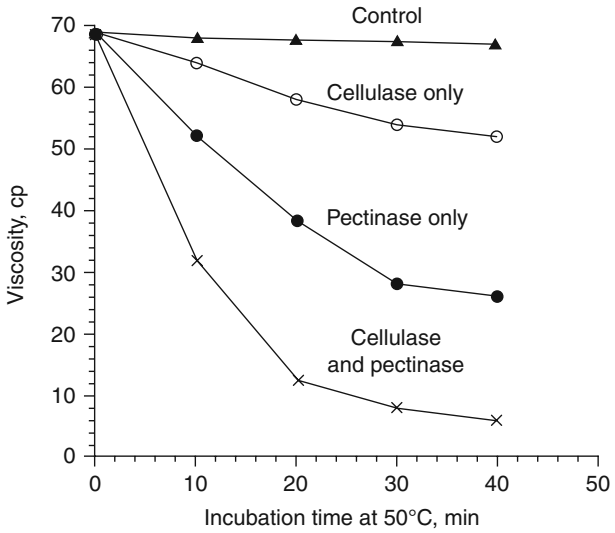

Figure 23.5. Effect of selected enzymes on apricot puree viscosity (cellulase and pectinase each added at 150 ppm levels). (*Source*: Hart et al. (1994).)

Table 23.5. Formulation for Apricot Jam and Preserve

Ingredient	Unit	Higher Quality (50/50)	Standard Quality (45/55)
Water	lb (kg)	20 (9.1)	20 (9.1)
Fruit	lb (kg)	100 (45.5)	82 (37.3)
Pectin, rapid set	Oz (g)	6.12 (175.8)	6.12 (175.8)
Sugar	lb (kg)	100 (45.5)	100 (45.5)
Acid solution[a]	Fl. Oz (mL)	16 (475)	14 (415)
Cooking temperature to finish[b]	°F (°C)	221 (105)	221 (105)
Soluble solids	%	65	65
Yield	lb (kg)	160 (972.7)	157 (71.4)
pH		3.3	3.3

Source: Adapted from Lopez (1981b).
[a]The acid solution is prepared by mixing 1 pound of citric acid with 1 pint of hot water. Sufficient quantity is added to adjust to the indicated pH.
[b]The finishing temperature applies to cooking at or near sea level. At higher elevation, the temperatures are corrected for difference between 212°F and the boiling point of water.

was effective in increasing flux at an enzyme level as low as 75 ppm and that flux increased with time during filtration. Cellulase was shown to inhibit flux when used alone or in combination with pectinase, even though it contributed to reducing viscosity of the puree (Fig. 23.5).

Apricot Jam/Preserve

Apricot jam, juice/nectar, and puree are processed on a much smaller scale than canned, dried, and frozen apricots. A typical formulation for making apricot jam or preserve is shown in Table 23.5. Benamara et al. (1999) prepared a "light" apricot jam and studied the effects of partial substitution of aspartame for sucrose on the quality of jam. Substitution of aspartame for 90% or 100% of the sugar did not give satisfactory results; 80% level was the maximum substitution possible. Changes in color of apricot jam during storage increased with increasing concentration of added aspartame; this was probably due to gradual breakdown of the aspartame to release free aspartic acid and phenylalanine, which underwent a browning reaction with sugars. Dragovic-Uzelac et al. (2005) reported on a method for determining the authenticity of apricot jam by comparing its phenolic compounds profile with that of raw fruit. The phenolics were analyzed by HPLC with UV diode-array detection.

Other Products

There are a variety of baked goods and specialty products processed in apricot producing countries. Many of these products have rather limited commercial significance in international trade. Often times, fresh or processed apricots are used in local or regional culinary applications, such as soups, salads, garnish, and in side dishes.

APRICOT BY-PRODUCTS

A number of by-products from apricot processing have been reported in the literature. It is to be noted that the commercial processing of these by-products vary from country to country. Seeds or kernels of the apricot grown in central Asia and around the Mediterranean are so sweet that they are sometimes substituted for almonds, especially in sweets or desserts (Anon. 2010b). The Italian liqueur *amaretto* and *amaretti biscotti* are flavored with extract of apricot kernels rather than almonds; furthermore, oil pressed from these kernels has been used as cooking oil (Anon. 2010b).

Kernels

Apricot kernel is an important source of dietary protein as well as oil and fiber (Seker et al. 2010). The use of apricot pit/kernel has been explored to extract oil, benzaldehyde, and as an alternative source of proteins (Hallabo et al. 1975; Rahma et al. 1994; Sharma and Gupta 2004; Vursavus and Ozguven 2004). The oil from apricot kernel is very rich in essential fatty acids, especially linoleic acid.

Conditions for extraction of oil from high quality apricot kernels were optimized by Fathollahzadeh et al. (2010); especially, the effects of moisture content and compression axis were studied on the amount of force needed to crack apricot pits and kernels. It was observed that, with increasing

moisture content of the apricot pits and kernels, the energy for cracking decreased. Their study also revealed that cracking an apricot pit requires higher rupture force and energy when compressed along its length and that cracking an apricot kernel requires higher rupture force when compressed along its thickness.

While apricot kernels contain appreciable amounts of protein, it also contains amygdalin, a cyanogenic glycoside that gives the kernels a strong bitter flavor. Conventional apricot kernel debittering processes typically use large amounts of water and energy (Silem et al. 2006).

Kernel Flour

The utilization of apricot kernel flour (AKF) as fat replacer (up to 40% reduction) in cookies was studied by Seker et al. (2010). Addition of AKF decreased the spread ratio and increased the hardness of the cookies; however, sensory evaluation revealed that the cookies containing AKF were acceptable to the panelists at all concentrations from 10% to 40% addition level, though 10–20% fat replacement with AKC was found best for physical quality attributes of the cookies.

INNOVATIVE PROCESSING TECHNOLOGIES

A number of innovative technologies have been investigated for processing apricot products. This section covers some of those reported in the literature recently.

High Pressure Processing

Patrignani et al. (2009) studied the effect of high pressure homogenization (HPH) on *Saccharomyces cerevisiae* inactivation and physicochemical features in apricot juice; their results demonstrated that repeated HPH passes at 100 MPa allowed a significant inactivation of the spoilage yeast inoculated in both juices. However, the inactivation of the considered strain was greatly affected by the food matrix. Furthermore, the refrigeration of the treated samples prevented cell recovery and, in some cases, induced a further decrease in cell viability in the inoculated sample thereby allowing a further increase in the juice shelf life.

Pulsed Electric Field

The use of pulsed electric field (PEF) for preservation of different apricot products has been reported recently. Evrendilek et al. (2008) reported using a bench-scale PEF system (OSU-4) (Figure 23.6) for the inactivation of *Penicillum expansum* in apricot nectar. After inoculation of apricot nectar with *P. expansum* spores at the level of 105–106 CFU/mL, the samples were processed by OSU-4 PEF system as a function of differing electric field strengths (0, 13, 17, 20, 23, 27, 30, and 34 kV/cm). The results showed that with an increase in electric field strength and processing time, germination tube elongation and spore germination rate were completely inhibited. Furthermore, light and SEM observations revealed considerable morphological alterations in fungal conidia such as cytoplasmic coagulation, vacuolations, shrinkage, and protoplast leakage. This was one of earliest studies reporting on the inactivation of *P. expansum* using PEF technology.

Evrendilek et al. (2009) investigated the effectiveness of PEF treatment for inactivation of *Botrytis cinerea* that was inoculated into apricot nectar. Based on the measurement of germination tube elongation, spore germination rate, and light and SEM microscopic observations, PEF processing proved to be effective in inactivating *B. cinerea*; they

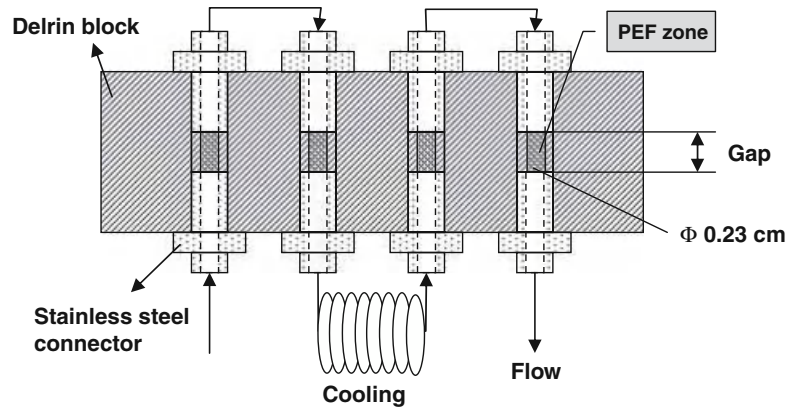

Figure 23.6. Schematic drawing of co-field flow treatment chambers for OSU-4 PEF systems. (*Source*: Evrendilek et al. (2008), schematic provided by author.)

concluded that this method could be used to prevent product loss in fruit juice/nectars due to *B. cinerea* contamination.

CHEMICAL/NUTRITIONAL COMPOSITION AND DIETARY BENEFITS

Apricots, available throughout the year, in fresh, frozen, canned, or dried form, are a flavorful source of nutrients and are a convenient way to accomplish the "five-a-day" requirement of five servings of fruits and vegetables daily. Apricots, especially unpeeled, are a good source of fiber, which is important to a healthy diet and can help control weight and lower cholesterol levels. Dried apricots are a concentrated source of fiber and one of the highly nutrient-dense dried fruits (Rieger 2004).

Apricots and its processed products are low in fat, specially saturated ones, and are rich source of some important nutrients. Chemical and nutritional composition of raw apricot and its processed products is shown in Table 23.6. Apricots are an excellent source of potassium, iron, and magnesium. It should be noted that varietal differences could also contribute to variations in the composition of raw and finished products. Also, the values shown here are for the fruit that is grown

Table 23.6. Composition of Apricots and Their Processed Products (Per 100 g Edible Portion)

	Unit	Raw	Canned[a]	Frozen[b]	Dried[c]	Nectar[d]
Proximate						
Water	g	86.35	82.56	73.3	30.89	84.87
Energy	kcal	48	63	98	241	56
Protein	g	1.4	0.53	0.7	3.39	0.37
Total lipid (fat)	g	0.39	0.05	0.1	0.51	0.09
Ash	g	0.75	0.37	0.8	2.57	0.29
Carbohydrate, by difference	g	11.12	16.49	25.1	62.64	14.39
Fiber, total dietary	g	2	1.6	2.2	7.3	0.6
Sugars, total	g	9.24	14.89		53.44	13.79
Minerals						
Calcium, Ca	mg	13	11	10	55	7
Iron, Fe	mg	0.39	0.39	0.9	2.66	0.38
Magnesium, Mg	mg	10	8	9	32	5
Phosphorus, P	mg	23	13	19	71	9
Potassium, K	mg	259	138	229	1162	114
Sodium, Na	mg	1	4	4	10	3
Zinc, Zn	mg	0.2	0.11	0.1	0.39	0.09
Copper, Cu	mg	0.078	0.079	0.064	0.343	0.073
Manganese, Mn	mg	0.077	0.052	0.05	0.235	0.032
Selenium, Se	μg	0.1	0.1	0.4	2.2	11.9
Vitamins						
Vitamin A, IU	IU	1926	1322	1680	3604	1316
Vitamin C, total ascorbic acid	mg	10	2.7	9	1	0.6
Thiamin	mg	0.03	0.016	0.02	0.015	0.009
Riboflavin	mg	0.04	0.02	0.04	0.074	0.014
Niacin	mg	0.6	0.304	0.8	2.589	0.26
Pantothenic acid	mg	0.24	0.092	0.2	0.516	0.096
Vitamin B-6	mg	0.054	0.054	0.06	0.143	0.022
Folate, total	μg	9	2	2	10	1
Carotene, beta	μg	1094	789	NR[a]	2163	786
Vitamin E (α-tocopherol)	mg	0.89	0.6	NR	4.33	0.31
Lutein + zeaxanthin	μg	89	26	NR	0	14

Source: USDA (2010).
[a]In light syrup pack, with skin, solids and liquids.
[b]Frozen, sweetened.
[c]Sulfured, uncooked.
[d]Canned.
[e]Not reported.

and processed in the United States; therefore, some differences can be anticipated in composition of apricots and their processed products in other regions of the world owing to different climatic and soil conditions, agricultural practices, postharvest handling, and processing techniques.

Apricots, in comparison with other major fruits, contain significantly higher amounts of flavonoids, especially catechin and epicatechin at 4.40 and 20.20 mg/100 g fruit, respectively. A variety of dietary flavonoids have been found to inhibit tumor development (Shahidi and Naczk 1995). The role of phenolic compounds is discussed in more detail in Chapter 31 "Plums and Prunes."

Apricot seeds were used to treat tumors as early as 502 AD, and apricot oil was used against tumors and ulcers in England in the 1600s (Rieger 2004). The American Heart Association (AHA) continues to recommend an overall healthy dietary pattern that is rich in fruits, vegetables, whole grains, low-fat dairy products, lean meats, poultry, and fish. Diets rich in fruits, vegetables, whole grains, and fish have been associated, in many studies, with a lower risk of cardiovascular disease and stroke (AHA 2003). Apricots are rich in beta-carotenes. Because beta-carotene turns to vitamin A in the body, it is often referred to as vitamin A on food labels. The beta-carotenes play a critical role in fighting disease and infections by maintaining strong immunity; protect the eyes; help keep skin, hair, gums, and various glands healthy; and help build bones and teeth.

Jimenez et al. (2008) studied the effects of canning and freezing on the antioxidant properties as compared with raw apricot. The results showed that raw apricots exhibited the highest inhibition of oxidation (evaluated by the lipid peroxidation assay); the freezing process had a slight loss of antioxidant activity, whereas canned apricots completely lost their antioxidant capacity. Furthermore, the capacity of raw apricot to scavenge superoxide radicals was higher than that of butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT). Canned apricots showed higher ABTS radical scavenging capacity than the raw fruit (Jimenez et al. 2008).

In addition to many other food uses, fresh or processed apricots could be an excellent source of healthy and nutritious breakfast. Kartashov et al. (2003) reported that people who eat breakfast are significantly less likely to be obese and diabetic than those who usually do not. Eating just half cup of preserved or three fresh apricots provides 35–45% of the daily recommended intake for vitamin A and one serving of fruit (APC 2010).

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24
Cranberry, Blueberry, Currant, and Gooseberry

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Abstract: Cranberries (*Vaccinium macrocarpan*) and blueberries (Highbush or cultivated: *V. corymbosum* L.; Lowbush or wild: *V. anngusfolium Ait*; Rabbiteye: *V. ashei Reade*) are among the three Native American fruits (the other is Concord grape). These berries have gained significant popularity because of their beneficial effects on our health. The highly acidic cranberries are utilized mostly as processed products. The condensed tannins or proanthocyanidins contained in cranberry fruit are reported to be beneficial against urinary tract infection. Blueberries are soft, small, sweet, and less acidic fruit, which do not require peeling or cutting and can be consumed as such. Like bilberry, blueberry consumption is suggested to improve eye health. They are also reported to reverse age-related decline in brain functions and muscle strength. Besides reviews on these important features, the coverage includes, production, harvesting, physicochemical, nutritional, phytochemical quality, and processing of major products of cranberries, blueberries, currants, and gooseberry.

SECTION 1: CRANBERRY

INTRODUCTION

Cranberries are a healthy fruit that contribute color, flavor, nutritional value, and functionality. Because of their

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versatility and blendability, applications using cranberries are extensive. This section presents information on cranberry history, cultivation, physicochemical characteristics, nutritional and health considerations, and the processes for manufacturing the cranberry products.

Historical

Cranberries are among the only three Native American fruits (the other two being the blueberry and the Concord grape), widely utilized by Native Americans long before the Pilgrims arrived in 1620. They combined crushed cranberries with deer meat and melted fat to make pemmican—a food that was kept for an extended time without refrigeration. Native American women also used cranberry juice as a dye in making rugs and blankets. Legend has it that cranberries were served at the first Thanksgiving in Plymouth, Massachusetts.

To various Native American tribes, cranberry was known by many different names. The Cape Cod Pequot and New Jersey Leni-Lanape tribes called the red berry "ibimi" or bitter berry. To the Pilgrims, the shape of the cranberry blossom resembled the head of a crane; therefore, the berry was named "crane berry," and later shortened to "cranberry."

The first recorded harvest of cranberry was documented in Dennis, Massachusetts, in 1816. Soon after, cranberries became a shipboard staple during trans-Atlantic voyages to prevent scurvy, caused by vitamin C deficiency. During World War II, American troops consumed about 1 million pounds of dehydrated cranberries a year.

The modern cranberry industry took shape soon after the turn of the twentieth century. At that time, fresh fruit marketing was the focus for use in sauces and relishes. Since fresh cranberries are harvested during September through November, their usages peaked during the Thanksgiving and Christmas holidays. The development of canned cranberry sauce made cranberry consumption possible on a year-round basis. Today, cranberry products ranging from cranberry juice cocktail, cranberry juice blends, to sweetened dried cranberries (SDCs) are available around the world.

Classification

The North American cranberry (*Vaccinium macrocarpon*) is recognized by the US Department of Agriculture (USDA) as the standard for fresh cranberries and cranberry juice cocktail. The European variety, grown in parts of central Europe, Finland, and Germany, is known as *V. oxycoccus*. This is a smaller fruit with slightly different anthocyanin and acid profiles than the North American variety. In Europe, this fruit is commonly known as lingonberry or English mossberry.

Cultivation

Cranberries are a unique fruit, which grow and survive only under a special condition of acid peat soil, an adequate fresh water supply, and a growing season that extends from April to November. Principal cranberry growing areas in North America all exist in the northern latitudes of 40–50°.

Cranberries grow on hearty vines in beds layered with sand, peat, and gravel. These beds, commonly known as bogs or marshes, were originally formed as a result of glacial deposits. Historically, cranberries grow in natural wetlands. The water used is constantly recycled from its source, in and out of the bogs for irrigation, spring frost protection, winter flooding, and, of course, for harvest. Normally, growers do not replant each year since an undamaged perennial cranberry vine will survive indefinitely. Some vines on Cape Cod are more than 150 years old and are still bearing fruit. As a matter of fact, the majority of cranberry growers are multigenerational families, some fifth and sixth generation, with two to three generations working and living together on their cranberry farms.

Several different cultivars of cranberries are used in the United States and Canada. The most dominant variety that represents over 50% of cultivar usage is known as "Stevens" characterized by dependable high yields. "Early Blacks" represent 12% of the cultivars with their excellent keeping quality and high color. "Ben Lears" make up 9% of the cultivars and are grown in short-season areas because of its early fruit development and high color content. "Howes" variety represents 7% of the cultivars and the remaining varieties include "Searles," "Pilgrims," "McFarlin," "Bergman," and "Crowley."

Harvesting

Cranberries are typically harvested from mid-September to early November. Originally, cranberries were harvested by hand. Changes in techniques have been developed such that two types of harvesting procedures can be used.

Dry harvest: Until the 1950s, dry harvested cranberries were scooped by hand off the vines. In the early mid-1960s, mechanical pickers were developed and their use became common practice. These mechanical pickers comb the berries off the vine using moving metal teeth. Dry harvested cranberries are used to supply the fresh fruit market. These cranberries are most often used for cooking and baking.

Wet harvest: Cranberries have pockets of air inside the fruit. Because of this, cranberries float in water, and thus, the bogs can be flooded to aid in removal of the fruit from the vines. Water reels, nicknamed "egg-beaters," are used to stir up the water in the bogs (Fig. 24.1). By this action, cranberries are dislodged from the vines and float to the surface of the water. "Booms" are used to corral the berries into one area (Fig. 24.2) so they can be vacuumed into trucks and shipped to the receiving station for cleaning, sorting, and grading. The quality-graded fruit is sent to freezer storage. Frozen fruits can be kept for over 1 year, allowing production of cranberry juices, sauces, and ingredients to occur year-round.

Figure 24.1. Water reels dislodging fruit from vines.

Wet harvested cranberries are used for juices, sauces, and as an ingredient in processed foods.

Berry color is one of the key factors in determining when a bog is ready to be harvested. Some important factors that affect color are growing regions, variety, weather, and time of harvest. The fruit with the redder color comes from the Northwest region. Growers here are able to delay harvest longer because of reduced risk of frost, thereby enhancing color development in the cranberry.

Four factors that play a significant role for optimum cranberry crop yields are as follows:

1. An optimized fertilizer program.
2. Good weather during the pollination period (summer).
3. Adequate pest management program for insects, weeds, and diseases.
4. Adequate irrigation and/or rainfall throughout the growing season.

Figure 24.2. Cranberries "boomed" and waiting for receiving trucks.

WORLD PRODUCTION AND CONSUMPTION

The majority of the world's cranberries are grown in five US states, two Canadian provinces, and a small area of Chile. On the basis of volume, the proportions of the total cranberry crop grown in each of these locations are Wisconsin, 43%; Massachusetts, 20%; New Jersey, 6%; Oregon, 5%; Washington, 2%; and Quebec and British Columbia, 21%; and Chile, 3%.

The total US commercial crop in 2009 was 690 million pounds (6.9 million barrels—1 barrel is equal to 100 pounds). The total global commercial crop for cranberries in 2009 was 920 million pounds or 9.2 million barrels. The average yield per acre in 2009 was 182 barrels/acre or 182,000 pounds. Industry-wide, the estimated area of cranberry production is approximately 50,000 acres. On average, every acre of cranberry bog is supported by about 4–10 acres of wetlands, uplands, and woodlands. This not only creates open space for those who live around these areas but also provides natural habitat for rare and endangered species of plants and animals as well as protected areas for deer, wild turkey, sandhill cranes, eagles, etc. Cranberry growers build birdhouses and eagle stands and encourage wildlife to remain around the bogs. As with any good balanced ecological system, the beneficial insects and birds take care of those less desirable as the food chain dictates. Growers take pride in their environmental stewardship, heritage, and traditions.

Cranberries are handled and processed for use as (1) fresh cranberries, 10%; (2) cranberry sauce products, 15%; (3) shelf-stable SDCs, 20%; and (4) cranberry juice/juice drink products, 50%. The overall retail value of these consumer products in 2009 was approximately 2.0 billion dollars. Americans consume over 500 million pounds of cranberries a year, 20% of this during Thanksgiving week alone.

PHYSICOCHEMICAL AND NUTRITIONAL QUALITY

Determination of Quality

Cranberries bounce! This is one way the quality of cranberries is judged. As mentioned earlier, cranberries have pockets of air inside which enable them to bounce.

A damaged or spoiled cranberry does not bounce, an observation that led to the development of the first cranberry bounce board separator in the late 1800s. This method is still used in some locations to select quality fruit. More advanced technologies used today include electronic sorting which can remove fruit that is either too light or too dark and ultraviolet

sorting which is useful in removing berries that have a degree of rot present.

Chemical Composition

Proximate composition of raw cranberries is listed in Table 24.1. These numbers may vary slightly from one crop year to another but are generally representative of average values.

The cranberry has a unique chemical composition that sets it apart from other North American fruits. The combination of high-acid content (~2.0%) and low Brix level (~7.5°Brix) gives pure cranberry juice a Brix/acid ratio of about 3.75, which makes it extremely tart and unpalatable in a single-strength form. In contrast, apple juice and orange juice have Brix/acid ratios of above 10.

Another unique characteristic of the cranberry is astringency created by significant quantities of tannins. The cranberry also contains an unusual mixture of organic acids. Citric and malic are the predominant acids followed by quinic (~1.0%) and benzoic (~0.01%), which is uncommon in most popular fruits. The chemical composition of cranberry juice is shown in Table 24.2.

Table 24.1. Composition of Raw Cranberries

Component	Percent
Water	86.5
Protein	0.4
Ash	0.2
Fat (lipids)	0.2
Dietary fiber	4.2
Available carbohydrates	8.5

Source: USDA (1999).

Table 24.2. Chemical Composition of Cranberry Juice

Component	Percent
Acids	
Citric	1.0
Quinic	1.0
Malic	0.7
Benzoic	0.01
Sugars	
Glucose	2.9
Fructose	1.0
Tannins	0.3
Pectin	0.1
Anthocyanins (mg/100 mL)	40.0
Flavonols (mg/100 mL)	17.75

Source: Courtesy Ocean Spray Cranberries, Inc.

Anthocyanins, Total Phenolics, and Antioxidant Capacity

The characteristic red color of cranberries, juice and beverage, and products is due to anthocyanin pigments. Zheng and Wang (2003) reported concentration of major anthocyanins in cranberry (cv. Ben Lear) as peonidin 3-galactoside (213.6 μg/g fresh weight), peonidin 3-arabinoside (99.7 μg/g), cyanidin 3-galactoside (88.9 μg/g), cyanidin 3-arabinoside (48.0 μg/g), and peonidin 3-glucoside (40.4 μg/g). Other phenolic compounds analyzed were vanillic acid (49.3 μg/g), caffeic acid (42.5 μg/g), quercetin 3-galactoside (70.4 μg/g), and quercetin 3-arabinoside (34.4 μg/g). Wang and Stretch (2001) reported average anthocyanin and total phenolic concentrations in ten cranberry cultivars as 34.8 mg of cyanidin 3-galactoside per 100 g and 141.2 mg of gallic acid equivalent per 100 g of fresh weight, respectively. The average antioxidant capacity of these cranberry cultivars expressed as micromole of Trolox equivalents (TEs) per gram of fresh weight was 10.4. Wu et al. (2004) reported total (sum of lipophilic and hydrophilic) antioxidant capacity (micromole TE) of 8983 in one whole cup (95 g) serving of cranberry. Among the fruits analyzed by these researchers, cranberries showed high (2.00 μmol TE/g) lipophilic antioxidant capacity (L-$ORAC_{FL}$), second only to avocado (5.52 μmol TE/g).

Nutritional Quality and Health Considerations

Nutritional Quality

Besides phytochemicals, cranberry products contain dietary fiber and certain vitamins and minerals. Cranberry concentrate contains nutritionally significant quantities of vitamin C and potassium (Table 24.3). In an unsweetened form, cranberries are low in calories, sodium, and free from cholesterol and saturated fats.

Health Considerations

Historically, the health-promoting properties of cranberries have been based on folklore remedies, which have existed for centuries. Native American Indians and early settlers recognized the health-giving properties of this fruit.

Cranberries have been used in many different forms as a folk remedy for the treatment of urinary tract infections (UTIs). These infections cause frequent and painful urination. The first reported use of cranberries by conventional medical practitioners was in 1923 (Blatherwick and Long 1923). It was suggested that cranberries acidify urine, killing the bacteria causing UTIs. A study conducted at the Harvard Medical School (Avorn et al. 1994) determined that regular consumption of cranberry juice reduced the amount of bacteria in the urinary tracts of elderly women. Rather than acidification of the urine, however, these researchers concluded

Table 24.3. Nutritional Values of Cranberries (Per 100 g Product)

	Cranberry Product				
Nutrient	Frozen[a]	Concentrate	Sweetened/Dried[b]	Flavored SDC[c]	Powder
Calories (kcal)	48	198	298–367	337–342	360
Calories from fat (%)	0	0	11–12	5	2
Total fat (g)	0.5	0	1.2–1.4	0.5	0.2
Saturated fat (g)	0	0	0	0	0
Cholesterol (mg)	0	0	0	0	0
Sodium (mg)	3	14	3–4	2–3	29
Potassium (mg)	73	500	40–90	11	734
Total carbohydrate (g)	10	49	82–88	83–84	89
Dietary fiber (g)	4	<0.5	6–9	5–6	6
Sugars (g)	4	22	64–69	67–68	37
Protein (g)	0.6	<0.5	<0.5	<0.5	<0.5
Vitamin A (IU[d])	0	0	70[e]	16,200[f]	0
Vitamin C (mg)	18	58	0	1	5
Calcium (mg)	10	39	10–18	4	184
Iron (mg)	0.6	1.7	0.5	0	4

Source: Courtesy Ocean Spray Cranberries, Inc.
[a]Whole or sliced.
[b]Regular, soft and moist, and glycerated forms.
[c]Orange, blueberry, cherry, strawberry, or raspberry flavored sweetened dried cranberries (SDCs).
[d]As provitamin A.
[e]Value for glycerated forms of sweetened dried cranberries. Regular and soft and moist forms contain 0 IU.
[f]Value for orange flavored sweetened dried cranberries. Other flavors contain 0 IU.

that something specific to the cranberry actually prevented bacteria from adhering to the lining of the bladder. Howell et al. (1998) identified condensed tannins or proanthocyanidins (PACs) from the cranberry fruit as the component that prevented *Escherichia coli*, the primary bacteria responsible for UTIs, from attaching to cells in the urinary tract. These organisms are flushed out from the urinary tract rather than being allowed to adhere, grow, and lead to infection. Based on a randomized double blind study, Howell et al. (2010) showed that administration of PACs standardized cranberry powder at dosages containing 72 mg of PAC per day may offer some protection against bacterial adhesion and virulence in the urinary tract.

The antiadhesion mechanism may work beyond the bladder in fighting certain bacteria in other parts of the body including the oral cavity (periodontal gum disease) and stomach (ulcers). For example, Weiss et al. (2002) suggested that compounds in the cranberry prevent certain bacteria found in the mouth from adhering to teeth and gums. Burger et al. (2000) suggested that the same antiadhesion mechanism fights *Heliocobacter pylori*, the bacteria that cause stomach ulcers. This study suggests that the cranberry's antiadhesion effect prevents the bacteria from attaching to the stomach lining and causing an ulcer.

Howell and Foxman (2002) suggested that regular consumption of cranberry juice cocktail may decrease the need for certain antibiotics.

Maher et al. (2000) reported potential benefits of cranberry juice in protecting against cholesterol oxidation. In their study, cranberry juice was tested for its ability to inhibit oxidation of LDL cholesterol and proved to be an effective antioxidant. A pilot, double-blind placebo-controlled trial (Valentova et al. 2007) assessed the effect of consumption of dried cranberry juice (DCJ) for 8 weeks on 65 healthy young women. While consumption of 400 mg DCJ/day had little effect on the parameters tested, a 1200 mg amount of DCJ/day resulted in statistically significant decrease in serum levels of advanced oxidation protein products. This study showed that cranberry fruits have effects not only on prevention of UTI but also on the prevention of oxidative stress.

There is strong epidemiological evidence that diets high in vegetables and fruits contribute to an overall anticancer effect. Preliminary evidence suggests that powerful cancer-fighting antioxidants are found in the cranberry seeds. The cranberry seeds have been found to contain a high level of tocotrienols. Cranberry seed oil contains significant amounts of these potent forms of Vitamin E. The unique combination of phytochemicals found in cranberry fruit may produce synergistic health benefits. Possible chemopreventive mechanisms of action by the cranberry phytochemicals include induction of apoptosis in tumor cells, reduced omithine decarboxylase activities, decreased expression of matrix metalloproteinases associated with prostrate tumor metastasis, and anti-inflammatory activities (Neto 2007).

CRANBERRY PRODUCTS

Table 24.4 lists various cranberry products along with information regarding storage conditions, shelf life, packaging, and various applications. As indicated before in terms of processed products, 50% of cranberries in the United States are utilized as juice and drinks, about 15% as sauce, and 20% as SDCs. Figure 24.3 shows steps involved in making various cranberry products.

Cranberry Juice Processing

After cranberries are harvested, they are cleaned and sorted for color and then frozen in 1000 pound bins. During the

Table 24.4. Cranberry and Processed Products

Product	Product Description	Packaging	Shelf Life	Comments	Applications
Fresh	Whole, fresh cranberries	12-ounce consumer bag or 40 lb box	32–34°F (0–1°C), 3 months	Available September–November	Bakery products, sauces
Frozen whole	Whole cranberries	40 lb box	0 ± 15°F (–18 ± 9°C), 18 months	Available year-round	Bakery products, sauces, condiments, dairy products
Sliced	3/8″ (10 mm) thick	20 lb box	0 ± 15°F (–18 ± 9°C), 18 months	Available year-round; individually quick frozen (IQF)	Bakery products, sauces, condiments, dairy products
Liquid					
Single-strength juice	7.5°Brix	44 gallon drum or tanker	0 ± 15°F (–18 ± 9°C), 2 years	Direct expressed juice	Beverages, natural colorant
Concentrate	50°Brix, 14 ± 1.5% titrable acidity	5 gallon pail, 50 gallon drum or tanker	0 ± 15°F (–18 ± 9°C), 2 years	Highly colored, pure cranberry concentrate	Beverages, natural colorant, condiments, dairy products, confections
Puree	5.4° or 6.1°Brix	33 lb pail or 50	0 ± 15°F (18 ± 9°C), 18 months	Well colored, high pectin content	Sauces, beverages, bakery products
Shelf-stable products					
Sweetened dried cranberries	Sugar-infused dried fruit	25 lb box	12 months at <65°F (18°C) or 18 months at <45°F (7°C); shelf stable in cool, dry conditions	No artificial color, flavor, or preservative; excellent color retention	Bakery products, cereals, trail mix, snack foods, dairy products, confections
Flavored SDC	Sugar-infused, cranberry-based dried fruit with natural flavor topically coated	25 lb box	12 months at <65°F (18°C) or 18 months at <45°F (7°C); shelf stable in cool, dry conditions	Firm yet tender fruit texture; versatile and cost-effective; available in raspberry, cherry, strawberry, blueberry, orange flavors	Bakery products, cereals, trail mix, snack foods, dairy products, confections
Cranberry powder	Spray-dried cranberry concentrate	100 lb drum, 50 lb drum	2 years in dry ambient storage	Soluble, hygroscopic fruit	Nutracueticals, confections, beverages, colorant, teas

Source: Courtesy Ocean Spray Cranberry, Inc.
Note: Variations of sweetened dried cranberries:

1. Regular: Distinct cranberry flavor, tart, 11–14% moisture.
2. Soft and moist: Eat out of hand, less tart, softer, 13–16% moisture.
3. Glycerated: Remains soft in low-moisture system ($a_w = 0.45$–0.53).

Figure 24.3. Process flow diagram for cranberry products.

rest of the year, they are then pulled out of frozen storage as needed to be extracted, filtered, and then concentrated into a 50°Brix juice concentrate. This concentrate is utilized for processing into cranberry juice drinks or sold, as is, in the market.

There are several different methods for extracting juice from the fruit: pressing, mash depectinization, and countercurrent extraction. Prior to pressing or mash depectinization, the fruit is milled to a specific size. Pressing uses a larger piece size to reduce the amount of insoluble solids in the pressed juice. When depectinization is followed, the piece size is reduced to increase the rate of depectinization and thus minimize the amount of pectinase required.

- *Pressing*: This method uses a giant press (e.g., Reitz-Willmes) (Fig. 24.4) and mechanical action to express the juice. This cold process produces a high-quality juice with excellent flavor attributes. The juice color is also very stable since no heat has been used to degrade the anthocyanin pigments. The yield is approximately 75%.
- *Mash depectinization*: This process involves blending size-reduced cranberries with enzymes to digest the fruit into a mash. The entire process can take 4–12 hours at approximately 52°C. This mash is then extracted via either a Bucher Press or by centrifugation. This method generates extremely high yields—sometimes over 100%. The negatives include length of processing time and heat degradation, which affects color, flavor, and shelf life of beverage.
- *Countercurrent extraction*: Countercurrent technology is a gentle process involving a large screw (Fig. 24.5). Sliced fruit is deposited in one end and water into the opposite end. Through countercurrent flow of the two material streams, juice extraction takes place. This cold process produces very high-quality juice with yields exceeding 90%. The other benefit is that the coproduct produced is an intact fruit piece that can be further processed into SDCs by infusing with sweeteners (sugar, sucrose syrup, juice concentrates, etc.) and then drying to a specific moisture range.

Once the cranberry juice is extracted by one of the methods previously mentioned, it is then filtered. Filtration can take on many different forms:

Types of Filters	
Screen	Plastic or stainless steel
Bag	Woven fiber
Media	Diatomaceous earth, perlite
Membrane	Polymer, ceramic, stainless steel
Pore Size	
Media	<5 μm
Microfilter	0.1–1.5 μm
Ultrafilter	0.005–0.1 μm
Nanofilter	0.001–0.008 μm

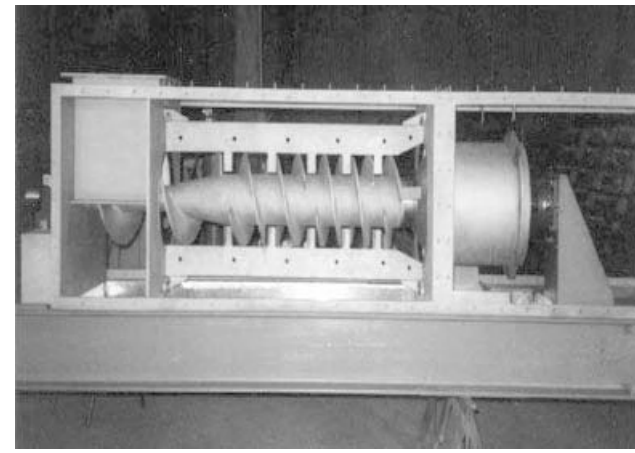


Figure 24.4. Reitz-Willmes press.

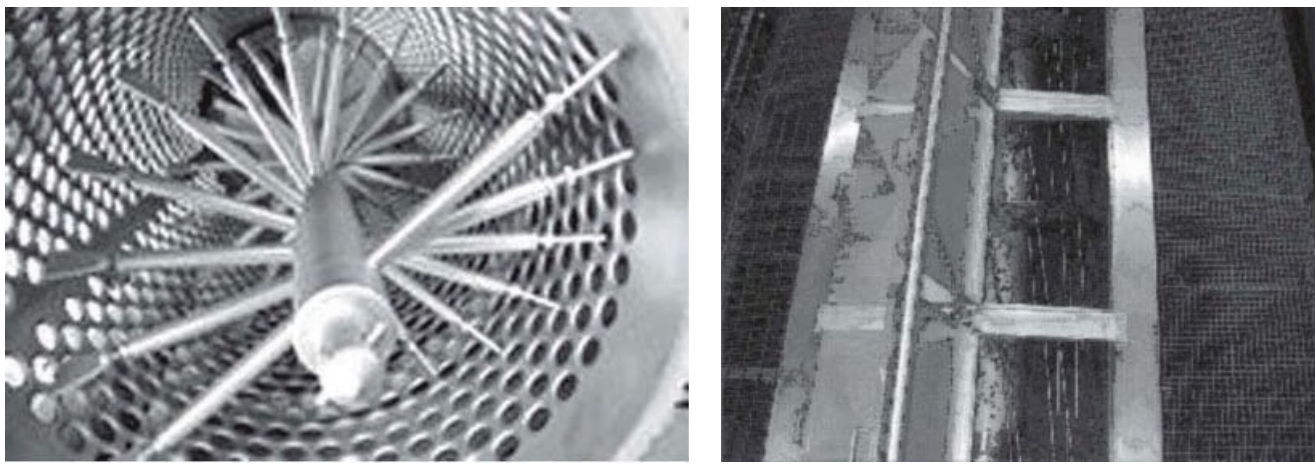
Once filtered, the juice is concentrated. Concentration improves microbial stability and also reduces storage and shipping volumes. Single-strength cranberry juice is about 7.5°Brix, whereas standard concentrate is 50°Brix. Concentration to 50°Brix involves reverse osmosis and evaporation. Figure 24.6 shows how a typical RO system operates.

Evaporation can occur using single effect, triple effect, or triple effect with regeneration as shown in Figures 24.7–24.9. Single pass, multiple effect evaporators having no recirculation are considered the preferred method since the juice sees minimal time at elevated temperatures.

The concentrate is then filled into drums and stored at –18°C for industrial sale. Refrigerated bulk storage can also be used for short-term periods prior to use.

Sweetened Dried Cranberries

Because cranberry is highly acidic, infusing this fruit with sweeteners prior to drying reduces its acidity and makes it more acceptable in the dried form. The infused-dried cranberries also known as sweetened dried cranberries or SDCs are used in many ways (Table 24.1). US Patent 5,320,861 (Mantius and Peterson 1994) described a process for extracting cranberry juice and infusing and drying extracted cranberries to make SDCs. This sequential two-step process of extraction and infusion based on countercurrent principle using flights in a screw conveyer (Fig. 24.5) with intermittent forward and reverse motion works very well for a firm fruit such as cranberries. In this process, the raw fruit is frozen prior to



(**A**) (**B**)

Figure 24.5. Countercurrent technology.

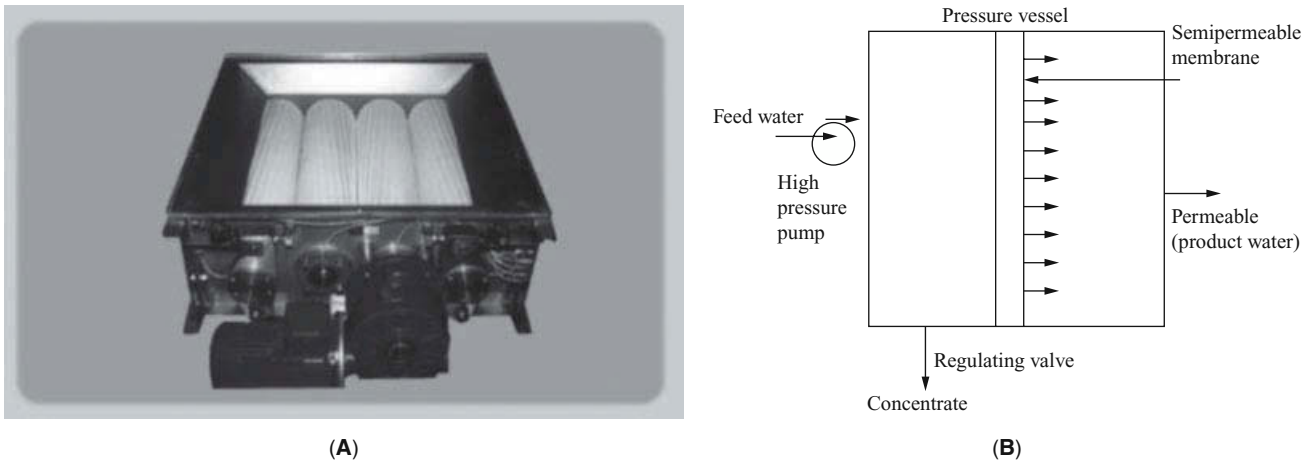


Figure 24.6. Reverse osmosis operation.

extraction. The residence time and temperature for juice extraction is about 120–150 minutes and 24°C, respectively. The residence time and temperature for infusing cranberries prior to drying is 120–300 minutes and 38–54°C, respectively. The extracted cranberries are infused to 40–55°Brix and dried to a water activity of 0.50–0.55. US patents 7,767,242 (Bauman et al. 2010) and 7,781,008 (Sinha et al. 2010) described processes for buoyant infused-dried whole cranberries having water activity of 0.25–0.60 with at least 30% buoyancy. The SDCs and infused-dried whole cranberries find application in many products including ready-to-eat cereals and trail mixes.

SUMMARY

Cranberries are an extremely versatile fruit. When incorporated into other food products, they provide refreshing flavor as well as a characteristic red color. Used in combination with other fruits, cranberries can accentuate and enhance the flavors of these fruits. Because of their health benefits, cranberries are experiencing an expansion into the food and beverage industry. Available year-round and in a variety of forms, cranberries can be used to enhance numerous products and applications in the food and beverage industry.

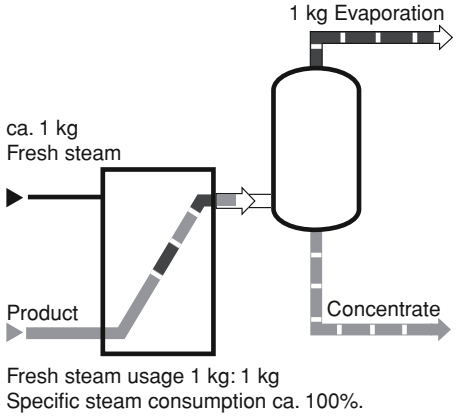


Figure 24.7. Single-effect evaporation.

SECTION 2: BLUEBERRY

INTRODUCTION

Blueberries (family, Ericaceae; genus, *Vaccinium*) are a soft fruit native to North America. The Native American tribes revered blueberries. Parts of blueberry plant were used as medicine and blueberry juice was used to treat coughs. Dried blueberries were added to stews, soups, and meats. In the 1880s, a blueberry canning industry began in the northeast United States (Anon 2004a). Blueberries contain polyphenolic compounds, most prominently anthocyanins, which have antioxidant and anti-inflammatory effects. Moderate-term blueberry supplementation has been suggested to provide neurocognitive benefits (Krikorian et al. 2010). This section reviews the production, processing, and quality aspects of blueberries.

PRODUCTION AND CONSUMPTION

Blueberry is a perennial crop that can produce for more than 30 years. The ideal conditions for cultivating blueberries require sandy soil, high in organic matter, pH of 4.5–5.0, and a water table 2–3 ft deep to provide moisture during the growing season. Blueberry planting takes

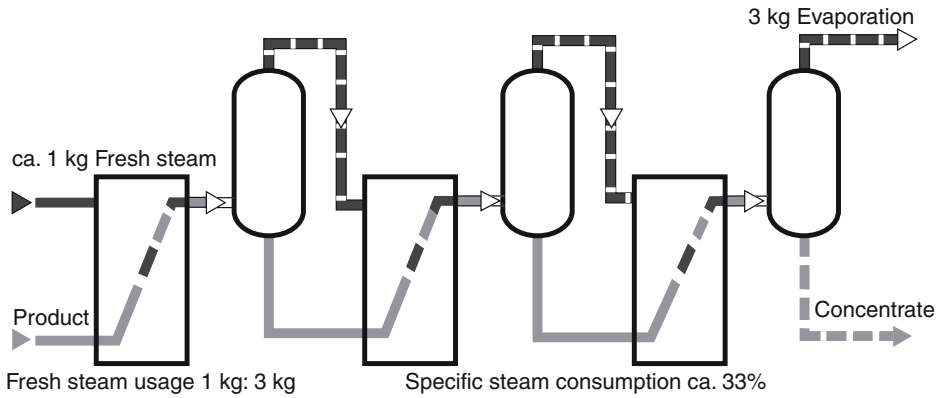


Figure 24.8. Triple-effect evaporation.

about 2–3 years to establish and harvesting can begin in third or fourth growing season. However, the plants require 6–8 years to reach full production potential. As the berries do not mature uniformly, harvesting is done two to five times during the season. More than 85% of blueberries are commercially grown in United States (54%) and Canada (34%). The blueberry production in both these countries, especially in Canada, has increased by almost 50% between 2005 and 2009 (Table 24.5). In 2009, Canada had about 9000 more harvested acres (34,148 hectares) under blueberry production than the United States (25,564 hectares). However, the estimated blueberry yield in the United States (0.64 tons/hectare) was more than twice (0.30 tons/hectare) that of Canada (FAO 2011).

Outside the United States and Canada, Poland was the largest blueberry producer with about 10% of the world production (Table 25.5). In the United States, Michigan leads in cultivated blueberry production, followed by New Jersey, Oregon, North Carolina, Georgia, and Washington. The state of Maine is the largest producer of wild blueberries.

Classification

Three classes of blueberries (highbush or cultivated, rabbiteye, lowbush or wild blueberry) are commercially grown in the United States. Table 24.6 lists fruit characteristics of selected blueberry varieties.

1. *Highbush* (*Vaccinium corymbosum* L.) *blueberries*: The first highbush varieties were transplanted from wild. There are at least 40 improved highbush varieties. Northern highbush and southern highbush blueberries have been developed from a limited germplasm. About 95% of cultivated blueberries consist of the northern

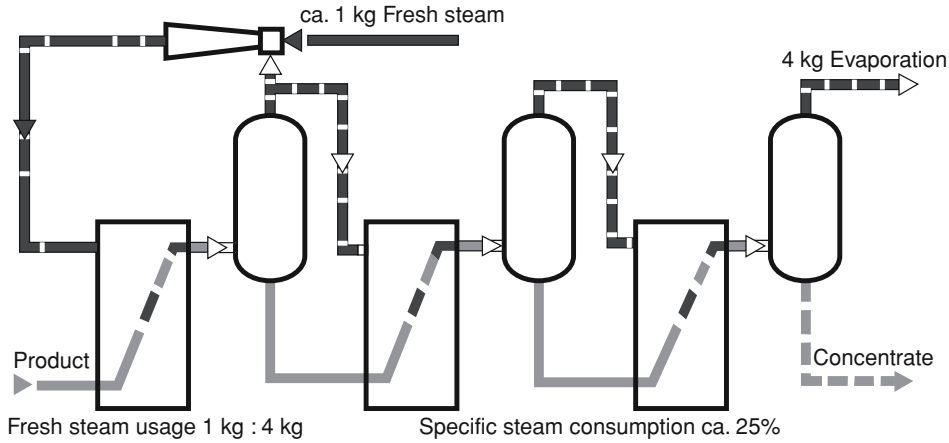


Figure 24.9. Triple-effect evaporation with regeneration of steam.

Table 24.5. Blueberry Production in Leading Countries and World (Mt)

Country	1980	1990	2000	2005	2009
1. United States	46,381	79,940	134,446	135,534	165,198
2. Canada	13,647	36,114	59,035	69,410	103,070
3. Poland	0	1700	21,500	5000	11,023
4. Sweden	500	100	100	2200	2576
5. Lithuania	0	0	6500	7933	1794
6. Italy	523	700	1896	1484	1509
7. The Netherlands	0	2500	3800	4000	5389
8. New Zealand	18	1230	1500	2000	2700
World (Total)	62,069	124,324	240,412	240,376	311,959

Source: FAO (2011).

Table 24.6. Characteristics of Selected Blueberry Varieties

Variety	Fruit Characteristics
I. Highbush (cultivated blueberries)	
1. Bluecrop	A leading commercial variety released in 1952; high-dependable yields; height to 4–6 ft; mid-season; small scar; light blue color; firm; good sugar–acid balance; medium to large size; good for fresh pack and for processing
2. Duke	Released in 1987; medium size; light blue; firm berry with a small scar; good for IQF and fresh shipping
3. Elliott	Released in 1973; high-yielding berry with firm fruit and strong to mildly acid flavor; light blue color; medium size; late season fruit
4. Jersey	Released in 1928; mid to late season fruit; light blue color; medium size, firm texture; mild flavor; machine harvests well
5. Legacy	Released in 1995; insufficient winter hardiness; late season fruit; high fruit quality; stores well
6. Rubel	Released in 1911; machine harvests well; mid-season; small-medium size; medium blue color; firm texture; mild flavor
7. Sierra	Released in 1988; large, firm berries; high fruit quality; suitable for machine harvest
II. Southern highbush	
1. O'Neal	Low winter chill requirements (200–300 h); large size fruit with sweet flavor
2. Reveille	Medium size fruit; medium blue color, firm texture; excellent flavor; fruit can crack during extended periods of rain
III. Rabbiteye	
1. Brightwell	Large fruit, gritty texture; tough skin
2. Premier	Large fruit with excellent color and taste; one of the best eating rabbiteye blueberries
3. Powderblue	Small-medium fruit with light blue color; the berries have slight white powdery coat
4. Tifblue	Released in 1955. Regarded as a benchmark for all rabbiteye varieties; medium-large light blue fruit

Note: Early season varieties ripen in late June; late-season varieties continue through August.
Sources: Anon (2004b, 2004c, 2004d).

highbush varieties grown in the cooler northern temperate zone. These berries generally need 160 frost-free days. Severe winter temperatures (about –20°C or below) will injure most highbush varieties. However "half-high" varieties, which are hybrids of highbush and lowbush blueberries (plants are 2–4 ft tall), can tolerate severe winter conditions (Anon 2004b). The highbush plants are woody shrubs and may grow higher than 10 ft. Kalt et al. (2001) reported that the berry weight of highbush and southern highbush varied from <1 to 4.0 g/berry, although most highbush fruits were between 1 and 3 g/berry. In contrast, berries from lowbush clones were smaller and had a much narrower range of fruit weight; all clones had fruit no greater than 0.5 g/berry. The fruit size distribution was symmetrical for the fruits of the lowbush genotypes but not for highbush genotypes analyzed. The berry size is governed by genetic and environmental factors.

2. *Southern highbush* varieties with low chill tolerance have been developed to boost blueberry production in the southern United States. Besides being adaptable to growing conditions of this region, these new varieties inherit some characteristics of the northern highbush, such as a late bloom date and a shorter ripening period. With late bloom date, these varieties tend to face a lower risk of frost damage during the flowering stage, a critical period of fruit development. With the shorter ripening period, blueberries from southern highbush varieties can be harvested around mid-April through late May, earlier than most rabbiteye blueberries. This extends marketing season and allows growers to take advantage of the premium prices typically available early in the season. The southern highbush berries tend to be not as soft as northern highbush berries and lend to machine harvested well.
3. *Lowbush* (*V. angustifolium* Ait; also called wild) berries are not commercially planted, but natural stands are pruned, sprayed, and harvested in the northeastern United States (primarily Maine) and eastern provinces of Canada. The strands of lowbush blueberries are made up of numerous wild clones; as a result, the commercial lowbush berries are more heterogeneous than the commercial highbush or rabbiteye blueberries. The wild blueberry plants are about 1 ft high. The fruits are typically smaller in size than highbush or rabbiteye blueberries. Table 24.7 gives maturity-related differences for selected wild blueberry clones in fresh berry weight, dry matter, soluble solids, acidity, firmness, and anthocyanins. When fully ripened, the Cumberland had higher percentage of dry matter and soluble solids than other varieties analyzed.
4. *Rabbiteye* (*V. ashei* Reade) blueberries grow in the relatively warmer climates of the southeastern United States. They are not winter-hardy but drought tolerant. The plants are comparable with highbush blueberries; the berries have slightly fibrous mouth feel. They are typically marketed for fresh use.

Table 24.7. Characteristics of Selected Lowbush (Wild Blueberries) Clones at Various Maturity Stages

Maturity	Blomidon	Cumberland	Fundy
I. *Unripe*			
1. Berry fresh wt (g/berry)	0.217	0.220	0.305
2. Soluble solids (%)	7.52	8.71	7.70
3. Dry matter (%)	13.80	14.62	12.63
4. Firmness (N)	97.52	72.28	95.68
5. Titratable acidity (mEq/g dry wt)	0.730	0.928	1.227
6. Anthocyanins (mg/g dry wt)	4.38	6.77	7.08
II. *Ripe*			
1. Berry fresh wt (g/berry)	0.292	0.344	0.357
2. Soluble solids (%)	10.72	12.18	10.55
3. Dry matter (%)	15.95	16.23	14.03
4. Firmness (N)	79.17	49.00	72.76
5. Titratable acidity (mEq/g dry wt)	0.466	0.461	0.845
6. Anthocyanins	9.51	10.14	13.46
III. *Overripe*			
1. Berry fresh wt (g/berry)	0.631	0.600	0.761
2. Soluble solids (%)	13.13	14.22	11.92
3. Dry matter (%)	16.81	17.32	14.89
4. Firmness (N)	58.45	49.94	58.74
5. Titratable acidity (mEq/g dry wt)	0.354	0.332	0.652
6. Anthocyanins	8.88	8.91	12.86

Source: Kalt and McDonald (1996).

Consumption

According to USDA's per capita availability data (USDA 2008), in 2008, about 66% (0.80 lbs) blueberries were consumed as fresh and 34% (0.39 lbs) as processed. Blueberry consumption in the United States has been steadily increasing from a total of 0.44 lbs in 1990 to 1.20 lbs in 2008. The states of New Jersey and North Carolina specialize in growing blueberries for the fresh market. In these states, more than 70% of blueberries produced are sold for fresh consumption.

Frozen berries are bulk frozen or individually quick frozen (IQF), a process that ensures freshness while preserving nutrients. Processed blueberries are used as ingredients in bakery, dairy, and convenience foods. Dried berries are used as ingredients in ready-to-eat cereals and many snack food products. Blueberries are also processed into jam/jellies, syrup, juice/concentrates, and baby foods.

PHYSICOCHEMICAL AND NUTRITIONAL QUALITY

Brix, Acidity, and Sugars

Unlike some fruits, soft, small, sweet, and less acidic blueberries do not require peeling or cutting and can be consumed as it is. Conner et al. (2002) reported Brix and acidity of cultivated blueberries in the range of 11–12.6° and 0.90–2.46%, respectively. On an average, the wild blueberries have lower acidity (0.4–0.7%) than cultivated blueberries. Their Brix ranges from 7° to 14° depending on harvest time and year of production. Both cultivated and wild blueberries contain mostly glucose and fructose.

Flavor

Blueberries have fruity and floral notes due to esters, ethyl acetate, and 3-isopropyl-butyrate. Other flavor compounds are branched aldehydes, 3-methyl-butyraldehyde, and 2-methyl-butyraldehyde (fruity notes); benzaldehyde (almond flavor); hexanol, heptanal, and nonanal; and terpenes, 1,8-cineole, and linalool with traces of cymene, limonene, 1-terpineol, and 3-carene. Citral, which has a strong lemon note, was identified in Ranococas and Bluecrop varieties. Alcohols, 1-butanol, 1-pentanol, 1-hexanol, 2-ethyl-1-hexanol, 1-heptanol, 1-octanol, and 1-nonanol, and several furan derivates have also been found (Anon 2004e).

Anthocyanins, Phenolics, and Antioxidant Capacity

The typical blue color of blueberries is due to the presence of anthocyanin pigments. Zheng and Wang (2003) reported four major anthocyanins, malvidins (purple color), petunidins (blue-purple), delphinidins (blue-violet), and cyanidin (red) in highbush blueberries (cv. Sierra). The total anthocyanin (TACY) pigment concentration measured was 1.1 mg/g, of which malvidins were 34.5%; petunidins, 31.1%; delphinidins, 18.7%; and cyanidins, 15.8%. Individually, delphinidin 3-galactoside was the lead pigment (17.0%) followed by malvidin 3-galactoside (13.6%), petunidin 3-galactoside (13.0%), and cyanidin 3-galactoside (13.0%). Kalt et al. (2001) reported anthocyanins and phenolics content in highbush blueberries as 1.18 mg/g (cyanidin 3-glucoside equivalent) and 1.91 mg/g (gallic acid equivalent) fresh weight, respectively. They reported anthocyanin and phenolic contents in lowbush blueberries as 1.63 mg/g (cyanidin 3-glucoside equivalent) and 3.76 mg/g (gallic acid equivalent), respectively. The average antioxidant capacities (oxygen radical absorbency capacity or ORAC) of highbush and lowbush berries were 45.2 and 69.8 μmol of TE per gram fresh weight (Kalt et al. 2001). In highbush blueberry (cv. Sierra), anthocyanins and chlorogenic acid (CG) accounted for 56.3% and 20.9% antioxidant activity, respectively (Zheng and Wang 2003). Connor et al. (2002) indicated that increases in antioxidant activity, total phenolics, and anthocyanins during cold storage are cultivar dependent.

It is suggested that unlike fruits such as grapes, for which significantly higher antioxidant levels are found in seeds due to tannins, in blueberries, majority of the antioxidants are concentrated in skins. Further, blueberry leaf tissues had greater phenolics and antioxidant capacities than the fruit tissues (Ehlenfeldt and Prior 2001). Wu et al. (2004) reported that based on a serving size (one cup containing 145 g blueberries), the wild (lowbush) blueberry had the highest total antioxidant capacity (13,247 μmol TE) among fruits analyzed followed by cultivated (highbush) blueberry (9019 μmol TE) (Table 24.8).

Using model systems containing purified anthocyanin (cyanidin 3-glucoside), CG, and blueberry polyphenol oxidase (PPO), it was shown that the degradation of anthocyanin did not occur in the presence of PPO, but the addition of CG led to the degradation of anthocyanin via a coupled oxidation mechanism involving CG-o-quinone, which led to a complete discoloration of the reaction mixture (Kader et al. 1998). Srivastava et al. (2007) reported recoveries of total polyphenols (TPPs), TACYs, and Trolox equivalent antioxidant capacity (TEAC) in blueberry juice extracts (blueberries were steam blanched, depectinized, crushed, heat processed at 85°C for 2 minutes, and packed in glass bottles) from Tifblue and Powderblue cultivars as 25%, 29%, and 69%, respectively. Storage at 23°C and 35°C for 2 months showed about 35–50% retention of TACY and TPP, and 76–87% TEAC. Storage at −20°C for 2 months showed about 75% retention of TACY and TPP and over 90% of TEAC. Storage

Table 24.8. Antioxidant Activity, Anthocyanins, and Phenolic Concentrations of Blueberries

Blueberries	ORAC (μmol TE/g)	Anthocyanins (mg/100 g)	Phenolics (mg/100 g)
I. *Northern highbush*			
1. Bluecrop	17.0 ± 1.2	93.1 ± 1.6	189.8 ± 10.9
2. Duke	18.1 ± 0.2	101.2 ± 1.5	181.1 ± 10.4
3. Jersey	20.8 ± 0.6	100.1 ± 2.3	206.2 ± 4.1
4. Rubel	37.1 ± 0.5	235.4 ± 6.1	390.5 ± 6.5
II. *Southern highbush*			
1. O'Neal	16.8 ± 1.9	92.6 ± 4.6	227.3 ± 6.9
III. *Rabbiteye*			
1. Tifblue	23.0 ± 2.6	87.4 ± 5.6	361.1 ± 16.6
2. Climax	13.9 ± 4.1	90.8 ± 5.2	230.8 ± 7.3
3. Brightwell	15.3 ± 2.8	61.8 ± 1.8	271.4 ± 12.7
IV. *Lowbush*			
1. Cumberland	27.8 ± 2.6	103.6 ± 0.9	295.0 ± 13.2
2. Blomidin	28.8 ± 2.1	91.1 ± 0.7	313.0 ± 6.4
3. Fundy	42.0 ± 2.0	191.5 ± 2.5	433.0 ± 45.5

Source: Prior et al. (1998).

Table 24.9. Nutrient Values of Blueberries

Nutrients/100 g	Blueberries, Raw[a]	Canned Blueberry in Syrup[a]	Infused-Dried Cultivated Blueberries[b]	Infused-Dried Wild Blueberries[b]	Infused-Dried Organic Wild Blueberries[b]	Dehydrated Blueberries[c]
Calories (kcal)	57.0	88.0	290	305	280.0	353.0
Calories from fat (kcal)	3.0	3.0	20.0	19.0	11.0	21.5
Total fat (g)	0.33	0.33	2.19	2.06	1.17	2.39
Saturated fat (g)	0.028	0.027	0.3	0.3	0.1	NA
Polyunsaturated fat (g)	0.146	0.144	0.4	0.8	0.8	NA
Monounsaturated fat (g)	0.047	0.047	1.4	1.0	0.3	NA
Cholesterol (mg)	0.00	0.0	0.0	0.0	0.0	0.0
Sodium (mg)	1.0	3.0	18.0	15.0	22.0	38.0
Potassium (mg)	77.0	40.0	252.0	166.0	144.0	561.0
Total carbohydrate (g)	14.49	22.06	77.9	80.3	78.6	89.0
Total fiber (g)	2.4	1.6	16.6	15.4	15.1	8.19
Total sugar (g)	9.96	20.46	61.2	64.9	60.5	80.80
Sucrose (g)	0.11	NA	NA	NA	NA	NA
Glucose (g)	4.88	NA	NA	NA	NA	NA
Fructose (g)	4.97	NA	NA	NA	NA	NA
Protein (g)	0.74	0.65	2.03	2.43	0.84	4.22
Calcium (mg)	6.0	5.0	255.0	380.0	49.0	38.00
Vitamin C (mg)	9.7	1.1	<0.10	76.0	<0.10	81.90
Vitamin A (IU)	54.0	36.0	14.0	33.0	4.0	630.0
Water (g)	84.21	76.78	16.8	13.8	NA	3.00

NA, not available.
[a]Data from USDA: http://www.nal.usda.gov/fnic/foodcomposition/cgi-bin/list_nut_edit.pl.
[b]Courtesy Graceland Fruit Inc, Frankfort, MI, USA (www.gracelandfruit.com).
[c]Data from Esha Nutritional Database.

at 6°C for 2 months showed retention of about 66% TACY and TPP and over 90% TEAC.

Nutritional Quality

Table 24.9 provides the nutritional values of blueberry and its products. As is seen, raw blueberries have low calories and can be a natural source of fiber, sugars, vitamins, and minerals. The dried blueberries are high in dietary fiber and potassium.

Health Considerations

In addition to potential effects on cancer and heart disease, phytochemicals present in antioxidant-rich fruits such as blueberries are suggested to reverse the age-related declines in balance and coordination, muscle strength, and brain functions (learning and memory) (Joseph et al. 1999). It is suggested that berry fruits, such as blueberries and strawberries, may exert their effects directly through alterations in cell signaling to improve neuronal communication, calcium buffering ability, plasticity, and stress signaling pathway (Shukitt-Hale et al. 2008).

Similar to bilberry, intake of blueberry is believed to improve eye health and reduce eyestrain. This beneficial effect of blueberries on eyes is believed to be one of the reasons for increased demand of blueberries in Japan.

BLUEBERRY PRODUCTS

As indicated previously, most of the wild blueberries and about 30% of cultivated blueberries are processed into various products. IQF and frozen blueberries can be used directly in some applications. The IQF process consists of various steps beginning with passing the berries through a multilayer shaker dock that removes, sticks, leaves, etc., which are too large to fall through the holes in the dock. Good berries are led into successive pans that contain water to separate heavy solids, such as stones, etc. Subsequently, the berries are sanitized with chlorine water spray (20–35 ppm chlorine). For the IQF process, the berries pass through a freezer tunnel with a high-velocity cold air of –40°F for about 10 minutes. Then, they are led through a destemming reel to remove stems before being laser sorted and inspected for defects. The culled berries are generally made into puree.

Infused Frozen Blueberries

Infused frozen blueberries, which are infused with sweeteners to about 25–40°Brix and pasteurized, have been finding

increasing use in bakery industry where direct use of frozen products can create problems because of excess and freely available moisture. Furthermore, the unpasteurized berries can be a source of enzymes such as amylase, which affect pie fillings (lower viscosity) if added directly.

US Patents 6,254,919 (Phillips 2001) and 4,713,252 (Ismail 1987) described methods to prepare sugar-added blueberry products having moisture in the range of 30–50% and 10–40%, respectively.

Blueberry Juice

Blueberry juice can be made from both fresh and frozen berries. With this soft fruit, a screw juice expresser with appropriate screens to separate the juice from other parts of the fruit can be used. The juice can be further clarified with bentonite and gelatin, filtered and pasteurized at 85°C for 90 seconds (Chung et al. 1994). A single-strength blueberry juice is about 8–12°Brix. Frozen blueberry juice concentrates of 45–65°Brix can be made by vacuum concentrating single-strength blueberry juice and freezing to less than –18°C.

Often, blueberry juice is blended with other juice products.

Blueberry Puree

Single-strength blueberry puree and puree concentrates can be made by crushing berries, passing through a pulper/finisher, pasteurizing, cold filling (for single-strength puree and vacuum concentrating to make puree concentrates), and freezing as above. These products are suitable for use in sauce and fillings.

Canned Blueberries

Canned blueberries can be light or heavy syrup packed or water packed. For this, fresh or frozen blueberries are placed in cans, light syrup or water is added to cover the head space, and cans are sealed and heat processed at about 93–95°C (200–203°F) with 25–30-minute holding time.

Blueberry bakery fillings can be made from fresh/frozen blueberries and/or blueberry puree or concentrates by adding sweeteners and stabilizers according to requirements, heat processing, and packaging.

Infused-Dried Blueberries

Infused-dried and freeze-dried blueberries are commercially available for use in ready-to-eat cereals and as snacks. Infused-dried blueberries, which are produced by infusing either wild or cultivated blueberries with a sweetener prior to drying, typically have moisture content of 8–14% and a water activity of 0.40–0.60. These products have fresh-like texture, color, and flavor and are shelf stable. They are utilized as ingredients in snacks, breakfast bars, energy bars, and ready-to-eat cereals.

Freeze-Dried Blueberries

Freeze-dried blueberries are light, crispy, of low bulk density (about 0.10), and their water activity is slightly above 0.20. These products have found increasing use in ready-to-eat cereals because of their light texture, low bulk density, and water activity. The freeze-drying is based on a direct conversion of ice to vapor (sublimation) to dry a product. Freeze-dried blueberries can hold their shape. Freeze-drying process utilizes IQF blueberries. The frozen berries are placed in a freeze-dryer heating plate having same temperature as the frozen berries and vacuum (e.g., less than 6 mbar at which the boiling point of water is less than 0°C) is applied. Subsequently, the plates are heated to a desired temperature and the product dried to a desired moisture level. Generally, freeze-drying is a lengthy process and the cost of the freeze-dried products is about three to five times higher than products dried by other methods.

SECTION 3: CURRANT AND GOOSEBERRY

INTRODUCTION

Like blueberries, currant (*Ribes sativum*) and gooseberry (*R. grossularia*) are small fruits. The plants are shrubby bush (small tree) that grows well in cool climates. Unlike gooseberries, which have soft thorns, currants are thornless. Currants grow in grape-like clusters and can be red, black, pink, or white in color. Gooseberries are generally bright red fruit; however, they can also be pale green. A hybrid between gooseberry and black currants produces jostaberries (*R. nidigrolaria*). These fruits are nearly black in appearance and two to three times the size of a typical currant.

Production

Table 24.10 gives data on production of currant in leading countries and the world aggregate. The Russian Federation leads world currant production followed by Poland. Germany and these two countries are also significant producers of gooseberry (Table 24.11).

CURRANT AND GOOSEBERRY VARIETIES

Selected Currant Varieties

1. *Titania*: This is a black currant variety, which produces good quality large fruits that can be machine harvested. The plants are upright and vigorous and can reach a height of 2 m. Normally, the plants reach full maturity in three seasons as opposed to four to five seasons for most popular varieties.

Table 24.10. Currants Production in Leading Countries and World (Mt)

Country	1980	1990	2000	2005	2009
Russian Federation	NA	NA	260,000	431,500	314,000
Poland	111,957	130,409	146,780	186,809	196,453
Germany	158,070	146,538	158,300	150,000	11,800
Austria	27,846	24,130	22,861	19,442	19,375
United Kingdom	20,100	16,146	12,300	19,700	12,995
Ukraine	NA	NA	19,887	24,800	23,200
Czech Republic	NA	NA	18,089	15,057	3200
Hungary	16,107	15,157	11,848	12,097	7268
France	5915	7519	8382	11,401	8634
Denmark	1316	4000	4000	11,251	12,685
World (Total)	475,844	478,757	690,353	911,659	634,263

Source: FAO (2011).

2. *Ben Alder*: This is a late-season black currant. The plants are compact and suitable for machine harvesting. The fruits are small but high in anthocyanins and vitamin C. Because of color stability, it is liked for juice production.
3. *Red Lake*: This is a mid-season ripening red currant variety. Fruits are large and of good quality. This is a good variety for juice production.
4. *Jonkheer Van Tets*: This is a popular early-season red currant. The plants are susceptible to frost damage. The fruits are medium size and of good flavor.

Selected Gooseberry Varieties

1. *Invitica*: This variety produces a pale green, large fruit with good flavor suitable for fresh market and processing. The plants of this variety are vigorous with spreading bush.
2. *Xenia*: This variety produces dark red fruit with oval shape. The fruit ripens early to mid-season.
3. *Hinnonmaki Red*: This variety produces dark red fruit of medium size. The flavor is tangy sweet. It adapts well to different growing conditions and can be machine harvested.

PHYSICOCHEMICAL AND NUTRITIONAL QUALITY

Brix and Flavor

Black currant has higher Brix (16.2°) than red (9.7°) and white counterparts (13.0°). Similarly, the Brix of red gooseberries is slightly higher (12.0°) than pale green/yellow varieties (9.3°) (Maatta-Riihinen et al. 2004). The aroma of black currants emanates from naturally present ester compounds (methyl acetate, ethyl acetate, methyl butanoate, ethyl butanoate, etc.), terpenes (3-Caene, terpinolene, and *cis*- and *trans*-ocimene are major terpenes), terpenoids, alcohols, aldehydes, and ketones (Mikkelsen and Poll 2002). Generally, esters are linked with fruity, sweet notes; terpenes with nutty; dry camphor with chemical type of sensation; and aldehydes and ketones with old, earthy notes.

Anthocyanins, Phenolics, and Antioxidant Capacity

Fifteen anthocyanins have been identified in black currant extracts. Of these, delphinidin 3-glucoside, delphinidin 3-rutinoside, cyanidin 3-glucoside, and cyanidin 3-rutinoside

Table 24.11. Gooseberry Production in Leading Countries (Mt)

Country	1980	1990	2000	2005	2009
1. Germany	80,979	84,182	88,200	38,039	42,000
2. Russian Federation	NA	NA	50,000	64,000	47,000
3. Poland	37,023	34,848	28,514	16,719	15,787
4. Ukraine	NA	NA	8400	8200	6100
5. Czech Republic	NA	NA	6824	3568	3326
6. Hungary	13,563	8220	4649	1305	1870
7. Austria	1187	1641	1815	1657	1654
8. United Kingdom	7400	2733	1500	1610	2243
World (Total)	220,872	198,590	193,379	136,715	120,931

Source: FAO (2011).

Table 24.12. Anthocyanins, Flavonol, and Total Phenolic Content (mg/100 g) of Black Currants, Red Currants, and Gooseberries

Fruit	Anthocyanins[a]	Flavonol[b]	Total Phenolics[c]
1. Black currant	756–1297	72–87	2230–2790
2. Red currant	113	9.5	1400
3. Gooseberry	83	51	1320

Source: Kahkonen et al. (2001).
[a]As cyanidin 3-glucoside.
[b]As rutin.
[c]As gallic acid.

accounted for >97% of the TACY content. Furthermore, the amounts of anthocyanin 3-O-rutinosides were higher than 3-O-glucosides (Slimestad and Solhelm 2002). The notable anthocyanin in red currants was cyanidin 3-O-sambubioside (72 mg/kg fresh weight), and as expected, red currants did not contain any delphinidins (blue-violet pigments) (Maatta et al. 2003). Similarly, red gooseberries contain only cyanidins (240 mg/kg fresh weight) (Maatta-Riihinen et al. 2004). Table 24.12 shows concentration of anthocyanin, flavonol, and total phenolics in black currant, red currant, and gooseberry (Kahkonen et al. 2001). As can be seen, black currants contain a very high concentration of these bioactive compounds.

Nutritional Quality

Table 24.13 shows typical nutritional data of currants and gooseberry. Black currants have high vitamin C content (Hakkinen et al. 2000). Black currants also have higher vitamin A and potassium content.

PROCESSED PRODUCTS

Various processes can extend availability of these seasonal fruits throughout the year. Like other fruits, currants and gooseberries can be frozen as IQF or block frozen, and stored for processing.

These fruits find increasing use in pie fillings, jelly, jam, juice, etc. Black currant juice is liked in many parts of Europe.

Black Currant Juice

A process for making black currant juice (Mikkelsen and Poll 2002) is as follows:

In this process, approximately 75% of anthocyanins remained in the juice. Important aroma compounds in this juice are terpenes, 3-carene, α-terpinolene, and *cis*-ocimene, and esters, ethyl acetate, methyl butanoate, and ethyl butanoate. During juice processing, the relative concentration of methyl butanoate, ethyl butanoate, and ethyl hexanoate decreased to less than 10%.

Black Currant Nectar

Iversen (1999) made black currant nectar of 16°Brix (standardized with honey and sugar) and a pH of 3.0 from frozen berries of cv. Ben Lomond. The nectar was pasteurized at 80°C for 27 seconds in an APV Pasilac plate heat exchanger, model 1090, at flow rate of 180 L/h. Pasteurization caused

Table 24.13. Nutritional Values of Selected Currants and Gooseberries

Nutrients/100 g	Black Currants (European), Raw	Currants, Red and White, Raw	Gooseberries Raw	Gooseberries, Canned, Light Syrup Pack
Calories (kcal)	63.0	56.0	44.0	73.0
Total fat (g)	0.41	0.20	0.58	0.20
Saturated fat (g)	0.034	0.017	0.038	0.013
Polyunsaturated fat (g)	0.179	0.088	0.317	0.110
Monounsaturated fat (g)	0.058	0.028	0.051	0.018
Cholesterol (mg)	0.00	0.00	0.0	0.00
Sodium (mg)	2.0	1.0	1.0	2.0
Potassium (mg)	322.0	275	198.0	77.0
Carbohydrate (g)	15.38	13.80	10.18	18.75
Total fiber (g)	NA	4.3	4.3	2.4
Sugars (g)	NA	7.37	NA	NA
Protein (g)	1.40	1.40	0.88	0.65
Calcium (mg)	55.0	33.0	25.0	16.0
Vitamin C (mg)	181.0	41.0	27.7	10.0
Vitamin A (IU)	230.0	42.0	290.0	138.0
Water (g)	81.96	83.95	87.87	80.10

NA, not available.
Source: USDA: http://www.nal.usda.gov/fnic/foodcomposition/cgi-bin/list_nut_edit.pl.

about 3–18% and 8–9% loss of ascorbic acid and anthocyanins, respectively. The choice of pectinase enzyme used in juice extraction mainly affected the recovery of ascorbic acid and not anthocyanins.

- Thaw frozen fruit
- Mill/Crush
- Heat (75°C/2 min)
- Cool to 50°C
- Add enzyme (pectinase, Grindamyl LB, Danisco at 0.4 mL per kg of black currant)
- Hold at 50°C for 2 hours
- Press (using high pressure tincture press HP-5 M)
- Pasteurize at 98°C for 1 minute
- Clarify with gelatin (0.03 g galatin per liter juice and stir)
- Add kieselsol (0.25 g per liter juice, without stirring, to further aid in clarification)
- Filter at room temperature
- Pasteurize at 98°C for 30 seconds
- Fill in package
- Chill
- Store

Black Currant and Gooseberry Juice Concentrate

Black currants juice can be concentrated to 65°Brix. This concentrate usually has 16–18% acidity as citric acid. This concentrate can be used to make single-strength juice of 11°Brix. Red currant and gooseberry concentrates can also be used to make single-strength juice of 10.5°Brix and 8.3°Brix, respectively.

Jelly and Jam

Currants and gooseberries can be made into jellies (45 parts fruit components and 55 parts sweetener solids; the finished soluble solids content is 65°Brix) and jams and preserves (47 parts by weight of the fruit component to 55 parts of sugar; the finished product should be of minimum 65°Brix).

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25
Strawberries and Raspberries

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Abstract: Strawberries (*Fragaria amanassa*) are cultivated worldwide but grow well in a cool, moist climate. It is a popular dessert fruit—used extensively in ice cream, yoghurt, fruit fillings, jelly and jams. However, 75% of strawberries in the United States are utilized as fresh. This chapter provides a review of important strawberry varieties, production and consumption trends, physicochemical and nutritional quality including, flavor, color pigments, phenolic compounds, and antioxidant capacity. It also discusses major strawberry products.

The second part of this chapter deals with raspberries (red raspberries: *Rubus ideaus*; black raspberries: *R. occidentalis*) that contain many beneficial compounds including dietary fiber, minerals, vitamins, and fruit sugars. Raspberries contain ellagic acid, which is suggested as an anticarcinogenic/antimutagenic compound.

SECTION 1: STRAWBERRIES

INTRODUCTION

Strawberry is a member of Rosaceae (Rose) family and *Fragaria* (F) genus. The wild European strawberry is mainly from *Fragaria vesca* L.; the cultivated varieties are hybrids from *F. chilosensis* and *F. virginiana*. The strawberry, *F. amanassa*, is cultivated worldwide (Menager et al. 2004) but grows well in a cool, moist climate. Fruits grow on stems in groups of three and are hand-harvested at full ripeness. Strawberries are not true berries in the "botanical sense" but an aggregate fruit. Roots produce new plants that bear fruits. The flesh of strawberry is an enlarged receptacle and unlike other berries, seeds (achenes) are attached to the skin of the fruit.

STRAWBERRY VARIETIES

The three major classes of strawberries based on the day length that stimulate bud formation (Anon 2004a, 2004b, 2004c; Hanson and Hancock 2000) are: (a) June-bearer or short-day, (b) Ever-bearer, and (c) Day-neutral. Short-day strawberries initiate flower buds in the fall when days are

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relatively short, and bear fruits in the following spring. Everbearers initiate flowers and fruits during the long days of summer. Day-neutrals can initiate flower buds during day of any length. Fruit characteristics such as color, flavor, firmness, size, shape, yield, storage, transport, processing, and end-use quality are considered when selecting a particular variety for cultivation. Characteristics of important strawberry varieties are listed here.

1. *Annapolis*: Early to midseason variety, large berries, light-red appearance, soft texture, mild flavor, suitable for freezing, and fresh consumption.
2. *Earliglow*: Early to midseason variety, excellent flavor and color, fruit size tends to decrease as the season progresses, suitable for retailing and freezing.
3. *Hood*: Developed from ORUS 2315 and Puget Beauty, early to midseason, medium to large fruit, round, conic, glossy, excellent internal, and external color, medium firm, high solids and high acidity, low drip loss, suitable for retailing and processing.
4. *Totem*: The predominant cultivar in Pacific Northwest, United States, developed from Puget Beauty and Northwest, early to midseason, large fruit, fully red internal and external color, high solids, good flavor, color, and firmness, suitable for retailing and processing.
5. *Jewel*: Mid to late season, developed from *Senga Sengana*, large berry, good flavor, bright and glossy red, good for freezing.
6. *Allstar*: Mid to late season, orange–red color, large conical, medium firm, mild sweet flavor, processing quality fair.
7. *Selva*: A California variety, ever-bearer or a day-neutral cultivar released in 1983, large berry, exceptionally firm but flavor is regarded as fair to poor unless fully ripened, skin is bright red and glossy, dessert and processing quality fair.
8. *Chandler*: Ever-bearer, large berry, medium firmness, good dessert and processing quality.
9. *Camarosa*: Large conical-shaped fruit, good color, excellent taste and firm texture, good for fresh market, slicing/dicing.
10. *Senga Sengana*: Developed in 1954, deep red color, medium size, soft texture, round shape, excellent freeze–thaw stability. This variety is grown in Poland where the majority of strawberries are processed and sold as frozen.

PRODUCTION AND CONSUMPTION

The estimated production of strawberries in 2009 was 4,132,352 metric tons (Mt). The United States was the largest producer with about 31% (1,270,694 Mt) of world total followed by Turkey 7% (291,996 Mt), Spain 6% (263,700 Mt), Poland 5% (188,907 Mt), and Japan 4% (185,000 Mt) (FAO 2010). Poland had the highest acreage (about 53,551 ha) under strawberry production, followed by the United States (23,000 ha). During 2000–2009, the world production of strawberries expanded by 25% and in the United States, production increased by about 47% (Table 25.1).

Strawberry is a popular dessert fruit (extensively used in ice cream and yoghurt). It is also used in fruit fillings, jellies and jams, energy bars, breakfast cereals, etc. In the United States, it is the leading berry with per capita consumption of about 3.0 kg. About 75% of strawberries produced in the United States are utilized as fresh; the remaining 25% are processed, mostly as frozen (USDA 2010).

Hepatitis A (a viral liver disease) outbreak occurred in some parts of the United States in 1997, from consumption of sliced, frozen strawberries. Washing strawberries with

Table 25.1. Strawberry Production in Leading Countries and World

	Production (Mt)				
Country	1980	1990	2000	2005	2009
United States	318,420	568,940	862,828	1,053,242	1,270,690
Turkey	23,000	51,000	130,000	200,000	291,996
Spain	98,700	206,500	344,865	320,853	263,700
Poland	179,816	241,284	171,314	184,627	198,907
Japan	193,300	217,100	205,300	196,200	184,700
S. Korea	84,325	108,438	180,501	201,995	205,000
Russia	NA	NA	160,000	221,000	158,000
Mexico	78,119	106,912	141,130	162,627	233,041
Germany	66,981	73,973	104,276	146,500	158,563
Italy	225,000	188,266	195,661	146,769	56,400
World (Total)	1,795,525	2,463,346	3,290,703	3,779,120	4,178,152

Source: FAO (2011).

chlorinated water has been reported to significantly cut levels of bacteria, hepatitis A virus, and other viruses that indicate possible contamination by animal or human wastes (Williamson 1998).

Electron beam irradiation with 1 and 2 kGy dosages extended strawberries shelf life by 2 and 4 days, respectively by suppressing fungi on stored fruits. However, the firmness of irradiated fruits was lower than the control (Yu et al. 1995).

PHYSICOCHEMICAL AND NUTRITIONAL QUALITY

Sugars, Organic Acids, and Flavors

Similar to other fruits, strawberry flavor is a balance between naturally present sugars and organic acids. Macias-Rodriguez et al. (2002) reported main soluble carbohydrates in strawberries are glucose, fructose, and sucrose, followed by myo-inositol. The sucrose content is shown to decrease during storage (Perez and Sanz 2001; Castro et al. 2002). Among organic acids, citric acid predominates, malic acid, and ascorbic acid are also present. According to Perez and Sanz (2001), malic acid content decreases sharply during strawberry ripening. Table 25.2 gives quality-related data on Camarosa and Selva strawberries (Castro et al. 2002). The sucrose content of Camarosa strawberries was shown to be almost twice that of Selva. However, Selva strawberry had twice as much glucose, and fructose than the Camarosa. In both varieties, the predominant sugar was glucose. In terms of acidity, Camarosa had more citric and malic acids than Selva. The ascorbic acid content was similar in both varieties. Sugars contribute to flavor and color development during fruit ripening and are the major nonvolatile flavor components in strawberries (Bood and Zabetakis 2002). In a study of 24 strawberry cultivars (Azodanlou et al. 2003), correlation between overall acceptance and sensory attributes of aroma, sweetness, and juiciness were shown to be 0.94, 0.87, and 0.49, respectively. Although aroma showed highest correlation ($r = 0.94$) with overall acceptance, sweetness ($r = 0.87$) measured as Brix was also a good indicator of quality.

Lefever et al. (2004) studied pectin composition and cell wall enzyme activities of strawberry varieties. The softer variety, *Senga Sengana*, had more water-soluble pectic constituents, and higher activities of pectin methylesterase and polygalacturonase than the firmer variety, Darsanga. Further, the firmer strawberry varieties had lower drip loss (an important consideration for fruits used in processing) upon thawing than softer varieties.

Nunes et al. (2005) reported water loss is one of the major factors affecting changes in color of stored strawberries. According to these researchers, water loss accelerated senescence of fruits, leading to membrane degradation and release of enzyme polyphenol oxidase (PPO) to cause anthocyanin degradation. They suggested that since partially ripe strawberries are able to develop normal red color during storage, harvesting the fruit when they have developed about three-quarter color can help with color loss during storage. In addition, postharvest operations, such as prompt recooling, packaging, and refrigerated storage should help with color retention during shipping and retailing.

Use of nano-packing material (synthesized by blending polyethylene with nano-powder made up of nano-Ag, kaolin, anatase TiO_2, and rutile TiO_2) having lower relative humidity and oxygen transmission rate was shown to maintain the sensory, physicochemical, and physiological quality of strawberries at a higher level during storage at 4°C for 12 days compared with normal packing consisting of polyethylene bags (Yang et al. 2010).

Table 25.2. Characteristics of Selected Strawberries (without stem) 48 Hours after Harvest and Freezer Storage (–18°C) for 6 Months

	Camarosa		Selva	
Characteristics	Harvest	Freezer Storage	Harvest	Freezer Storage
Total solids (g/100 g)	9.12 ± 0.20	6.68 ± 0.05	12.69 ± 0.09	7.4 ± 0.59
Sucrose (mg/g)	9.09 ± 0.00	0.00 ± 0.00	5.83 ± 0.20	2.78 ± 0.02
Fructose (mg/g)	30.73 ± 0.03	16.75 ± 0.97	55.12 ± 4.25	32.83 ± 0.36
Glucose (mg/g)	35.37 ± 0.5	21.95 ± 0.67	67.58 ± 1.11	33.78 ± 0.36
Citric acid (mg/g)	7.65 ± 0.25	9.26 ± 0.85	5.19 ± 0.37	6.15 ± 0.14
Malic acid (mg/g)	1.17 ± 0.07	1.18 ± 0.02	ND	4.92 ± 0.45
Ascorbic acid (mg/g)	0.36 ± 0.01	0.06 ± 0.01	0.38 ± 0.05	0.17 ± 0.00
Total phenolics (mg/g)	6.35 ± 0.29	8.32 ± 0.05	9.83 ± 0.18	7.74 ± 0.10
Anthocyanins (mg/100 g)	48.19 ± 1.4	61.36 ± 1.66	29.98 ± 0.98	28.99 ± 0.21
Ash (g/100 g)	0.48 ± 0.01	0.52 ± 0.00	0.33 ± 0.01	0.34 ± 0.02
pH	3.66	3.50	3.73	3.52

Source: Castro et al. (2002).
ND, not detected.

Table 25.3. Flavor Volatiles in Strawberries (Cv. Cigaline)

Compound	Concentration (μg/kg) At Physiological Maturity (42 days After Anthesis)	
	Mean	Range
Furanones		
Mesifurane	1917	1462–2435
Furaneol	6217	5707–6841
Esters		
Methyl butanoate	755	625–887
Methyl 2-methylbutanoate	209	54–321
Butyl acetate	61	41–90
Isoamyl acetate	56	21–87
Methyl hexanoate	105	23–145
Hexyl acetate	48	41–57
(E)-hex-2-enyl acetate	210	96–321
Terpenes		
(E)-furan linalool oxide	30	15–47
(Z)-furan linalool oxide	37	24–52
C_6 compounds		
Hexanal	43	19–71
(E)-hex-2-enal	370	299–462
Hexanol	211	39–410
Lactones		
γ-decalactone	2887	2540–3279
Carbonyls		
Pentan-2-one	704	558–812
Acids		
2-methylpropanoic acid	2130	1698–2562
Butanoic acid	4103	3905–4560
2-methyl butanoic acid	9810	8750–10,450
Hexanoic acid	12,744	11,240–14,414
Alcohols		
Benzyl alcohol	40	19–61

Source: Menager et al. (2004).

The fruity, green grass, and other flavor notes of strawberries emanate from esters, alcohols, and carbonyl compounds, which are biosynthesized from amino acid metabolism. Important flavor compounds in strawberries are methyl butanoate, ethyl butanoate, methyl hexanoate, cis-3-hexenyl acetate, and linalool. Menager et al. (2004) showed that in an immature strawberry fruit (cv. Cigaline), C_6 compounds, in particular (E)-hexen-2-al, was the main component; furanones and esters were not detected until the fruit was about half red in color. As ripening progressed, C_6 compounds decreased but furanones, acids, lactones, and esters increased. At full maturity, furaneol and mesifurane were more than other flavor compounds (Table 25.3). Organic cultivation practices had no effect on strawberry volatilities (Hakala et al. 2002).

Quality of Organic Versus Conventional Strawberries

Reganold et al. (2010) reported that organic strawberries had lower weight than the conventional strawberries. The fruit firmness of the organic and conventional berries were not significantly different; however, the organic strawberries were darker red and had higher antioxidant activity, ascorbic acid, total phenolics and total anthocyanins than conventional berries.

Color, Phenolic Compounds, and Antioxidant Capacity

The bright red color of fresh strawberries is due to anthocyanins, pelargonidin-3-glucoside, pelargonidin-3-rutinoside, and cyanidin-3-glucoside (Garzon and Wrolstad 2002; Wang et al. 2002; Kosar et al. 2004). Strawberry varieties differ in their anthocyanin content. For example at harvest, the total anthocyanin content of Camarosa strawberries was about 60% more than that of the Selva. Freezing strawberries caused little loss in color; in fact, the anthocyanin content of Camarosa strawberries increased by 27% after 6 months of frozen storage (Table 25.2). Shin et al. (2008) showed higher anthocyanins, flavonoids, and total antioxidant capacity of strawberries stored at 3°C for 20 days in air than in strawberries stored under similar temperature and time in 20% CO_2 atmosphere.

Maintaining the natural color is a challenge in processed strawberries. About 20% of pelargonidin-3-glucoside was reported lost at refrigerated storage in 9 days (Zabetakis et al. 2000). Rwabahizi and Wrolstad (1988) reported lower anthocyanin concentration in strawberry juice clarified by ultrafiltration (possibly due to the removal of high molecular weight constituents) than by conventional filtration. Similarly, strawberry concentrates made from juices clarified by conventional filtration were perceived better in appearance than those clarified by ultrafiltration. As would be expected, there were higher anthocyanin losses (from thermal processing) in strawberry concentrates than in juices (Garzon and Wrolstad 2002).

Cano et al. (1997) investigated high-pressure treatment (50–400 MPa) combined with heat (20–60°C) to inactivate color and flavor affecting enzymes PPO and peroxidase (POD) in strawberry puree. The high-pressure treatments caused 60% and 25% loss of PPO and POD activities, respectively. However, Rwabahizi and Wrolstad (1988) indicated that browning during concentration and storage of strawberry juice was nonenzymatic. The pH optima of strawberry PPO were reported to be 5.5 with catechol and 4.5 with 4-methylcatechol (Wesche-ebeling and Montgomery 1990). Since the pH of strawberry is generally below 4.5 (Table 25.2), PPO may not have a significant role in browning of strawberry products. Addition of ascorbic acid was shown to have a negative effect on the color of strawberry

Table 25.4. Phenolic Compounds in Strawberries (mg/100 g Frozen Fruit)

Compounds	Camarosa	Chandler
ρ-OH-benzoic acid	0.15 ± 0.02	0.26 ± 0.02
ρ-coumaric acid	2.07 ± 0.04	1.38 ± 0.02
Ellagic acid	0.36 ± 0.02	0.42 ± 0.01
Cyanidin-3-glucoside	0.72 ± 0.01	0.95 ± 0.01
Pelargonidin-3-glucoside	11.72 ± 0.12	16.24 ± 0.08
Myricetin	0.69 ± 0.01	0.36 ± 0.03

Source: Kosar et al. (2004).

syrup (Skrede et al. 1992). It is believed that hydrogen peroxide produced as a result of ascorbic acid degradation affects anthocyanins.

Table 25.4 gives data on phenolic compounds (benzoates, ρ-coumaric acid, ellagic acid, anthocyanins, flavonoids, and myricetin) found in strawberries (Kosar et al. 2004). The concentration of anthocyanins, pelargonidin-3-glucoside was about 17 times higher than cyanidin-3-glucoside, and ellagic acid concentration decreased as the strawberries ripened. In a study on the effects of environmental factors and cultural practices on quality, it was shown that strawberries grown on a hill plasticulture had higher levels of soluble solids, total sugar, ascorbic acid, citric acid, flavonoids, and antioxidant capacities than those grown on a flat-matted row. The concentration of ellagic acid glucoside (believed to be better absorbed than ellagic acid) was slightly higher as well (Wang et al. 2002).

Wang and Lin (2000) reported antioxidant capacity, anthocyanins, and total phenolics of strawberries at different stages of fruit maturity, and in strawberry juices. Table 25.5 shows a typical data on these for Allstar strawberry variety. At full ripeness, antioxidant activity was the highest (12.0 μmol TE (Trolox equivalent)/g on wet basis). Wu et al. (2004) analyzed both lipids and water-soluble antioxidants and found more water soluble (35.41 μmol TE/g, as is basis; % moisture = 91.1) than lipid soluble (0.36 μmol TE/g) antioxidant activity in market samples of strawberries. The difference between maximum and minimum values of total antioxidant capacity was 12.51 μmol TE/g, which is close to 12.0 μmol TE/g reported by Wang and Lin (2000).

NUTRITIONAL QUALITY

Besides, phenolic constituents and antioxidant properties, which have created interests in plant products, strawberries are a good source of potassium and vitamin C. However, in fresh strawberries, 26–50% ascorbic acid is lost when cut surfaces are exposed to air for 5 minutes. Even freezing strawberries did not stop loss of ascorbic acid (Table 25.2). A study of two important strawberry cultivars, Camarosa and Selva, showed that the latter variety not only had higher resistance to thawing but also had higher ascorbic acid, protein, and total phenolics (Castro et al. 2002).

Table 25.5. Oxygen Radical Absorbance Capacity (ORAC), Anthocyanins, and Total Phenolics in Strawberry (Cv. Allstar) at Different Maturity and in Strawberry Juice

Strawberry	ORAC[a] (μmol of TE/g)	Anthocyanins[b] (mg/100 g)	Total Phenolics[c] (mg/100 g)
50% red berry			
Wet basis	9.7 ± 0.2	16.2 ± 2.1	91.0 ± 1.9
Dry basis	81.8 ± 1.8	143.4 ± 18.6	916.0 ± 11.5
80% red berry			
Wet basis	10.4 ± 0.3	23.6 ± 2.3	94.0 ± 0.8
Dry basis	95.4 ± 2.7	216.5 ± 21.1	971.0 ± 6.9
Full red berry			
Wet basis	12.0 ± 0.5	38.9 ± 1.1	96.0 ± 0.9
Dry basis	118.8 ± 4.9	385.1 ± 10.9	946.0 ± 8.9
Strawberry juice			
Wet basis	12.2 ± 0.3	23.3 ± 1.3	95.0 ± 1.1
Dry basis	120.8 ± 2.9	230.7 ± 12.8	943.0 ± 10.4

Source: Wang and Lin (2000).
[a] μmoles of Trolox equivalent.
[b] milligrams of pelargonidin-3-glucoside.
[c] Gallic acid equivalent.

Table 25.6 shows nutritional values per 100 g in strawberries and its products. Fresh and frozen strawberries and strawberry juices are low-calorie products. Even the sugar-infused and dried strawberries, which are used as snacks and as ingredients in various foods, on an ounce (28 g) serving size basis, contribute less than 100 calories. These products are also a good source of dietary fiber.

STRAWBERRY PRODUCTS

Improved production, postharvest handling, storage, transportation, processing, packaging, and quality control techniques provide year-round availability of strawberries and strawberry products. As has been indicated before, about 25% of strawberries produced are processed. There are several processed strawberry-based products including juice, jelly, jam, fruit fillings, variegates, various dried strawberries, etc. Increasingly, consumers are looking for fresh (color, flavor, and texture) fruit-like qualities and nutritional values in processed products. Beginning with steps involved for frozen strawberries, selected processing methods and products are discussed here.

Frozen Strawberries

Strawberries are either block frozen or individually quick frozen (IQF) after the removal of stems and cap at the point

Table 25.6. Nutritional Values of Strawberries

Nutrients/100 g	Fresh Strawberry[a]	Frozen Strawberry[a]	Strawberry Juice[a]	Infused-Dried Strawberry[b]	Dehydrated Strawberry[c]
Calories (kcal)	32.0	35.0	30.0	325.0	345.0
Calories from fat (kcal)	2.7	1.0	3.60	9.36	38.34
Total fat (g)	0.30	0.11	0.40	1.04	4.26
Saturated fat (g)	0.015	0.01	0.02	0.10	NA
Polyunsaturated fat (g)	0.155	0.05	0.19	0.50	NA
Monounsaturated fat (g)	0.043	0.01	0.05	0.10	NA
Trans fat (g)	0.0	0.0	0.0	<0.10	0.0
Cholesterol (mg)	0.0	0.0	0.0	<0.10	0.0
Sodium (mg)	1.0	2.0	1.0	25.0	12.0
Potassium (mg)	153.0	148.0	166.0	382.0	1909.0
Total carbohydrate (g)	7.68	9.13	7.00	82.20	80.70
Total fiber (g)	2.0	2.10	0.10	10.20	6.10
Soluble fiber (g)	0.80	0.65	0.03	3.80	NA
Insoluble fiber (g)	1.20	1.45	0.07	6.40	NA
Sugars (g)	4.66	6.96	6.90	70.30	73.90
Protein (g)	0.67	0.43	0.60	3.16	7.02
Calcium (mg)	16.0	16.0	14.00	160.0	161.0
Vitamin C (mg)	58.8	41.20	28.40	95.0	652.10
Vitamin A (IU)	12.0	45.0	20.0	41.0	311.00
Water (g)	90.95	90.0	91.60	12.0	3.0

NA, not available.
[a]USDA.
[b]Graceland Fruit Inc., Frankfort, Michigan, United States.
[c]Esha Nutritional database, Salem, Oregon, United States.

of production. The preparatory steps after harvesting consist of precooling (about 0–2°C) the harvested strawberries to remove field heat; air classifying to remove leaves, field debris, etc.; removing berry caps, leaves, etc.; quick rinsing or washing, preferably with about 20 ppm chlorinated water; inspecting and grading for size and defects; quick freezing the fruit individually (at about –40°C) in a blast air freeze tunnel; and packaging and storing under frozen temperatures. Quick freezing helps in minimizing large ice crystal formation, which are believed to cause drip losses on thawing. The IQF strawberries are free flowing, and hold their color and shape better. Thus, they are preferred as raw materials for manufacturing value-added products like freeze dried or infused dried strawberries.

Frozen Sugar Pack Strawberries

In this case, sugar is added to the strawberries after removing stems and caps, and the product is stored frozen at below –18°C. For example, 4 + 1 (80% fruit + 20% sugar) and 7 + 3 (70% fruit + 30% sugar) pack strawberries in a 30 lb pail will contain 24 lb strawberries and 6 lb sugar, and 21 lb strawberries and 9 lb sugar, respectively. These products are used in many applications. However, before using in dairy products such as yogurt and ice cream, they should be pasteurized.

Strawberry Puree

Purees can utilize fruits, which are not sold as fresh or frozen. They generally form raw material for making fruit fillings, variegates, juices, jams, etc. For making strawberry puree, it is not critical to remove berry cap. The preparatory steps of precooling, washing, and grading are essentially the same as described for frozen strawberries. Subsequently, the berries are cut/chopped and passed through different dimension sieves, depending on whether the product contains seeds or not. For example, to make strawberry puree with and without seeds, the diameter of sieve opening would be 1.33 ± 0.19 mm and 0.76 ± 0.076 mm, respectively. Then, the puree is pasteurized by heating at 88°C for about 2 minutes and cooled to about 15°C. Following processing, the product is quality analyzed, filled in containers, and stored frozen. The single-pack strawberry puree will have almost the same Brix as that of the starting raw fruit. However, concentrated strawberry purees of about 28°Brix are also available. The puree may be treated with enzymes and filtered before concentration to provide better quality puree for use in jams, juices, etc.

Sweeteners such as sucrose can also be added to the puree to adjust Brix as per the end use.

Strawberry Juice and Concentrate

Garzon and Wrolstad (2002) described a process, which is similar to commercial production, to manufacture strawberry juice and concentrate. The processing steps are as below (it may be noted that a Bucher press or a centrifuge can also be used for separation of strawberry juice):

1. Thaw IQF or block frozen strawberries overnight at room temperature.
2. Crush with a hammer mill (Model D Commuting Machine; W.J. Fitzpatrick Co., Chicago, IL, USA) equipped with a circular pore mesh, 1.27 cm in diameter, at a speed of 182 rpm.
3. Depectinize in a steam-jacketed kettle at 50°C for 2 hours by adding Pectinase, Rapidase® Super BE @ 3 mL/kg (Gist-Brocades Laboratories, Charlotte, NC, USA). Conduct Alcohol test for pectin (1:1 juice–isopropanol + 1% HCl; incubate further until the test for pectin is negative).
4. Press, after adding 1% rice hull as press aid, at 300 kPa for 30 minutes using a Willmes press bag, Type 60 (Moffet Co., San Jose, CA, USA).
5. Filter at 27.6 kPa with 2% diatomaceous earth as filtering aid and using a multipad filtration unit (Strassburger KG, Westhofen, Worms, Germany); the unit equipped with a pad filter SWK supra 2600 (Scott Laboratories, Inc., San Rafael, CA, USA).
6. Pasteurize at 88°C for 1 minute using a tubular heater with screws, Wingear type (Model 200WU; Winsmith Co., Springville, NY, USA).
7. Concentrate to 65°Brix using Centritherm evaporator, type CT-1B (Alfa Laval, Lund, Sweden). Two passes are needed to achieve the final concentration, and the juice can reach a temperature as high as 80°C.

Strawberry Jelly, Preserve, and Jam

Among various fruit jelly and jams, strawberry jelly (45 parts by weight of fruit juice ingredients to 55 parts of sweeteners, see Code of Federal Regulations 2003: CFR 21, 150.140) and preserves and jams (47 parts by weight of fruit ingredient to each 55 parts by weight of sweeteners, see CFR 21, 150.160) are on the top of the list because of their unique color, flavor, and taste. The soluble solid contents of finished jelly and jam are not less than 65%.

Stabilized Frozen Strawberries

Processed frozen products such as stabilized frozen (strawberry fruit pieces are combined with a syrup matrix containing sweeteners, pectin, starch, and carrageenan or other gums, and heat processed) or infused frozen strawberries for use in ice cream, sorbets, yogurts, and bakery products are made by infusing and pasteurizing whole or sliced strawberries (Sinha 1998) in sugar syrup or other types of sweeteners. These products typically are about 35°Brix, so that they do not become hard at freezer temperatures. The products are pasteurized and can be added directly to the formulations.

Infused Dried Strawberries

As the name implies, infused dried strawberries are produced by infusing strawberries to a range of sweetness level, prior to drying. These products have found better acceptance in the ingredient market than the traditionally dried strawberries. It has been reported that osmotic treatment of strawberries at atmospheric pressure had a positive effect on flavor (Escriche et al. 2000).

Freeze Dried Strawberries

Freeze dried strawberries have found great success as fruit ingredients in ready-to-eat cereals. Freeze drying retains the typical bright red color of strawberries better than other drying methods. Besides, the freeze-dried strawberries have crisp texture and their low bulk density (approximately about 0.1 g/cc) is closer to ready-to-eat cereals. Both whole and sliced strawberries can be processed as freeze dried. However, this product requires special laminated packaging to maintain the crisp texture.

SECTION 2: RASPBERRIES

INTRODUCTION

Raspberries (also termed "Brambles") belong to the genus *Rubus* and family Rosaceae (rose). Cultivated raspberries have been derived from the wild red raspberries (*Rubus ideaus*) and black raspberries (*Rubus occidentalis*). These soft and delicate fruits with small seeds and hollow core are aggregates of hairy drupelets, which adhere to one another. The origin of red raspberry dates back to fourth century AD at Mt. Ida, in the Caucasus Mountains of Asia Minor. The British are credited with popularizing and improving red raspberry cultivation throughout the Middle Ages. The black raspberry is indigenous to North America (Anon 2004d).

Raspberry plants are a biennial, summer or autumn bearing, and grow on leafy canes (thus called caneberries) in temperate regions of the world. The root system of this plant is perennial and capable of living for several years where there is a good drainage system. All cultivars, especially new plants, are susceptible to root rots. Red and black raspberries dominate commercial production; however, purple and yellow raspberries are also grown for the fresh market.

Table 25.7. Raspberries Production in Leading Countries and World Aggregate

	Production (Mt)				
Country	1980	1990	2000	2005	2009
Russia	NA	NA	130,000	175,000	120,000
Serbia and Montenegro	NA	NA	56,059	84,331	NA
Poland	19,507	28,457	39,727	60,000	81,778
United States	12,000	23,650	51,256	82,826	60,056
Germany	20,603	27,241	33,700	7000	5068
Canada	8942	14,213	16,247	14,152	12,607
France	6900	6400	8743	5742	7349
Hungary	18,530	27,208	19,804	6724	4967
Spain	NA	1000	2500	7000	9550
World	231,726	303,622	408,705	510,448	486,889

Source: FAO (2011).
NA, not available.

PRODUCTION AND CONSUMPTION

Raspberry production in the top ten leading countries of the world is given in Table 25.7. Russia leads in raspberry production. In the United States, raspberry production is concentrated in the states of Oregon and Washington. In Washington State, the leading red raspberry variety is "Meeker," which is a late season, summer fruiting raspberry. In Oregon, "Willamette" an early fruiting, medium–small fruit, typically sold for processing is popular. It is also one of the few cultivars resistant to raspberry bushy dwarf virus infection that causes lower yield and crumbly fruits.

More than 90% of raspberries produced in Oregon and Washington are red raspberries and the remaining black raspberries, Oregon being a leader in production of the latter. In the United States, most of the raspberries produced are processed (Table 25.8). Generally, machine-harvested fruit is used for processing, and handpicked fruits are sold for fresh consumption or to premium quality market. Machine harvesting has become critical to enhance production; however, it requires coordination and synergies of efforts among fruit growers, plant breeders, and other researchers to develop new varieties and use of acceptable insect control practices suitable for machine harvesting of raspberries. Typically, the machine-harvested fruits are used for fruit juice and puree/pulp market. There is a growing demand for superior quality whole IQF and frozen fruits in terms of color, shape, size, and freedom from diseases and insects for use as dessert fruit and other applications.

Table 25.8. Red Raspberry and Black Raspberry Production in Oregon and Washington States of United States

	1980	1990	2000	2005	2009
	(1000 lb)				
Red raspberry					
Oregon					
Production	10,600	21,500	9600	7200	5400
Utilization					
Fresh	600	500	900	1300	1100
Processed	10,000	21,000	8700	5900	4300
Washington					
Production	12,600	28,080	71,250	70,300	65,700
Utilization					
Fresh	2240	1280	4000	1400	700
Processed	10,360	26,800	67,250	68,900	65,000
Black raspberry					
Oregon					
Production	3100	2550	3600	4240	3130
Utilization					
Fresh	30	30	30	20	NA
Processed	3070	2520	3570	4220	NA

Source: USDA (2010).
NA, not available.

PHYSICOCHEMICAL AND NUTRITIONAL QUALITY

Bushway et al. (1992) reported physical, chemical, and sensory characteristics of five red raspberry cultivars (Table 25.9). According to these researchers, titratable acidity, sucrose, and total sugar could serve as a predictor of flavor in frozen raspberries. The "Newburg" cultivar with highest concentration of sucrose and total sugars was most preferred by panelists, and the traditional red color in frozen raspberry cultivars was liked more than the deeper purple color of cultivar "Boyne." Malowicki et al. (2008) reported Brix and titratable acidities (as % citric acid) of Washington grown "Meeker" and "Willamette" raspberries as 9.6 and 8.7; and 1.28% and 2.10%, respectively. The major sugars in "Meeker" were fructose and glucose; citric acid was the main organic acid.

Typical physicochemical properties of selected raspberry cultivars grown are given in Table 25.10 (Ancos et al. 2000a, 2000b). Cultivars "Autumn Bliss" and "Heritage" are early (harvested in May) season, "Zeva" and "Rubi," late (harvested in autumn, October) season berries. Generally, the late, season cultivars have higher °Brix, anthocyanins, total phenolics, and ellagic acid content. The main color pigments found in the four raspberry cultivars were cyanidin-based anthocyanins (sophoroside, glucoside, glucorutinoside, and rutinoside) and pelargonidin derivatives (sophoroside and glucoside). Late season cultivars showed greater anthocyanin content than early, season fruits.

Color Pigments of Raspberries

Boyles and Wrolstad (1993) reported the average anthocyanin contents (mg/L cyanidin-3-glucoside) of red raspberry

Table 25.9. Sugar and Color Profiles of Selected Red Raspberry Cultivars from Maine, United States

	Cultivars				
Characteristics	Boyne	Festival	Latham	Newburg	Taylor
% Total sugar	6.14	4.84	6.10	7.68	6.30
% Fructose	2.28	2.09	3.71	3.01	2.67
% Glucose	1.93	1.88	2.39	2.43	2.28
% Sucrose	1.93	0.87	0.00	2.24	1.35
% Soluble solids	9.6	10.0	10.6	12.3	11.1
% Acidity (as citric)	1.46	1.85	1.43	1.81	2.09
pH	3.04	3.02	3.05	3.13	2.98
Hunter color					
L	18.25	17.58	21.17	21.27	20.59
a/b	17.97	22.93	22.40	22.46	22.53

Source: Bushway et al. (1992).

cultivars "Willamette" and "Meeker" as 620 and 320, respectively. The high pigment concentration of "Willamette," a desirable characteristic, increased with ripeness. Approximately, 90–97% of anthocyanins were composed of cyanidin and 3–10% pelargonidin. Cyanidin-3-sophoroside (cyd-3-sop) was the pigment with highest concentration in red raspberry varieties "Willamette" and "Meeker." However, Polish cultivars "Veten" and "Norna" showed much lower concentration of cyd-3-sop.

Processing raspberries can change the quantitative distribution of pigments through partial hydrolysis of glycosidic substituents and/or anthocyanin polymerization. Low total anthocyanin and elevated levels of cyanidin-3-glucoside indicate degradation due to processing and storage. Black

Table 25.10. Physicochemical Characteristics of Selected Raspberry Cultivars

	Cultivars			
Characteristics	Autumn Bliss	Heritage	Zeva	Rubi
Brix	9.26	9.50	10.54	10.00
Acidity (% citric)	1.67	1.76	1.75	2.32
pH	3.65	3.87	2.88	2.65
Total solids (%)	15.23	14.69	16.33	17.98
Moisture (%)	84.77	85.31	83.67	82.02
Total anthocyanin (mg/100 g)	31.13	37.04	116.27	96.08
Total phenolics (mg gallic acid/100 g)	121.4	113.7	177.6	155.6
Ellagic acid (mg/100 g)	20.8	21.7	24.4	23.4
Vitamin C (mg/100 g)	30.2	22.0	29.6	31.0
Color				
L	25.89	25.80	18.29	21.26
A	35.03	34.98	33.03	35.10
B	19.05	18.34	17.78	18.63
Flavor volatiles (%)				
Caryophyllene	37.7	15.0	25.9	20.8
α-ionone	33.5	32.8	43.1	23.9
β-ionone	20.7	19.3	13.3	17.3
α-pinene	2.9	13.2	2.9	17.0
Citral	0.4	0.7	0.7	1.6
β-pinene	0.5	1.2	0.5	1.7
Phellandrene	2.4	11.4	12.9	10.4
Linalool	1.8	6.3	0.4	7.1

Source: Ancos et al. (2000a; 2000b).

raspberries can be distinguished from red raspberries by xylose containing pigments, cyanidin-3-sambubioside, and cyanidin-3-xylosylrutinoside (Torre and Barritt 1977). Tulio et al. (2008) reported presence of five anthocyanins in black raspberries: cyanidin 3-sambubioside, cyanidin-3-glucoside, cyanidin-3-xylosylrutinoside, cyanidin-3-rutinoside, and pelargonidin-3-rutinoside. Of these, cyanidin-3-rutinoside, and cyanidin-3-xylosylrutinoside comprised 24–40% and 49–58%, respectively, and were significant contributors of antioxidant potency of black raspberries. Wada and Ou (2002) reported 0.65 mg/g and 5.89 mg/g anthocyanins in red and black raspberries, respectively. These authors indicated that red raspberries anthocyanins were composed of cyanidin-3,5-diglucoside (89.25%) and cyanidin-3-glucoside (10.75%); black raspberries were made of cyanidin 3-(6′-*p*-coumaryl) sambubioside (22%) and cyanidin 3-(6′-*p*-coumaryl) glucoside (77.0%).

Table 25.11. Average Antioxidant Activity (ORAC), Anthocyanin Content, and Total Phenolic Content in Raspberry Juice of Different Maturity Raspberries (on a Fresh Weight Basis)

Raspberry	ORAC (μmol of TE/g)	Anthocyanin (mg/100 g)	Total Phenolics (mg/100 g)
Red raspberry			
Green	16.5 ± 0.8	1.0 ± 0.2	181 ± 5.0
Pink	10.9 ± 0.6	7.2 ± 1.2	99 ± 1.5
Ripe	18.2 ± 0.8	68.0 ± 3.0	234 ± 5.1
Black raspberry			
Green	33.7 ± 4.0	1.7 ± 0.6	338 ± 7.1
Pink	16.1 ± 0.6	22.8 ± 1.4	190 ± 3.5
Ripe	28.2 ± 1.4	197.2 ± 8.5	267 ± 4.3

Source: Wang and Lin (2000).

Flavor of Raspberries

Volatile components contributing to the fresh raspberry aroma are α-pinene, citral, β-pinene, phellanderrene, linalool, α-ionone, carryophyllene, and β-ionene. Malowicki et al. (2008) reported 29 flavor compounds in "Meeker" red raspberries from different sites. Flavor compounds, α-ionone, β-ionene, geraniol, linalool, (Z)-3-hexenol, and raspberry ketone were considered important in differentiating red raspberries from others. Aprea et al. (2009) reported presence of hexanal and hexanol that induce herbaceous notes in the headspace of "Tulameen" raspberries.

Freezing raspberries for 12 months had little affect on flavor volatiles; however, color pigment cyanidin-3-glucoside decreased by about 26.0% in late season raspberry cultivar "Zeva" (Ancos et al. 2000b).

Phenolic Compounds and Antioxidant Capacity

Liu et al. (2002) reported that the color of raspberry juice correlated with the total phenolic, flavonoid, and anthocyanin content of raspberry. The "Heritage" variety contained the highest total phenolic content (512.7 ± 4.7 mg/100 g), followed by "Kiwigold" (451.1 ± 4.5 mg/100 g), "Goldie" (427.5 ± 7.5 mg/100 g), and "Anne" (359.2 ± 3.4 mg/100 g). Similarly, the "Heritage" had the highest total flavonoids (103 ± 2.0 mg/100 g), followed by "Kiwigold" (87.3 ± 1.8 mg/100 g), "Goldie" (84.2 ± 1.8 mg/100 g), and "Anne" (63.5 ± 0.7 mg/100 g). Raspberry extracts equivalent to 50 mg of "Goldie," "Heritage," and "Kiwigold" fruits inhibited the proliferation of HepG2 human liver cancer cells by 89.4% ± 0.1%, 88% ± 0.2%, and 87.6% ± 1.0%, respectively. Variety "Anne" had the lowest antiproliferation activity of the varieties measured (70.3% ± 1.2%). The antioxidant activity of these raspberry varieties showed significant positive correlation ($P < 0.05$) with the total phenolics and flavonoids found in raspberry. However, there was little significant correlation ($P > 0.05$) between antiproliferative activity and the total phenolics/flavonoids, suggesting that other phytochemicals (such as anthocyanins and ellagic acid) may have a role in the antiproliferative activity of raspberries.

Wang and Lin (2000) measured oxygen radical absorbance capacity (ORAC) of juices from black raspberry and red raspberry at different maturities (Table 25.11). As expected, juice made from ripe fruits had higher antioxidant activity than that from green or pink berries; and black raspberry juice had higher antioxidant activity than red raspberry juice. Moyer et al. (2002) reported very high anthocyanin content of 627, 607, and 464 mg/100 g and ORAC values of 104.6, 146.0, 110.3 μmol TE/g in black raspberries cultivars "Munger," "Jewel," and "Earlysweet," respectively.

Ellagic Acid

Phenolic compound ellagic acid, a dimeric derivative of gallic acid, is suggested as an anticarcinogenic/antimutagenic compound. It is present in plants in the form of hydrolyzable tannins called ellagitannins. Ellagitannins are esters of glucose with hexahydroxydiphenic acid and when hydrolyzed ellagic acid and dilactone of hexahydroxydiphenic acid are produced. Studies with ellagic acid on rodents at Ohio State University have shown significant prevention and reduction of certain cancers (Funt et al. 2004). When added to cultured cancer cells *in vitro*, ellagic acid is shown to stop cell division and cancer cells eventually die by apoptosis, while sparing normal cells (Anon 2004e). However, currently, the role of ellagic acid on human cancer patients is inconclusive. A study at Ohio State University (Anon 2004f) indicated "Heritage" red raspberry with highest amount of ellagic acid in the pulp among several raspberry cultivars. Raspberry seeds generally had higher ellagic acid content than the pulp (Table 25.12). Borges et al. (2010) showed that raspberries are rich source of ellagitannins in the form of lambertianin C and sanguiin H-6, accounting for 58% of their antioxidant capacity.

Table 25.12. Ellagic Acid Content of Raspberries (μg/g Dry Weight)

	1997		1998	
	Pulp	Seed	Pulp	Seed
Red cultivars				
Caroline	36.0	173.4	52.5	799.2
Autumn Bliss	22.3	98.9	42.0	263.6
Heritage	40.5	105.8	39.2	467.2
Ruby	39.7	176.4	10.0	85.6
Yellow cultivar				
Anne	11.1	177.7	7.8	60.5
Black cultivar				
Jewel	17.0	240.0		

Source: Anon (2004c).

Wada and Ou (2002) reported total ellagic acid ranging from 47 mg/g in red raspberries to 90 mg/g in black raspberries grown near Salem, Oregon. They indicated that free ellagic acid level was 40–50% of the total ellagic present. Rommel and Wrolstad (1993) reported an average concentration of ellagic acid and its derivatives in experimental and commercial raspberry juice samples as 30 ppm (0.003%) and 52 ppm (0.052%), respectively. Raspberry juice produced by diffusion extraction (where the berries were exposed to high temperature (63°C) for several hours, thus releasing ellagic acid from the cell walls) contained about twice as much ellagic acid as juice made by high-speed centrifugation. The ellagic acid derivatives (4-arabinosylellagic acid, 4-acetylxylosylellagic acid, and 4-acetylarabinosylellagic acid) with the exception of ellagic acid itself remained quite stable with processing and during 6 months of raspberry jam storage. The initial free ellagic acid content of 10 mg/kg increased twofold when processed into jam, and it continued increasing up to 35 mg/kg after 1 month of storage. Thereafter, a slight decrease was observed until 6 months of storage. The increase in ellagic acid was possibly due to the release of ellagic acid from ellagitannins with heat treatment (Zafrilla et al. 2001).

Nutritional Quality

Rao and Snyder (2010) reviewed nutrient and phytochemical composition of red raspberries, the bioavailability and metabolism of raspberry phytochemicals, and their biological activities. Red raspberries contain many beneficial compounds, including fruit sugars, protein, lipids, dietary fiber, minerals, and important vitamins. Typical nutritional profile of raspberries and its products according to National Educational and Labeling Act (NELA) is given in Table 25.13.

Table 25.13. Nutritional Values of Raspberries

Nutrients/100 g	Red Raspberry	Black Raspberry	Fresh Raspberry Juice	Infused Dried Red Raspberries[a]	Dehydrated Raspberries
Calories (kcal)	49.00	73.00	30.0	309	354
Calories from fat (kcal)	5.00	13.00	0.0	14.0	35.73
Total fat (g)	0.55	1.42	0.00	1.52	3.97
Saturated fat (g)	0.02	NA	0.00	0.2	NA
Polyunsaturated fat (g)	0.31	NA	0.00	0.4	NA
Monounsaturated fat (g)	0.02	NA	0.00	1.0	NA
Trans fat (g)	0.0	0.00	0.00	<0.10	0.00
Cholesterol (mg)	0.0	<0.10	0.00	<0.10	0.00
Sodium (mg)	0.0	0.00	3.00	17.0	0.00
Potassium (mg)	152.00	199.20	153.00	162.0	1097
Total carbohydrate (g)	11.60	15.67	7.14	84.0	83.50
Total fiber (g)	6.80	NA	0.00	16.2	21.70
Soluble fiber (g)	1.22	NA	0.00	2.1	NA
Insoluble fiber (g)	5.58	NA	0.00	14.1	NA
Sugars (g)	4.80	NA	7.14	62.0	61.80
Protein (g)	0.91	1.49	0.31	4.0	6.57
Calcium (mg)	22.0	29.85	18.00	72.0	159.0
Iron (mg)	0.57	0.90	2.60	1.82	4.12
Vitamin C (mg)	25.00	17.91	25.00	98.0	180.50
Vitamin A (IU)	130.0	NA	66.70	76.0	939.0
Water (g)	86.60	81.02	89.40	8.3	3.00

Source: Esha nutritional database, Salem, Oregon, United States.
NA, not available.
[a]Graceland Fruit Inc., Frankfort, Michigan, United States.

Bushman et al. (2004) reported chemical composition, of raspberry seeds and oils and their antioxidant potential. According to these researchers, red raspberry and black raspberry seeds contained 18.7% and 15% oil, respectively. The total vitamin E content of red and black raspberry seeds were 33 mg/100 g and 16.2 mg/100 g, respectively. The ORAC value of cold press raspberry seed oil from red and black raspberry was almost same [53.0 μmol TE/g oil]. However, the ORAC value of red raspberry seed was very high 539.7 μmol TE/g seed compared to black raspberry (150.7 μmol TE/g seed).

RASPBERRY PRODUCTS

Availability of raspberries in IQF, bulk frozen, puree, jam, jelly, juice, concentrated syrups, and dried form enable consumers to enjoy this fruit year-round. The postharvest handling, storage, and processing of this fruit generally follow procedures similar to strawberries. Frozen seedless raspberry puree forms a base for many products including stabilized processed products for use in ice cream and sorbet. The raspberry puree, with or without seeds, can be made using sieves of about 1.5–3.2 mm, and 1.1 mm, diameter openings, respectively. Pasteurization and other steps are similar to strawberry puree processing. Single strength seedless raspberry puree is about 10°Brix. However, concentrated raspberry puree of about 28°Brix is also commercially produced for various applications.

Raspberry juice is blended in many beverages where it lends its characteristic flavor, color, and a balance of sweetness and tartness. Typically, similar steps (Boyles and Wrolstad 1993), as in the case of strawberry juice, are followed to make raspberry juice and concentrates. Raspberry concentrates of about 65°Brix, with an acidity of as high as 12%, are commercially available.

Raspberry drying process requires proper handling and use of smaller size IQF fruits because the large fruits have a tendency to breakdown during the process. The drying techniques are essentially similar to that of strawberries and other fruits presented elsewhere in this book.

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26
Sweet and Tart Cherries

Mónika Stéger-Máté

Abstract: This chapter is a review of the production and postharvest physiology, physicochemical and nutritional qualities, products and processing of sweet and tart cherry. It describes the origin, the taxonomy, cultivation, varieties, harvest, and storage of cherries. Apart from the carbohydrates, sugars, organic acids, vitamins, and minerals of cherries, the most important flavonoids and anthocyanins compounds and their antioxidant capacity are discussed. Furthermore, the most important steps of processing technologies of the high-quality semifinished (aseptic pure, concentrate) and finished products (quick-frozen, dried, canned, syrup, jam) are also taken into consideration. Finally, the quality requirements of the raw materials and finished products are pinpointed as well.

INTRODUCTION

Sweet Cherry

Sweet cherry production is showing an increase and there is more interest in varieties that are good for fresh consumption. The world's total sweet cherry production is around 1.6–1.8

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

Table 26.1. Sweet Cherry Production (Million Tons) in Leading Countries and World

	1990	2000	2004	2005	2006	2007	2008
1. Turkey	143,000	230,000	245,000	280,000	310,254	398,141	338,361
2. United States	142,180	185,070	256,824	227,522	266,349	281,862	225,073
3. Iran	85,411	216,313	174,576	224,892	225,000	225,000	198,768
4. Italy	100,470	145,672	95,169	101,295	110,910	106,189	134,407
5. Russian Federation	135,000	85,000	100,000	93,000	50,000	100,000	63,000
6. Spain	54,900	112,900	83,467	95,726	91,672	72,600	72,466
7. Syrian	19,400	56,285	35,400	53,441	63,966	75,034	48,300
8. Ukraine		76,200	85,300	100,200	48,900	68,200	74,700
9. Romania	67,700	73,700	50,988	117,895	104,791	65,163	67,664
10. France	82,422	66,494	61,748	69,024	68,122	47,557	40,356
11. Greece	47,065	57,393	46,174	46,352	44,100	62,763	42,000
12. Chile	13,700	31,050	32,000	35,000	40,000	60,000	46,000

Source: FAO (2011).

million tons, which is 0.35–0.40% of the fruits produced in the world. Consequently, sweet cherry belongs to the fruits that are grown in low quantities. Western Europe produces around 50% of the total sweet cherry yield; the United States is the largest exporter. The world's largest sweet cherry producing countries are Turkey, the United States, Iran, Italy, and Russia (Table 26.1). In Chile, the growth in sweet cherry production is remarkable, since production has doubled that of 2000 (FAO 2011).

Tart Cherry

In fruit producing and consuming countries, tart cherry is known as an industrial fruit. However, some Central and Eastern European countries are exceptions, where, besides industrial processing, fresh consumption of tart cherry is significant.

The world's annual tart cherry production is around 1 million tons, out of which 70–75% comes from Europe. The sweet cherry is produced throughout Europe, but tart cherry is more prevalent in Central and Eastern Europe (Table 26.2). The main growing regions are in the eastern provinces of Germany, Poland, areas of former Yugoslavia, and Hungary. The world's most important tart cherry producing countries are Russia, Turkey, Ukraine, the United States, and Poland. Most of the North American tart cherry production comes from Michigan.

PRODUCTION AND POSTHARVEST PHYSIOLOGY

Origin, Taxonomy, and Cultivation

Sweet Cherry

Sweet cherry (*Prunus avium* L.) belongs to *Prunus* genus within Rosaceae family. The number of sweet cherry varieties is over 30, most of which are native to Europe and Asia. The "bird cherry" (*P. avium* L.) with basic chromosome number $x = 8$ is considered to be the parent genus of today's cultivated varieties. Sweet cherry is usually diploid

Table 26.2. Tart Cherry Production (Million Tons) in Leading Countries and World

	1990	2000	2004	2005	2006	2007	2008
1. Russian Federation	221,000	200,000	225,400	230,000	122,000	250,000	157,000
2. Turkey	90,000	106,000	138,000	140,000	121,499	180,917	185,435
3. Ukraine		155,300	178,500	181,800	95,600	134,600	129,200
4. United States	94,710	127,640	96,615	122,651	119,658	114,850	97,250
5. Poland	77,464	139,595	201,734	139,851	194,928	107,651	201,681
6. Serbia		58,782	112,300	63,870	80,510	99,893	89,746
7. Iran	19,260	48,895	35,925	48,670	50,000	50,000	106,461
8. Hungary	61,175	48,894	77,513	48,082	60,177	42,571	68,155
9. Balarus		16,000	22,700	27,616	46,889	30,060	44,599
10. Germany	118,380	106,900	35,450	24,571	37,143	28,756	14,911

Source: FAO (2011).

($2n = 16$), but triploid ($2n = 24$) and tetraploid ($2n = 32$) forms also occur (Brown et al. 1996).

The shape of wild sweet cherry is quite variable. Botanically, shape is classified in the following way: ssp. *vium (sylvestris, actiana)*—real "bird cherry"; *convar. juliana*—"heart cherry" (heart-shaped sweet cherry varieties); *convar. duracina*—crispy sweet cherry. Taxonomic groups cultivated nowadays derive from the wild forms of sweet cherry (Terpó 1974).

Sweet cherry is grown almost everywhere in the temperate zone. It is a composite genus. Due to its origin, this genus needs warm and light conditions, but can also endure cold winter weather. It requires 550–600 mm precipitation annually. Sweet cherry prefers medium light (pH = 5.5–7.5), deep-layered soil, which is rich in nutrients. The root system of sweet cherry requires aeration and cannot tolerate slack water (Simon 2004).

Tart Cherry

Tart cherry (*Prunus cerasus* L.) taxonomically belongs to *Prunus* genus within Rosaceae family. Its original genetic center is in Anatolia and the Caucasus region. Tart cherry is considered to be a spontaneous hybrid of sweet cherry (*P. avium* L.) and European dwarf cherry (*Prunus fruticosa* Pall.). Genetically, it is an allotetraploid with $2n = 32$ chromosome number (Brown et al. 1996).

Terpó (1974) differentiated two races (convarietas) and three variety groups (provarietas) within the genus:

1. *Convarietas acida:* "Cigány" (dark color, dye juice).
2. *Convarietas vulgaris:*
   - *Provarietas vulgaris:* "glass cherry" (nondye juice, light red, firm fruit flesh, harmonic acidic flavor).
   - *Provarietas austera:* sweet tart cherries or Morella cherries (dark red, relatively soft fruit).
   - *Provarietas maraska:* Maraska cherries.

Tart cherry better adapts to climatic conditions than sweet cherry, thus it can be grown in many regions. It can survive winter temperatures (−20–25°C) without significant damages. Tart cherry requires medium water supply; beside 600 mm annual precipitation, it can be successfully grown without irrigation. It adapts to many types of soil (pH = 5.3–7.5). However, best yields can be achieved on deep-layered loamy soil that has a good structure, ensuring proper aeration, and water supply (Soltész 2004).

Varieties

Sweet Cherry

The fruit of sweet cherry is botanically a typical drupe. In terms of pomological properties, varieties show a great variability in shape. Regarding the fruit color, there are two main categories: dark and yellow sweet cherries. Within the dark cherry group, there are two further subcategories: red (dye juice, nondye juice) and black (dye juice) sweet cherries. Yellow cherries can be homogenously yellow or mottled. Upon the quality of the flesh, there are crispy sweet cherries (stiff texture) and soft or heart-shaped sweet cherries (soft flesh, high juice content) (Brown et al. 1996). In terms of shape, the fruit can be spherical, heart-shaped, and lengthwise. The size grades include: small (3–5 g), medium (5–7 g), large (7–9 g), and very large (9–12 g). In Western Europe, dark red and light red varieties are popular (e.g., Bigarreau varieties). However, yellow varieties are also produced and processed mainly by the canning industry. Mottled varieties (e.g., Bigarreau Napoleon) are significant in North American and French production, but the dark red, crispy Bing and noncrispy Lambert are the dominant varieties (Tóth 1997a).

Tart Cherry

The tart cherry fruit is a typical drupe. In terms of pomological properties, it shows less variability than sweet cherry. Tart cherry varieties, produced today, are divided into two groups, based on the color of the fruit flesh and the juice. One group includes the so-called Amarella cherries (light-colored flesh, almost colorless juice, e.g., Montmorency). The other group contains the Morello cherries (dark red flesh, dye juice) (Brown et al. 1996).

The shape of the fruit is not particularly variable, different spherical shapes (e.g., pressed sphere, regular sphere) occur. Fruit size ranges from small (3–4 g) through medium (4–5 g) and large (5–6 g) to very large (6–8 g) (Tóth 1997b).

In countries producing tart cherry, production of one variety seems to be predominant. Schattenmorelle varieties and their selected clones are grown in most European areas, especially in Germany. In Central and Eastern Europe, Pándy is the dominant variety under different names. In Western European states, particularly in France, the light-colored Montmorency and its derivatives prevail (Tóth 1997b). In the United States, 40–50% of the tart cherry production comes from Michigan, where the Montmorency variety is popular. Two Hungarian varieties, Újfehértói fürtös and Érdi bőtermő, are widely grown under names Balaton and Danube, respectively. There is a great interest toward Hungarian tart cherry varieties all over the world. All European countries, the United States, Chile, Australia, and China performed successful variety trials with Hungarian varieties that are now grown in these countries.

Harvest and Storage

Sweet Cherry

As sweet cherry is not a postripening fruit, it is harvested at full ripeness (and in some cases, a little earlier). Fresh consumption and export requires handpicked cherries. For

such purpose, long-stalk varieties are suitable. Fruits from machine harvest can be used for industrial processing. Optimal ripeness can be determined in many ways: based on color card, force required to remove the fruit from the stalk, pressure required to crack the flesh. Health, ripeness, fruit flesh firmness, color, and variety are basic selection criteria at cherry reception before storage.

When intended for fresh consumption, the following storage conditions are recommended: temperature: −0.5°C to 0.5°C humidity: 90–95%, and flowing air stream. Controlled atmosphere storage conditions are: temperature: −0.5°C to 0.5°C humidity: 90–95%, and gas composition: 2–3% O_2 and 2–3% CO_2. In normal atmosphere, shelf life is about 10–14 days, but in controlled atmosphere, it is 20–25 days (Sáray 2002). For small size consumer products, the combination of controlled atmosphere and foil packaging is used. Recommended conditions for cherry storage are: temperature: 0–5°C, and gas composition: 3–10% O_2 and 10–12% CO_2. The packaging device has to be equipped with vacuum and gas supply units. The main packaging material selection criteria are gas and vapor permeability, mechanical and welding properties, heat resistance, size, and labeling (Balla 2007).

Tart Cherry

Tart cherry can be harvested either by handpicking or mechanically or with the combination of both. Determination of the optimal harvest time, which is important for all harvesting options, is done by the following methods:

- Monitoring the force required to remove the fruit from the stalk.
- Application of a color card.
- Determination of the force required to crack the fruit flesh.
- Analyzing composition parameters (sugar, acid, refraction).
- Measuring the optical absorption of the fruit (Soltész 2004).

According to Kollár (1994), application of only the color scale itself is not sufficient enough, since the different ripeness levels of tart cherry are not characterized by well-defined colors. The pressure required to crack the flesh, shows a significant variability depending on varieties and ripeness levels. A comparison of these data for two varieties can be seen in Table 26.3.

In order to determine optimal harvest time, Kállay et al. (2007, 2010) monitored the tearing force required to remove the fruit from the stalk in case of four varieties, besides mechanical shaking. They came to the conclusion that the tearing force is gradually decreasing during ripening. Comparing the data with other tested parameters (juice yield, water-soluble dry matter, acid content), in case of three varieties, Érdi bőtermő, Maliga emléke, and Kántorjánosi, the tearing force was 0.95–1.05 N at the optimal harvest time, for Érdi jubileum it was 1.45 N.

Table 26.3. Pressure Required to Crack the Flesh of Tart Cherry

	Pressure Required to Crack the Flesh (kPa)	
Ripeness Levels (%)	*"Érdi bőtermő"*	*"Pándy"*
70	600	250
80	300	170
90	200	150
95	150	130

Source: Kollár (1994).

The postharvest cold storage, principles described for sweet cherry apply to tart cherry as well. Normal storage conditions are: temperature: 0°C to −1°C, humidity: 90–95%, and flowing air stream. Controlled atmosphere storage conditions are: temperature: 0−1°C humidity: 95%, and gas composition: 3–4% O_2 and 2–3% CO_2. In certain cases—short (7–8 days) storage—20–25% CO_2 level besides 1–2% O_2 concentration is recommended. The expected shelf life is about 1–3 weeks in normal atmosphere and 4–6 weeks in controlled atmosphere (Sáray 2002).

PHYSICOCHEMICAL AND NUTRITIONAL QUALITIES

Carbohydrates, Sugars, Organic Acids

The water-soluble dry matter content of different fruits depends on variety, ripeness, soil, and climatic conditions. Sweet cherry's water-soluble dry matter content is between 10–20% and 12–22% for tart cherries. Stéger-Máté et al. (2010) monitored the change of composition for tart cherry varieties at different stages of ripeness. At 75% ripeness, water-soluble dry matter content was between 11% and 14% and at 95% ripeness it increased to 14.5–17%.

A significant proportion of the water-soluble dry matter comes from soluble carbohydrates, mono- and disaccharides (glucose, fructose, and sucrose), which are main contributors to the energy content. Glucose–fructose ratio is an informative parameter in case of certain fruits. According to American and German nutritional data banks, glucose is dominant in fruits, the level of fructose is lower and sucrose hardly occurs (Tables 26.4 and 26.5).

However, based on Eastern European testing, two-third of total carbohydrates in sweet cherry is fructose (4.2 g/100 g), this is significantly higher than glucose (2.2 g/100 g) (Rodler 2005). Both sweet cherry and tart cherry contain sugar alcohol, sorbitol (sweet cherry: 0.76 g/100 g; tart cherry: 1.17 g/100 g), which has a laxative effect (Rodler 2005).

Table 26.4. Nutritional Values of Sweet Cherry (Nutrients/100 g)

Proximates	USDA 2010	Souci et al. 2008	Minerals	USDA 2010	Souci et al. 2008	Vitamins	USDA 2010	Souci et al. 2008
Water (g)	82.25	82.8	Calcium (mg)	13	17	Vitamin C (mg)	7	15
Energy (kcal/kJ)	63/263	62/265	Iron (mg)	0.36	0.35	Thiamin (μg)	27	39
Protein (g)	1.06	0.90	Magnesium (mg)	11	13	Riboflavin (μg)	33	42
Total lipid (fat) (g)	0.20	0.31	Phosphorus (mg)	21	24	Niacin (mg)	0.154	–
Ash (g)	0.48	0.49	Potassium (mg)	222	235	Pantothenic acid (mg)	0.199	0.190
Carbohydrate (g)	16.01	13.3	Sodium (mg)	–	2.7	Vitamin B_6 (mg)	0.049	0.045
Fiber, total dietary (g)	2.1	1.31	Zinc (mg)	0.07	0.085	Folic acid (μg)	–	52
Sugars, total (g)	12.82	–	Copper (mg)	0.06	0.100	Carotene, beta (μg)	38	35
Sucrose (g)	0.15	0.193	Manganese (mg)	0.07	0.086	Vitamin A (IU)	64	–
Glucose (g)	6.59	7.134	Fluoride (μg)	2	18	Vitamin E (mg)	0.07	0.13
Fructose (g)	5.37	6.32	Selenium (μg)	0	1.2	Vitamin K (μg)	2.1	1.5

Fruits contain significant amount of organic acids, which are responsible for fruit's sour tastes and refreshing effects. Each fruit has a specific organic acid profile. The acid content of sweet cherry is lower (0.2–0.7%) than tart cherry (1.0–1.9%). Malic acid and citric acid are the predominant acids in fruits; oxalic acid, shikimic acid, and fumaric acid also occur in smaller quantities (Usenik et al. 2008).

Some species of fruits are characterized by their acid–sugar ratio; in case of sweet cherry, it is 0.07 and for tart cherry, it is 0.20. The refreshing sweet–tart property of tart cherry is due to a lower Brix/acid ratio. Regarding complex carbohydrates, starch can be found in fruits, especially when unripe. However, it degrades to sugars during ripening. Pectin generally occurs in fruits (0.2–0.3 g/100 g), but its quantity is not significant (Souci et al. 2008). Dietary fibers are of great importance in a preventive diet. Fibers hinder the development of colon cancer, stomach, and intestinal disorders. Furthermore, they can positively influence fat and cholesterol absorption and ensure the peristaltic motion of the intestines. The water-soluble dietary fiber content of sweet cherry is 0.5 g/100 g and the water-insoluble fiber level is 0.81 g/100 g. In case of tart cherry, these values are 0.57 g/100 g and 0.47 g/100 g (Souci et al. 2008).

Vitamins

Vitamins are essential substances for living organisms. Even if they are needed in smaller quantities, they are indispensable for metabolism. Vitamins increase the nutritional value of fruits as well (Tables 26.4 and 26.5). Tart cherry and sweet cherry contain all vitamins in low concentrations, except vitamin B_{12} and vitamin D. Their thiamin (vitamin B_1) content is 26–50 μg/100 g; the quantity of riboflavin (vitamin B_2) is 33–60 μg/100 g. They also contain pantothenic acid, folic acid, vitamin B_6, ß-carotene, vitamin E, and vitamin C. The latter two vitamins play a significant role in the antioxidant protection system of the human body. They hinder the formation of peroxides, the release of harmful free radicals;

Table 26.5. Nutritional Values of Tart Cherry (Nutrients/100 g)

Proximates	USDA 2010	Souci et al. 2008	Minerals	USDA 2010	Souci et al. 2008	Vitamins	USDA 2010	Souci et al. 2008
Water (g)	86.13	84.8	Calcium (mg)	16	8	Vitamin C (mg)	10	12
Energy (kcal/kJ)	50/209	53/225	Iron (mg)	0.32	0.60	Thiamin (μg)	30	50
Protein (g)	1.00	0.90	Magnesium (mg)	9	8	Riboflavin (μg)	40	60
Total lipid (fat) (g)	0.30	0.50	Phosphorus (mg)	15	19	Niacin (mg)	0.400	
Ash (g)	0.40	0.50	Potassium (mg)	173	114	Pantothenic acid (mg)	0.143	
Carbohydrate (g)	12.18	9.88	Sodium (mg)	3	2	Vitamin B_6 (mg)	0.044	
Fiber, total dietery (g)	1.6	1.04	Zinc (mg)	0.10		Folic acid (μg)		75
Sugars, total (g)	8.49	–	Copper (mg)	0.104		Carotene, beta (μg)	770	240
Sucrose (g)	0.80	0.418	Manganese (mg)	0.112		Vitamin A (IU)	1283	
Glucose (g)	4.18	5.18				Vitamin E (mg)	0.07	0.13
Fructose (g)	3.51	4.283				Vitamin K (μg)	2.1	

therefore, they contribute to the prevention of arteriosclerosis and cancer.

Minerals

Potassium is one of the most important mineral (Tables 26.4 and 26.5), and these fruits are rich in this compound (sweet cherry: 222–235 g/100 g; tart cherry: 114–173 g/100 g). They are low in sodium, thus improving the adverse Na/K ratio of the human body. Some trace elements can also be found in these fruits with zinc, copper, and iron being prevalent. The level of copper (0.057 mg/100 g) is one of the highest out of all fruits. Ficzek et al. (2009) monitored macro- and microelements during the ripening of four tart cherry varieties (Érdi jubileum, Érdi bőtermő, Maliga emléke, and Kántorjánosi 3). The mineral content of Érdi jubileum is (P: 25–35 mg/100 g; K: 210–230 mg/100 g; Fe: 0.5–0.7 mg/100 g) and the mineral content of Kántorjánosi 3 is (Ca: 50–55 mg/100 g; Mg: 18–20 mg/100 g; K: 190 mg/100 g; Mn: 0.17–0.18 mg/100 g) at optimal ripeness.

Flavonoids, Anthocyanins, Antioxidant Capacity

Plants are rich in aromatic compounds. The most significant group within these aromatic substances is the flavonoids, which belong to the group of polyphenols.

Physiological Effect of Flavonoids

Flavonoids are produced by plants and their primary role is protection against harmful UV rays. Flavonoids are mainly responsible for the yellow, blue, pink, and red color of crops and flowers. However, these substances are not only important for plants but also for human health as well.

The positive physiological effect of flavonoid molecules on the human body has been proven by numerous clinical trials and studies (Wang et al. 1997). They influence the binding of reactive oxygen (Tsuda et al. 1996), the inhibition of lipoprotein's oxidation (Marshall et al. 1987, Vaca and Harms-Ringdahl 1989, Narayan et al. 1999, Wang et al. 1999, Ghiselli et al. 1998), and are able to hinder the development of cardiovascular diseases (Bertuglia et al. 1995). They have a synergistic effect with vitamins (enhance the nutritional value of vitamins C and E), which catalyzes their formation. Furthermore, their immunostimulating and anticarcinogenic effects have also been proven.

Within the flavonoid group, anthocyanins have antioxidant effects. Anthocyanins in food have been linked with health-promoting benefits such as antioxidant and anticancer activities (Koide et al. 1997, Rechkemmer 2000). Seymour et al. (2008) reported that eating of sour cherries reduced the lipid concentration of liver in animal experiment. Anthocyanins are reported to have antiinflammatory (Wang et al. 1999), antibacterial (Changwei et al. 2008), antistress, and immune system strengthening effects. Additionally, they are effective supplements of chemotherapeutic and other similarly serious treatments, for example, in case of patients suffering from HIV or cancer (Kamei et al. 1998, Koide et al. 1996, 1997).

Flavonoids

Flavonoids are the derivatives of the 2-phenyl-benzopyrene ring system, where the C_{15} carbon structure forms C_6-C_3-C_6 units.

The following compounds belong to the group of flavonoids: flavones, flavonols (3-hydroxyflavone backbone), flavanols, flavanones (2,3-dihydro-flavones), flavanonols (3-hydroxy 2,3-dihydro-flavones), anthocyanidins, proanthocyanidins (leuko-anthocyanidins), and isoflavonols (Harborne and Williams 1998).

The diversity of flavonoids is due to the different number and position of OH- and CH_3 groups. On the other hand, glycoside bounds also contribute to this variability, since they occur in plants and lead to higher stability and better water solubility. The glycoside form develops from the condensation of the flavonoid compound and a sugar.

$$\text{Glycoside} \Leftrightarrow \text{Aglycone} + \text{Sugar}$$

The occurrence of colorless flavonoid compounds shows a high degree of variability depending on the fruit variety. Bonerz et al. (2006) studied the level of phenolic compounds in five tart cherry varieties (Schattenmorelle, Gerema, Ungarische Traubige, Cigány 7, and Stevnsbear Birgitte) (Table 26.6).

Out of the flavonoids, he detected the presence of flavanols, particularly catechin (1–14 mg/L) and epicatechin (24–336 mg/L). The dominant flavonols are quercetin-3-rutinoside (18–59 mg/L) and quercetin-3-glucosylrutinoside (11–31 mg/L). Certain tart cherry varieties also contain quercetin-3-glucoside and kaempferol-3-rutinoside. Other phenolic compounds, which do not belong to the flavonoid group, have also been detected such as chlorogenic acid, neochlorogenic acid, and 3-coumarolquinic acid. When studying the flavonoid compounds of Balaton and Montmorency varieties, Kirakosyan et al. (2009) measured significant amount of isorhamnetin-3-rutinoside. Usenik et al. (2008) tested the same parameters of 13 sweet cherry varieties. The presence of epicatechin (4.3–45.1 mg/L) has also been detected, but its level was lower than measured from tart cherries. The concentration of rutin (20.6–57.8 mg/L), chlorogenic acid, neochlorogenic acid, and coumaroylquinic acid proved to be substantial.

Anthocyanins

Development of the color is the result of many factors. The structure of the aglycone is crucial, but it is influenced by other flavonoid molecules, which are mainly anthocyanins with different structure, occurring in different ratio.

Table 26.6. Phenolic Compounds in Cherry Varieties (mg/L)

	Schattenmorelle	Gerema	Ungarische Traubige	Cigány 7	Stevnsbear Birgitte
Catechin	2	14	10	1	4
Epicatechin	206	49	24	146	336
Neochlorogenic acid	398	998	831	212	394
Quercetin-3-(2^G-glucosylrutinoside)	29	31	11	19	31
Quercetin-3-rutinoside	59	31	27	23	18
Quercetin–glucoside	8	6	4	3	5
Kaempferol-3-rutinoside	13	9	6	4	8
Anthocyanin (sum)	682	756	569	698	858
Cyanidin-3-sophoroside	73	185	39	37	73
Cyanidin-3-(2^G-glucosylrutinoside)	410	395	361	439	515
Cyanidin-3-(2^G-xylosylrutinoside)	29	38	23	27	43
Cyanidin-3-rutinoside	164	125	140	180	213
Peonidin-3-rutinoside	5	13	7	15	14

Source: Bonerz et al. (2006).

The main subgroups of anthocyanidins, which differ in the number of hydroxyl groups found on the rings, are pelargonidin, cyanidin, delphinidin, peonidin, petunidin, and malvinidin (Fleschhut et al. 2006).

The increase in the number of hydroxyl groups makes the blue color more dominant with subgroups pelargonidin, cyanidin, and delphinidin prevailing, meanwhile an increase in the number of methoxy groups strengthens the red tone with subgroups peonidin, petunidin, and malvidin (Mazza and Miniati 1993, Kong et al. 2003). In tart cherry, cyanidin-3-glucosylrutinoside is considered to be the main compound, because its concentration reaches 60–67% of the total anthocyanin content, the remaining 25–33% is cyanidin-3-rutinoside. The presence of cyanidin-3-sophoroside and cyanidin-3-glucoside has been also reported (Blando et al. 2004). In the German Gerema, in the Hungarian Cigány 7, and in the Danish Stevnsbear Brigitte varieties, peonidin-3-rutinoside also occurs besides cyanidins (Bonerz et al. 2006). In sweet cherry, 79–96% of total anthocyanins are cyanidin-3-rutinoside. Other compounds that also contribute to the color are cyanidin-3-glucoside, pelargonidin-3-rutinoside, and peonidin-3-rutinoside (Usenik et al. 2008).

In 2000, the American Amway Corporation invested two million dollars to study the composition of Hungarian tart cherry varieties; technology testing, clinical trials, and extraction of the active ingredients have also been performed. According to their results, Hungarian tart cherry contains four–five times more anthocyanin than the American Montgomercy variety; thus, its nutritional and financial value is significantly higher compared with other European and American varieties (Wang et al. 1997).

At Michigan State University, studies were conducted on the effects of tart cherry on human health for a period more than 10 years. American Montmorency was tested alongside varieties originated from the Carpathian Basin with high dry matter content. Érdi bőtermő is grown as Danube, meanwhile Újfehértói fürtös is known as Balaton. The US 17 different antioxidant compounds have been found in these varieties that were mainly anthocyanin-based coloring agents, melatonin, many phenolic compounds, and vitamin E. These substances have antiinflammatory effect and play important role in the prevention of cancer and arthritis (Burkhardt et al. 2001).

Fresh tart cherry contains high concentration of melatonin, which is also produced by the pineal gland of the human body. Melatonin is an important antioxidant, because it can fight against free radicals in both aqueous and fatty conditions within the human body. Kirakosyan et al. (2009) studied the level of melatonin in products made from Balaton and Montmorency tart cherry varieties. They came to the conclusion that freezing and freeze-drying are the best processing technologies to preserve melatonin.

Tests performed on fruit samples justified that certain parameters (e.g., dry matter content, sugar, total acids, and vitamin C) show significant differences depending on the degree of ripeness (Sang et al. 2003, Stéger-Máté et al. 2003). In case of raw materials that are rich in ingredients with high biological value, monitoring the concentration during ripening is very important for the industry. The amount of certain parameters determine the characteristics of the product (e.g., carbohydrate- and acid content) and production costs (e.g., water-soluble dry matter content in case of concentrate production or preparation of the finished product) as well. On the other hand, the concentration of certain parameters is a significant factor regarding the quality of the finished product (e.g., vitamins, minerals).

Hungarian researchers monitored the development of antioxidant compounds in four tart cherry varieties (Érdi jubileum, Érdi bőtermő, Maliga emléke, and Kántorjánosi 3) during ripening (70%, 80%, 90%, and 100% ripeness, respectively). Érdi jubileum variety contains high amount of

polyphenols (170–260 mg/L), anthocyanins (90–178 mg/L), vitamin C (28–30 mg/100 g), and rutin (0.055–0.075 mg/mL) at 80–90% ripeness, which is optimal for mechanical harvest. Furthermore, the color of the fruit skin (depends on the anthocyanidin content) is the most important indicator of maturity and the quality of fresh cherries (Kállay 2008, Stéger-Máté et al. 2010). However, it is important to mention that composition, especially the quantity of compounds with antioxidant effect depends on the ripening stage to a great extent (Ficzek et al. 2009).

PRODUCTS AND PROCESSING

Besides fresh consumption, processing of sweet and tart cherries is significant. Industry requires that the fruits intended for processing correspond with the following criteria: variety identity, optimal ripeness, free from microbiological deterioration, homogenous and intense color, large fruit size, small seed size, thin fruit skin, stiff fruit flesh, and appropriate acid–sugar ratio, nonsusceptible for browning and free from the grub (worms) of *Rhagoletis cerasi* L.

Fruits that are intended for industry processing are usually harvested mechanically, thus these fruits are more damaged and susceptible for browning than handpicked ones. The occurrence of foreign materials, leaves, stem, etc. may be higher in these lots. Fruits are generally transported to the processing plant in plastic boxes. Following sampling and quality grading, fruits can be stored in cool warehouse for some days before processing into different products (Fig. 26.1).

Quick-Frozen Products

Quick-freezing is performed on both sweet and tart cherries with and without seeds. After reception, quality evaluation and selection, production begins with precooling. In case of destined (pitted) tart cherry, this step can lead to better texture properties and better seedless quality. This operation is carried out in cooling containers at 0–5°C. It is followed by stem removing, pitting, if the finished product is pitted. Freezing (by continuous, band-based, or fluidization-type equipment) is complete when the core temperature is −25°C. Frozen products thus produced, then undergo sorting and grading to improve the quality. They are packed in polyethylene bags or multilayer boxes. Packed products pass through a metal detector as well. Products are stored frozen (Binder 2002). Frozen sweet and tart cherries can be further processed. Smaller package size products are sold in retail outlets for households. Large packages are used by other food industries (e.g., baking, confectionery, dairy, canning, etc.).

Aseptic Puree

The pulp of sweet and tart cherries is a natural, semifinished product that contains pressed fruit flesh without seeds, skin and added materials. Fruit pulp itself is not eaten, but it is used as ingredient in several fruit-based products (e.g., baby foods, jams, juices, fruit sauces, etc.).

Technology

Raw Material Reception In order to produce aseptic pulp, fruits need to pass stringent quality control according to the following criteria: appropriate ripeness, sound, free from defects, insects, pathogens, insect, and free from foreign material.

Preparation The preparation of the fruits begins with a washing step, which is usually performed in a water bath. Fruit washing efficiency can be successfully improved by water circulation (e.g., aeration via nozzles). This is followed by a selection, then the fruit is disintegrated into irregular shape small particles. The goal of this step is to tear the skin of the raw material and to mash the fruit to attain coarse texture. This step is crucial for ensuring the effectiveness and evenness of precooking. The disintegrator equipment is often located above the precooking device, thus the cracked fruit can directly fall into the hopper of the precooking machine. Destoning/pitting is frequently performed before disintegration.

Precooking Precooking makes the tissue structure of the fruit soft and flowing. Therefore, pressing is easier and can be performed more efficiently. Furthermore, the enzymes in the fruit are inactivated as well. Inactivation of oxidative and pectolytic enzymes is particularly important, since they would cause color and texture damages in the pulp during subsequent processing and handling. This process is carried out in shell or double tube equipment.

Sieving The result of fruit pressing is the pulp. The sieving devices apply centrifugal force on the fruit, so its soft parts pass through the perforated sieve surface, meanwhile harder skin and seed particles are retained by the sieve.

To improve the efficacy and decrease losses, separation is performed gradually by using sieves of decreasing pore size. Generally, fruit flesh is pressed first in a coarse (1.2–0.8 mm) and then in a fine (0.6–0.4 mm) perforation device. The first step removes the majority of the fruit skin, meanwhile the second step chops tissue fibers.

Homogenization In order to achieve homogenous, smooth, creamy, texture and slow the settlement of formal particles, fruit pulps is homogenized. This step leads to increased virtual viscosity within the system and more consistent pulp.

Deaeration During sieving and homogenization, significant amount of air enters the fruit puree. Due to the fine particle size, this can lead to nondesired oxidation on an increased surface. This air can also ruin the effectiveness of

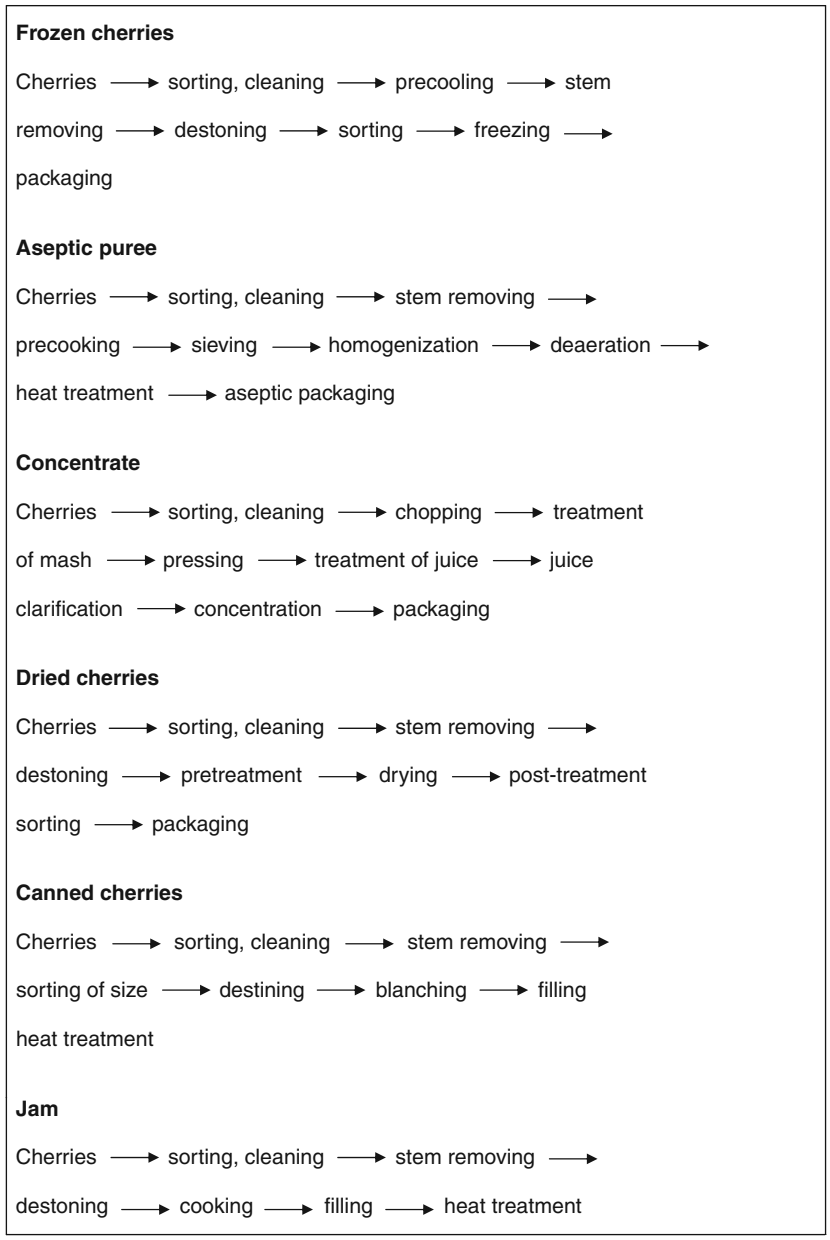

Figure 26.1. Process flow diagram for cherries.

the pasteurization equipment, thus aeration of the fruit pulp is recommended directly after homogenization. Deaeration is usually performed in a special tank that is under vacuum, where the fruits pulp enters by spraying.

Storage The finished fruit puree is stored in natural form or as 26–35% concentrate until further use. Long-time, intense heat impact spoils the nutritional values and sensory traits of the product. Safe storage besides preserving the valuable fruit properties can be achieved with aseptic technology. The unpacked puree is then heat treated in a tunnel system usually above 100°C (90–120°C) for about 0.5–2 minutes. To prevent postcontamination, it is packed into sterile packaging material under aseptic conditions. According to the size of the packaging material, the filling volume of modern packing machines can be adjusted (2–220 kg). They are suitable for filling "bag-in-box" and "bag-in-barrel" units as well. Fruit pulp can also be filled into large aseptic containers. In this latter case, sterile puree is pumped via a closed

system with overpressure into large stainless steel sterilized tanks.

Concentrate

Fruit concentrate is a semifinished product that contains the pressed juice of the fruit in concentrated form without added materials, seed, skin and tissue particles. It is stored in cool storage or in aseptic system following heat treatment.

Fruit concentrate is not consumed directly, but it is a raw material for different fruit products (e.g., fruit juices, baby foods, syrups, powdered fruit drinks, fruit gels, etc.). The appearance of concentrate can be: clean, filtered shiny concentrates, or cloudy with colloidal particles.

Technology

Raw Material For the production of fruit concentrates, fruits should be ripe, sound with stiff flesh, and high juice content. Acid–sugar ratio is also an important selection criterion. In case of tart cherry dark red, so-called dye juice, varieties are preferred for concentrate production.

Preparation Prior to pressing the juice, the green stalk of the fruit is removed, otherwise it spoils the color and quality of the juice. This is followed by a sorting, where extra attention is paid to sorting out moldy and deteriorated fruits. Microorganisms and their metabolites can cause quality problems if they get into the concentrate.

Pressing The process of juice extraction can be divided into separate operations. First, the fruit is cracked, where the tissue structure breaks up. Then, the crushed fruits undergo different treatments to increase juice yield, achieve better aroma, taste, color, and to avoid certain nondesired processes. Out of the currently known pretreatment procedures (thermal, enzymatic, freezing, vibration, ultrasonic, electroplasmolytic, and ionic irradiation), thermal and enzymatic treatments are preferred. Thermal treatment means warming the crushed fruit up to 80–85°C rapidly, then cooling back very quickly. This short-heat treatment inactivates the enzymes, cell walls become permeable, and color pigments in the skin and under the skin can be extracted to a higher extent. Besides thermal pretreatment, the addition of pectolytic enzymes to the fruit mash is also widely applied, where mainly the water-soluble pectins are decomposed. These enzyme products are characterized by high PTE (polytranseliminase) and PG (polygalacturonase) content. Although this process can be performed at 45–55°C, enzymatic pretreatment can also work between 10°C and 30°C. The time for this treatment, before pressing, is about 30–60 minutes.

Juice extraction is a process where the liquid phase is separated from the solid particles. There are several methods to perform this step such as pressing, diffusion extraction, centrifuge procedure, and reverse osmosis, which is based on membrane techniques. The method selected depends on the fruit to be processed, the features of the processing equipment, and the economical background.

Pressing is typical followed for juice extraction and can be complemented with the extraction of pomace. The juice yield is influenced by the properties of the pressing device, the fruit parameters, and preparation. Pressing machines, which are applied in fruit processing industries, work either fractionally (package press, basket press) or continuously (belt press, spiral press, and decanters).

Juice Clarification Fruit juices, thus extracted, are strongly turbid due to fine plant particles that are insoluble in water. In order to obtain appropriate finished product without turbidity and to preserve sensory properties (taste, aroma, color), these substances are removed. This process can be done with enzymes, physicochemical, and mechanical methods or their combinations.

During fruit clarification, protective colloids (pectin, starch, and hemicellulose) is decomposed, because they postpone or hinder sedimentation and formation of aggregates. This is performed with enzyme addition. The aim of the enzymatic treatment is to decompose pectin molecules found in the juice. However, the production of shiny filtered concentrate requires pectin degradation to be completed along with the break down of starch, hemicellulose, and araban. The process takes 1 ± 0.5 hour at 45–55°C. The efficiency of the enzymatic degradation can be tested with alcohol test for pectin and with iodine test for starch. For physicochemical clarification, china clay, which is of mineral origin, is the most popular and is usually used in combination with other agents. It has a good clarification performance in a short period of time. In case of enzymatic pectin degradation, solid china clay is added after the end of the enzymatic clarification and it is usually combined with gelatin treatment.

Mechanical clarification targets the elimination of natural fruit fibers and precipitation formed in the treatments described earlier. This process is carried out in different centrifuge and filtration devices. In practice, prefiltration can be performed in sedimentation centrifuges, meanwhile decanters are used for to decrease of fiber content in cloudy juices.

Concentration Clarified filtered and cloudy juices are ready for consumption and for further processing. There are two ways to preserve them. They are either packed in consumer packages right after production or they are concentrated, which results a semifinished product.

The aim of concentration is to decrease water content, increase dry matter content and shelf life, and to improve shipping and storage properties of the juice. This procedure is implemented in a way that the loss of valuable compounds (e.g., anthocyanins) and sensory traits are minimum. Techniques applied for juice concentration are evaporation, freeze concentration, and reverse osmosis.

Storage of Fruit Concentrates The Brix of the concentrates is usually in the 45–55°Brix range. Moreover, products made with freeze concentration or cloudy concentrates with specific composition are both in the 40–45°Brix range or bellow. These products can be stored under aseptic conditions or frozen. The juices can be concentrated up to 60–65°Brix, but its coloring properties rapidly decrease during storage.

Dried Fruits

Dried sweet cherry and tart cherry products are made from raw or frozen fruits. After removing the stalk and the seed, the fruit is preserved by drying. Then, the products are packed in polyethylene bags that retain the aroma and vapors.

In terms of further use, these dried fruits are the ingredients of fruit snacks, muesli mixes, muesli bars, fruit teas, and other products.

Raw Materials For dried tart cherry and sweet cherry production, only those fruits can be used that correspond with the following criteria: good quality, ripe, healthy, free from surface, and microbial damages.

Preparation Boxes containing the incoming sweet and tart cherries are directly emptied onto the tray of the stem-removing device, where the stem of the raw materials is removed. Raw materials are washed by the spraying performed on this equipment. In case fruits are purchased without stems, washing can be carried out in the universal washing equipment. If the size of the raw material is inhomogeneous, manual sorting is done to eliminate small and unripe berries, since it decreases the effectiveness of the destoning device. This is followed by precooking, where the target is to inactivate enzymes responsible for browning processes and to avoid the leakage of juice during destoning. The temperature of the precooking water is 76–80°C, in which the fruit spends 1–2 minutes. Tart and sweet cherries are destoned before drying. This step can be performed on a burr-system destoning device. In case of individual preferences, destoning can be left out, and then the fruit is dried with the seed. After destoning, there is an important selection step, where remaining seeds and broken seed residues are eliminated.

Drying Sweet and tart cherries are mostly dried in tunnel- or tray-based dryer machines. The proper distribution of the fruits on the tray plays an important role in the quality of the finished product. Trays are preferably made of stainless steel, because it is resistant to heat and the contact with the raw material does not result in any damages. Berries should not pass through the tray perforation, but it has to be as permeable to air as possible.

Sweet and tart cherries are dried down to 18–20% moisture content. The duration of drying is 8–10 hours, depending on the raw material and equipment. The highest drying temperature is 68–70°C. To produce 1 kg dried product, 3.5–5.5 kg destoned raw material is needed. Dried cherries are cooled in the postdrying section of the tunnel dryer device and on the belt that follows the dryer. This belt is also equipped with metal detector and final selection takes place on it as well. Sweet and tart cherries, thus dried, are stored under dry cool conditions.

Post-treatment Finished products can differ in size, color, purity, and even in moisture content. Further operations in the warehouses target the achievement of homogenous finished products. These operations might include grading based on size, color, moisture content, purity, and metal detection.

Added value can be created with procedures such as chopping, fine size selection to defined fractions, sieving, grinding, and mixture production.

Vacuum Drying In order to protect coloring agents and antioxidant compounds, vacuum drying is more and more frequently applied.

Its advantage comes from the fact that drying is done under reduced pressure; thus, high drying speed can be achieved at relatively low temperature. Compared to atmospheric drying, vacuum drying results in significant energy saving. Drying can be performed without substantial damages in product quality and the majority of valuable substances can be preserved. Vacuum dried products have good rehydration ability. Instant powdered products can be made with this technique from concentrates.

In modern production procedures, traditional drying technologies, which apply hot air, are complemented by a vacuum-microwave drying line. This new method enables the manufacture of special dried products with quick rehydration abilities and stable shape. These products have better quality and can be used for the manufacture of even more products.

Canned Fruit

Canned cherries are heat-treated products, in which the fruits are appropriately prepared (washing, stem removal, with or without seeds) in sweet syrup. Besides fruits and sugar, these products may contain alcohol, vinegar, spices, plant particles (for coloring, sweetening, flavoring, and decoration), and other additives (e.g., citric acid and solidification agents).

Depending on the sugar content and flavor of the syrup, there are different categories: sugar-free, slightly sweet (14–17°Brix), sweet (17–20°Brix), strongly sweet (>20°Brix), alcoholic (confectionery raw material), canned cherry with vinegar, and so-called pudding fruit with high fruit content.

Raw Material The optimal raw material for canned fruit processing is not totally ripe, but its color, taste, and aroma are already developed. However, the tissue structure should be solid enough.

Canned fruits are usually made from fresh fruits, but raw materials preserved with freezing, drying, and heat treatment can also be used.

Preparation Raw material preparation includes general and specific steps depending on the properties of the raw fruit and the canned fruit. Selection, washing, stem removing (specially designed reels, covered with rubber, rotating in the opposite direction), and destoning (e.g., Ferrum-type destoner with burr) are performed.

In order to produce eye-appealing finished products containing whole cherries, preparation includes size grading. This can be done by rotating drum/devices of different layout.

Grading is essential for more of the following preparation steps:

Precooking and the increase of sugar content are extremely significant operations of direct canned fruit production.

Beneficial changes, which take place during this process, improve the quality, sensory properties, and appearance of the finished product. The heating effect results in pliable texture, proteins denaturation, consequently enzyme activity declines and diffusion processes accelerate. Most of the gas in the fruit tissues goes away and liquid fills its emptied space. Consequently, the fruit will not float in the can, it will shrink and crack to less extent and the product would not be "short of syrup." Precooking can be performed in steam, water, or in solution. The solution may contain acids, glycerol, and sugars in different concentration. Fruits coming from the precooking equipment have to be selected. Soft, lax, discolored pieces are eliminated.

Filling, Closing, Heat Treatment The prepared raw material is filled into jars that are suitable for canned fruit packaging, and syrup is added. As the final dry matter content and acidity can be adjusted with the syrup, it is formulated such that finished product parameters meet regulatory levels, even after the diffusion processes. Due to the crack of the fruit skin, syrup is filled onto the fruit at around 60–65°C and the jar has to be closed immediately afterward by means of steam-vacuum closing. Effectiveness of closing is checked.

Canned fruits are preserved by pasteurization at 92–96°C. The duration of heat treatment is determined by the pH of the fruit, size of fruit pieces, and size of packaging.

Crystallized Fruits

This product group is preserved by increasing the sugar content to an extent where sugar concentration is high enough for further stability. Raw materials and their preparation is the same as written for canned fruits.

The most important preparation step is increasing sugar content. Appropriately prepared and precooked fruits provide a solution of 28–30°Brix. The concentration of the solution is increased 5°Brix on every 4th–5th day until the level of soluble solids in the fruit is 65–70°Brix. In the final solution, the fruit can be stored for a longer period under cool conditions. After achieving the desired dry matter content, fruits are dried and covered with sugar or chocolate coating.

Fruit Syrup

Products that belong to this category are produced from fruit juices or semifinished fruit products with the addition of sugar and additives. The result is a viscous product that is to be diluted with water before consumption.

Fruit syrups are produced from tart cherry juice than from sweet cherry. In case of light colored varieties, product appearance can be improved by the addition of varieties with dye-colored juice. The minimum water-soluble dry matter content of syrups is 60.0°Brix and the minimum fruit content is 33%. Sugars can be partly or totally substituted with honey. Addition of aromas, which are relevant to the fruits used, is allowed for flavoring.

Depending on the raw materials, the syrup can be filtered. Syrup production consists of sugar addition, homogenization, and filling. Syrups can be produced at cold and warm temperatures. Preservation can be done by heat treatment or with the addition of preservative agents.

Jams

Jam products are made of one or more fruits that have been pressed or chopped, and then they are concentrated by heat treatment to the desired extent. Besides fruits, jams may contain sugars or other sweetening compounds, stabilizing and gel-forming substances, acidulants, spices, herbs, their extracts, and other additives. Depending on the product character, texture can vary. These products are usually preserved by heat treatment, but preservatives may be added to certain jams.

Jams can be packed into consumer packaging, but they are also available in large, bulk form for the industry, for example, baking, dairy, and confectionary applications.

Preparation Jams can be produced directly from raw materials or from semifinished products, which are mainly aseptic fruit pulps.

Cooking Jam production is based on formulation and processing according to desired finished product quality. The process typically consists of, weighing ingredients, mixing acidulants, stabilizers, sweeteners as per the formulation (in small amount of water or juice), and heating the fruits about to 70–80°C. One of the important steps in jam production is cooking, where some of the sugar becomes inverted. If the invert sugar is formed in small quantities, it stabilizes the gel structure. However, high invert sugar level can damage the gel. Degree of inversion depends on pH, cooking temperature,

and cooking time. Alongside the inversion, a diffusion process takes place between the fruit and the surrounding syrup as well. At the same time, an increase in the concentration can also be seen due to the evaporation. When the desired dry-matter content is achieved, pectin solution is added to achieve the desired texture. The cooking process is continued for an additional 3–5 minutes, so that the water–sugar–pectin system can form a gel structure. The stability of the gel thus formed depends on the concentration and properties of pectin, pH, and sugar content. The pectin level required for jams is between 1.0% and 1.5%. Pectins are sensitive to pH. There is a slight variability in the optimal pH of different pectins, but it is generally around 3. Therefore, the pH of the jam is adjusted with acid addition. Acids, previously dissolved, are added immediately after the end of cooking step. In case jams are cooked with acids, the extent of sucrose inversion can be detrimental. This can damage pectin chains resulting in the decrease of gel formation capacity. If other additives (aroma, preservatives, etc.) are also included in the formula, they have are added at the end of the cooking process.

Jams are cooked in flat duplicator tanks or in spherical vacuum insulated devices.

Filling, Heat Treatment Jams intended for direct consumption are usually filled into small jars. Products intended for further industry processing are packed into boxes, plastic buckets, or stainless steel tanks with lids. Jams in consumer packaging (jar) are preserved by heat treatment. Products, made for the industry, are not filled into heat resistant containers, so addition of preservatives is necessary. In case of jars, heat treatment means pasteurization at 92–98°C. Products filled into steel tanks are preserved by aseptic technology. Pasteurized products are cooled immediately after the heat treatment to avoid the damage of the pectin chain and the gel structure.

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Grapes and Raisins

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Abstract: Grapes and grape products are among the world's most important horticultural products and consequently are of major commercial interest. They are served as a fresh fruit, dried into raisins, preserved or canned in jellies and jams, and crushed for making juice or wine. Preservation of grapes by drying is a major industry in several parts of the world where grapes are grown. Drying of grapes on the vine or by open sun drying, shade drying, or mechanical drying produces raisins. The grape with an outer waxy cuticle and a pulpy material inside is a complex product for dehydration. Loss of moisture from berries during drying is accompanied by changes in fruit structure and texture, such as fruit softening or loss of firmness, which are related to their microstructure. Researchers have evaluated various drying techniques to produce superior quality raisins. However, more research is needed to further refine and optimize the drying process and prevention of undesirable changes in color, flavor, and composition of raisins. Like in other crops, organically produced grapes and raisins have become a leading commodity. There is need to develop production practices and certification standards for organic raisins. The chapter describes the current status of various drying technologies and identified areas requiring further research.

INTRODUCTION

Grapes and grape products are among the world's most important horticultural products and consequently are of major commercial interest. They are served as a fresh fruit, dried into raisins, preserved or canned in jellies and jams, and crushed for making juice or wine. According to the Food and Agriculture Organization (2010), grapes were grown on 7.43 million hectare and approximately 66.9 million tons were produced during 2009. Approximately 71% of the world's grape production is used for wine, 27% as fresh fruit, and 2% as dried fruit (Wikipedia 2010). A portion of grape production goes to producing grape juice to be reconstituted for fruits canned "with no added sugar" and "100% natural."

Grapes probably originated in Asia Minor, in the region between and to the south of the Black and Caspian Seas; from there, they have spread to six continents. They are now grown everywhere with a reasonably favorable environment. North America is the native habitat for more than 70% of the world's grape species. Commercially, grapes are classified as either table or wine grapes, based on their intended method of consumption: eaten raw (table grapes) or used to make wine (wine grapes). Commercial grape varieties can also be classified into table grapes, dried or raisin grapes, wine grapes, sweet juice grapes, and canning grapes.

Preservation of grapes in the form of raisins is a major profit-making business in several countries where grapes

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are grown. The world raisin production in 2009 was estimated to be 1,062,500 tons (USDA 2009). The United States and Turkey are the major producers and exporters of raisins (USDA 2009). The US raisin production during 2002–2003 was 386,279 tons, the majority of which was produced from the Thompson seedless. During the same period, Turkey produced 220,000 tons of raisins. The United States is usually the largest raisin producer in the world, although Turkish production did surpass US production in 2006. Historically, the US and Turkish production combined has accounted for 80% of global raisin production (USDA 2009). The other raisin-producing countries are Greece, Mexico, Chile, Australia, South Africa, Iran, and India.

Raisin production was once a most labor-intensive activity involving up to 40,000–50,000 workers for a typical 6-week harvest. However, the new dried-on-the-vine (DOV) technology reduced labor requirements significantly and facilitated machine harvesting of the dry raisins, reducing worries about rain damage.

TYPES OF RAISINS

The word *raisin* comes from the French *raisin sec,* meaning dry grape. The term has become limited to the dried grapes of mainly three varieties, namely, Thompson seedless, Black Corinth, and Muscat of Alexandria.

In most of Europe, dried grapes are referred to as *raisins* or the local equivalent. In the United Kingdom, only three different varieties are recognized, which has forced the European Union (EU) to use the term *dried vine fruit* in official documents.

A *currant* is a dried Zante Black Corinth grape, the name being a form of the French *raisin de Corinthe* (Corinth grape). The word *currant* has also come to refer to the black currant and the red currant, two berries that are unrelated to grapes.

A *Sultana* was originally a raisin made from a specific type of grape of Turkish origin, but the word is now applied to raisins made from common grapes and chemically treated to resemble the traditional *Sultana*.

Sun-dried seedless raisins constitute 93% of the total raisin crop. The trade names of raisins may signify, besides the grape cultivar, the method of drying (natural, golden-bleached, sulfur-bleached, and lexia), the principal place of origin (Vostizza, Patras, Pyrgos, Smyrne, Malaga, and Valencia), the conditions in which the product is offered for sale (layers, loose, and seeded), the size grades (4 crowns, 3 crowns, 2 crowns, and 1 crown), and for the US grapes, maturity grades (B or better, C, and substandard), and quality grades (extra standard, standard, substandard, extra fancy, fancy, choice, etc.). Raisins are also classified as currants, golden raisins, monukka raisins, Muscat raisins, dark raisins, and Sultanas. Golden seedless raisins account for 5% of the total raisin crop. Golden raisins are mechanically dehydrated and specially treated with sulfur dioxide to preserve their golden color. Currants are seedless mini-raisins made from a specific variety of grape and are sundried for use in baking.

Based on their color, raisins are classified as dark raisins (which are dried in direct sunlight which results in a dark color), golden raisins (which are oven-dried, and then have sulfur added to preserve their color), Sultana raisins (which are brown in color), and green raisins (which are naturally green, but have sulfur added to bring out a brighter color).

VARIETIES SUITABLE FOR RAISIN PRODUCTION

Raisins are produced mainly from four varieties: Thompson seedless, Muscat, Sultana, and Black Corinth. Historically, Thompson seedless grapes have constituted 90% of the total raisin supply in the United States.

DRYING CHARACTERISTICS OF GRAPE BERRIES

Fruit Properties

Maturity, Harvesting, and Handling of Grapes for Processing

Physical (size, shape, color, and the nature of the waxy cuticle) and chemical properties (moisture content, sugar content, and acidity) of grapes at harvest have effect on the quality of raisins produced. These properties are influenced by several factors, some of which cannot be manipulated by the grower (variety and root stock, age of the vine, soil and climatic conditions), and others such as soil quality, irrigation management, nitrogen and potassium nutrition, growth regulator, pruning, and crop load, which can be altered by the grower. Some factors, like exposure to pathogens and diseases also affect the maturation and processing quality of grapes.

Gibberellins (GA_3) are commonly used during the bloom to loosen clusters and improve the quality of raisins. Peacock and Beede (2004) evaluated the effects of GA_3 application at different stages of berry development on dry down ratio, yield, and quality of raisins. They showed that bloom-time application of GA_3 improved raisin quality; the raisin and fresh weight yield were greatest when GA_3 was applied at a rate of 20 g/ha 7 days after the bloom (berry set stage).

Grape ripening is normally associated with an increase in sugars (°Brix), a decrease in acidity, and the development of characteristic color, texture, and flavor. These changes continue as long as the grapes remain on the vine, and stop after they are harvested. Such changes result in a gradual improvement until the optimum stage is reached, followed by a steady deterioration. Fresh grapes, with relatively high water contents, are very sensitive to microbial spoilage during storage; even in refrigerated storage. Therefore, they must be either consumed or processed within a few weeks following harvest. The optimum harvest maturity of grapes for

processing represents a compromise of a variety of factors, although consumer satisfaction should usually be the deciding factor (Winkler et al. 1974). Firm-ripe grapes ship and store better than either underripe or overripe ones.

The appearance of the berries, associated with the brilliance of their color and taste, help in the selection of clusters to be picked. Red and black grapes become intensely colored as ripening advances. The green color of white cultivars becomes more nearly white or yellow. The cluster stems also mature along with the berries obtaining a wood, straw, or yellow color. Owing to the absence of reserve material such as starch, which might be hydrolyzed to sugars after picking, grapes do not ripen after harvest. Thus, if the grape is not at its best in respect of maturity and quality at the time of harvest, it never will be, because all changes after harvest are deteriorative. However, appropriate postharvest handling and storage techniques can slow the rate of deterioration. While stem browning and excessive water loss can decrease quality, trimming, and careful handling improve the fruit quality.

Criteria for harvesting grapes include sugar (°Brix), acidity, pH, and sugar:acid ratio, the most important criterion being the sugar content of the grape. It is often determined as the total soluble solids using Brix refractometer or a hydrometer. Abbe's refractometer or saccharometer may also be used. While the hand refractometer is an efficient tool for judging the harvest maturity of individual clusters of table grapes, it is not recommended for use in determining the harvest maturity of wine grapes. Portable near-infrared (NIR) spectroscopy can be used to take nondestructive, accurate measurements of several chemical compounds in grapes, including sugars and acidity (Temma et al. 2002, Saranwong et al. 2003, Chauchard et al. 2004). The sugar:acid ratio is a better criterion than either sugar or acid alone for deciding the correct time of harvesting. Depending upon the cultivar and climate, acceptable sugar:acid ratio may fluctuate from 20:1 to 35:1 (Winkler et al. 1974). With an advancement in grape maturity, the acid content may drop significantly, especially in warm tropical regions, as a result of prolonged hot periods during ripening, thus, reducing fruit quality. Winkler (1954) reported a similar effect resulting from over cropping, which may delay maturation.

Weather conditions and date of harvest significantly affect drying time, with later harvests and shorter days slowing down drying by a few days (Peacock and Christensen 1998).

In the United States, grade- and standard-based maturity and berry characteristics, such as freedom from decay, visual mold, immature berries, sunburn, freezing, insect injury, and foreign material, are available for grapes used in processing and freezing. According to these standards, to be graded as US No. 1, grapes should be mature (i.e., have soluble solids of not less than 15.5% as determined by an approved refractometer), have similar varietal characteristics (skin and pulp color), and be free from defects due to decay, visible mold, immature berries, sunburn, freezing, attached insects or insect injury, and foreign materials, or any cause within the established tolerance limits (USDA 1997). However, grapes with lower maturity or fairly well maturity (soluble solids of not less than 14.5%) with defects within the tolerance limits are graded as US No. 2. However, no tolerance is provided for grapes in either standard that do not meet the maturity requirement.

Table grapes are harvested manually, while mechanical harvesters are used for grapes destined for raisin and juice production. Mechanical grape harvesters are large machines that pass over the vines and shake the grapes from their stems into collecting troughs, which are then emptied into boxes to be carried by trucks to a processing plant.

Drying Characteristics

Drying and Dehydration

Drying is probably the oldest and one of the most cost-effective methods for preserving fruits. It is a major industry in several parts of the world where grapes are grown. Drying of grapes on the vine or by open-air sun drying, shade drying, or mechanical drying produces raisins.

The grape, with an outer waxy cuticle and a pulpy material inside, is a complex product for dehydration. The outer waxy cuticle controls the moisture diffusion rates during drying. A chemical or physical treatment is generally applied to decrease skin resistance and, hence, improves moisture diffusion through the waxy cuticle (Ponting and McBean 1970). Loss of moisture from berries during air-drying is accompanied by changes in fruit structure and texture, such as fruit softening or loss of firmness, which are related to the fruit's microstructure (Bolin and Huxsoll 1987; Aguilera and Stanley 1999). Texture is an important quality criterion for raisins that are consumed after rehydration in breakfast cereals, and dairy and bakery products.

Sorption Equilibrium

The quality of dehydrated products like raisins largely depends on the water activity of the product, which in turn depends on the moisture content and temperature (Singh and Singh 1996). The adsorption and desorption isotherms demonstrate a concurrent increase in the equilibrium moisture content with increasing equilibrium relative humidity. This relationship is manifested in the form of sigmoid-shaped curves. The desorption curve identifies the type of water present in the product, and thus, provides preliminary information on the conditions driving the mass transport. The state of equilibrium resulting from multiple interactions on a microscopic scale is described by the relationship between the equilibrium water content of the product to be dried and the relative humidity of the atmosphere which surrounds it at a constant temperature. Desorption isotherms for grapes can be determined by placing the product in an atmosphere in which the relative humidity is controlled by solutions of

sulfuric acid (Azzouz et al. 2002). Environments in which the humidity is controlled can also be created using saturated solutions of various inorganic salts (LiCl, MgCl, $MgNO_3$, $NaCl_2$, and KCl), and then the equilibrium moisture contents for desorption isotherms can be determined using gravimetric method (Greenspan 1977; Suthar and Das 1997).

A number of models have been suggested to describe the relationship between equilibrium moisture content and equilibrium relative humidity (Mujumdar 1995). These have been adopted as standard equations by the American Society of Agricultural Engineers (ASAE) for the description of the moisture sorption of biological materials. Of these, the modified Henderson, modified Oswin, modified Chung-Pfost, and Guggenheim, Anderson, and de Boer (GAB) equations take into account the effects of temperature. According to the Henderson equation, the relationship can be written as follows:

$$a_w = \text{Experimental}\,(-BX_{eq}^{C}), \tag{27.1}$$

where a_w is the water activity, X_{eq} is the equilibrium moisture content on a dry basis (kg/kg), and B and C are the empirical constants. For Sultana (Turkish variety) grapes, Azzouz et al. (2002) estimated the following values for the B and C coefficients:

$$B = -0.892T - 314, \tag{27.1a}$$

$$C = -0.086T + 31, \tag{27.1b}$$

where T is the absolute temperature (K).

This relationship can be fitted to experimental curves.

Product Shrinkage

Shrinkage of tissues is a major physical change that occurs during drying of grape berries. It is recognized as an important consequence of fruit drying that has to be accounted for, since it modifies the dimension of the products, which in turn affects the mass transport phenomena (Wang and Brennan 1995; Ramos et al. 2003). Cellular shrinkage causes modifications in the global structure of grape berries and is directly related to the loss of water from cells. According to Hills and Remigereau (1997), drying results in loss of water from vacuolar compartment, with minor changes in the water content of cytoplasm or the cell wall compartments in parenchyma apple tissue. Loss of water during drying leads to loss of turgor pressure and cellular integrity (Jewell 1979).

Shrinkage of fruits also results in case hardening, a phenomenon that occurs when the drying rate is rapid. As the fruit surface dries faster than its pulp, internal stresses develop and fruit interior becomes cracked and porous. "Non-volatile compounds migrate with diffusing water, precipitate on the product's surface, and form a crust that keeps fruit dimensions thereafter." Consequently, the overall shrinkage is less when the drying velocity is higher.

Shrinkage and other changes in geometric features of cells can be quantified by image analysis (Bolin and Huxsoll 1987) using stereomicroscope (Ramos et al. 2003). These changes follow a smooth, exponential decrease over time, and a first-order kinetic model easily fits the data (Ramos et al. 2003). Cellular shrinkage, which follows an Arrhenius type of behavior increases with temperature from 20°C to 60°C. Drying conditions play an important role in determining the textural properties of raisins. "Slow drying achieved by low temperature, low air velocity, and high relative humidity produces uniform and dense products (Brennan 1994)". On the other hand, fast drying rates result in less dense, tougher products with a crust on the surface, a higher dehydration rate, and products with soft texture upon rehydration.

Azzouz et al. (2002) developed the following model to estimate shrinkage in Chasselas and Sultana varieties:

$$\text{Shrinkage} = 0.79 \times \frac{\text{Average local moisture content}}{\text{Initial moisture content}} + 0.22. \tag{27.2a}$$

Chemical Changes During Drying of Grapes

Drying either on the vine or on the ground provokes changes in the physical, chemical, and biological properties and modifies characteristics of grape berries. The moisture loss in DOV raisins occurs in a graduated, stepwise manner, with a rapid decline from an initial 86 ± 2% to 60 ± 5%, 108 days after first bloom, followed by a slower loss, and a final accelerated loss to 25 ± 4% 151 days after first flowering (Aung et al. 2004). Although the pattern of dry-matter accumulation was the same in large, medium, and small berries, the large berries contained higher levels of dry matter than the medium and small berries. Sucrose exhibited two maxima, on the 96th day and 123rd day from first bloom. A rise in sucrose levels preceded rises in sucrose, fructose, and sorbitol (Aung et al. 2004). Since sorbitol was not detected in mature berries, but was present and increased during the drying process, the authors proposed sorbitol or its biosynthetic enzyme as a useful indicator for determining raisin harvest dates. The moisture loss in untreated and pretreated grape berries is far more rapid with solar- or mechanical-drying processes than with the DOV method, but the pattern of moisture loss is the same (Di Matteo et al. 2000).

Air-Drying Kinetics

In the dehydration of grape berries by means of warm air, simultaneous heat and water (liquid and vapor) transport takes place in the pulp, in the peel (if present), and in the gaseous film surrounding the grapes. Since the duration of the thermal transient is generally far less than the duration of the drying process, mass transport occurs under isothermal conditions. In other words, the whole drying process is controlled by mass transport only (Bird et al. 1960; Peri and Riva 1984). Under the assumptions that pulp and peels (if present) are uniform and isotropic, and the grape berries are spherical, the mathematical model of grape dehydration can be reduced

to that of mass diffusion from a spherical body (Bird et al. 1960; Carslaw and Jaeger 1980). Any mathematical model that describes the diffusion of water through whole grape berries must account for its diffusion both in the pulp and in the peel (Di Matteo et al. 2000). Therefore, both processes are described by the model:

$$\frac{\partial C_i}{\partial t} = D_i \left(\frac{\partial^2 C_i}{\partial r^2} + \frac{2\partial C_i}{r\partial r} \right), \tag{27.2b}$$

where the index $i = 1$ refers to the pulp [i.e., for $r \in (0, R_1)$] and $i = 2$ to the peel [i.e., $r \in (0, R_1, R_2)$], D_1 is the water diffusivity in the grape pulp, which is much higher than that in the grape peel (D_2), C_1 the water concentration in grape pulp, C_2 the water concentration in the peel, r the distance from the grape center, and δ is the peel's thickness.

The drying curves for various values of drying conditions obtained for a single layer of grapes do not clearly indicate the existence of a first phase of drying. From the beginning of the process, the diffusion of water from the interior to the surface, where it evaporates, is limited. Diffusion becomes more difficult over time because of the shrinkage of the grapes and because of the formation of dry layers at the surface of the fruit (Diamante and Munro 1991).

Knowledge of the drying rate constant of grapes and its dependence on the conditions of the drying air is necessary to design optimal grape dryers. Several studies have been conducted to determine the drying constants for grapes under different drying conditions: at a single air temperature with two airflow rates for berries of different weights with various pretreatments (Martin and Stott 1957), taking into consideration velocity, ambient air temperature, and pretreatment of grapes on their drying time (Eissen et al. 1985), open-air sun drying and forced convective drying (Riva and Peri 1986), and microwave drying of grapes at different temperatures but one air velocity (Tulasidas et al. 1993).

Pangavhane et al. (2000) determined the drying rate constant for Thompson seedless grapes using a commercial pretreatment (cold dip) under a wide range of controlled drying air conditions (temperature, velocity, and relative humidity) normally used for commercial drying, and obtained the values of constants for empirical relations of the Arrhenius type. They described the drying behavior of grapes over time for the given conditions of the drying air with the following equation:

$$\mathrm{MR} = \frac{M - M_\mathrm{e}}{M_0 - M_\mathrm{e}} = c \exp(-kt), \tag{27.2c}$$

where MR is the moisture ratio, M is the moisture content on a percentage dry basis at time t, M_e the equilibrium moisture content on a percentage dry basis, M_0 is the initial moisture content on a percentage dry basis, c is the constant of the equation, k is the drying rate constant (per hour), and t is the time (h).

The equilibrium moisture content, M_e, for the raisin at different air temperatures and humidities can be computed using the well-known GAB equation (Singh and Singh 1996). However, this model was found to be inadequate for calculating the loss of moisture from composite materials. To describe the drying kinetics of such products, Page's equation has been shown to be better (Diamante and Munro 1991; Tulasidas et al. 1993; Doymaz 2006)

$$\mathrm{MR} = \exp(-kt^N), \tag{27.2d}$$

where N is Page's number.

The dependence of the drying constant, k or N from Page's equation, on the drying-air variables are modeled in the form of and Arrhenius-type model:

$$k \text{ or } N = \alpha_0 V^{\alpha 1} H^{\alpha 2} \mathrm{Experimental} \frac{-\alpha_3}{T_{abs}}, \tag{27.2e}$$

where α_0, α_1, α_2, and α_3 are the empirical constants of an Arrhenius-type equation, V is the airflow velocity, H is the absolute humidity, T is the air temperature, *abs* is the absolute temperature (K), and exp is the experimental value.

According to the authors listed earlier, Page's equation adequately describes the drying kinetics of a single, thin layer of Thompson seedless grapes, and the drying constant is influenced more by temperature than by the velocity or relative humidity of drying air. The experimental data fitted properly into the Arrhenius model.

In Monukka seedless grapes, Xiao et al. (2010) showed that both the drying temperature and air velocity affect the drying kinetics and quality of raisins produced under a thin-layer, air-impingement drying system. Xiao et al. (2010) found that compared to air velocity, the effects of drying temperature on drying time were more significant. They used Fick's second law to describe the drying characteristics of Monukka grapes. Using the slope of a linear plot [ln (MR) vs. time], they found that the moisture effective diffusivity (MR) changed from 1.82×10^{-10} to 5.84×10^{-10} m^2/s for temperatures between 50°C and 65°C. The drying temperature had a significant influence on D_eff and Eα was found to be 67 kj/mol. While the air hardness of dried raisins increased as the drying temperature increased, there was no relationship between air velocity and raisin hardness. Drying temperature also had a significant effect on the retention of vitamin C.

Cağlar et al. (2009) determined the thermal and moisture diffusivity of seedless grapes at a wide range of temperatures (50°C and 80°C) under infrared drying using the following equation:

$$\alpha\, \mathrm{Deff} \frac{\mathrm{d}M}{\mathrm{d}t} = a + b \cdot M + C \cdot T + d \cdot T \cdot M + e \cdot M^2 + T^2. \tag{27.3}$$

The earlier equation can be used to predict drying rates for seedless grapes without pretreatment. However, in case of pretreated seedless grapes, the equation given later was more suitable for prediction of drying rates (Cağlar et al. 2009):

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \alpha \exp(b \cdot M^c) \cdot \mathrm{d}T^e. \tag{27.4}$$

Ramos et al. (2010) developed a computer program for estimating water diffusibility parameters in a dynamic drying process with grapes. The program numerically solves Fick's second law for a sphere, by explicit finite differences in shrinking systems with anisotropic properties and changing boundary conditions. These authors used their program in a pilot-scale convective dryer with simulated air conditions observed in solar dryers. This method was found to yield very good predictions of the dynamic drying curves.

Pretreatment of Grapes Before Drying

In grape drying, the rate of moisture diffusion through the berries is controlled by the waxy cuticle of the grapes. A number of authors have reported the effects of pretreatments on drying rates and quality parameters (Bolin et al. 1975; Guadagni et al. 1975; Raouzeos and Saravacos 1986; Aguilera et al. 1987; Saravacos et al. 1988; Pala et al. 1993; Mahmutoglu et al. 1996; Tulasidas et al. 1996). Dipping in hot water, and the use of chemicals such as sulfur, caustic, and ethyl oleate (EO) or methyl oleate emulsions are some of the pretreatments that are widely used in grape drying. These chemicals facilitate the drying process by altering the structure of the waxy layer, thus reducing its resistance to water diffusion (Ponting and McBean 1970; Petrucci et al. 1973; Riva and Peri 1986; Doymaz 1998; Di Matteo et al. 2000). EO acts on grape skin by dissolving the waxy components, which offer high resistance to the transfer of moisture; however, high alkali concentrations and long dipping times can cause adverse changes in dried grapes (Saravacos et al. 1988).

The golden-bleach process is commonly used to produce light-colored (bleached) raisins in California. In this process, SO_2 is employed as a bleaching agent, which is also necessary for drying and storage to preserve the yellow color of the raisins. In the Greek process, Thompson seedless grapes are immersed in an aqueous solution containing 4.5% K_2CO_3, 0.5% Na_2CO_3, and 1% completely emulsified 0.4% olive oil for about 5 minutes. The dipped grapes are drained, and then spread on trays under direct sunlight for drying. In the soda-dip process, grapes are dipped for 2–3 seconds in a solution of 0.2–0.3% NaOH (caustic soda) at 93.3–100°C. Faint checks develop on the skins after the grapes are cooled by rinsing with cold water. Weaker sodas (Na_2CO_3 and $NaHCO_3$) are preferred to avoid the danger of over dipping. A small quantity of olive oil is often used in soda-dip process.

Raisins obtained from pretreatment with 2% dipping in oil were lighter in color, had better skin integrity, and scored the highest points for quality (41.1 of a total of 50 points) compared to those pretreated with 0.5% hot NaOH (35.7), 2.0% EO + 2.5% K_2CO_3 (39.9) and 0.4% olive oil + 7.0% K_2CO_3 (38.7), and the control (36.4). Pretreatment with 0.5% NaOH at 93.0 ± 1.0°C for 5 seconds produced raisins with a gummy or sticky surface, caused by oozing of syrup through microcracks in the skin; and pretreatment with 0.4% olive oil + 7.0% K_2CO_3 produced raisins with an oily surface (Pangavhane et al. 1999b). NaOH pretreatment adversely affected the uniformity of color, whereas 0.4% olive oil + 7.0% K_2CO_3 pretreatment imparted a reddish color to the raisins. Untreated berries produced brownish raisins.

Doymaz and Pala (2002) dipped grapes in an alkaline emulsion of EO (AEEO) and potassium carbonate (PC or K_2CO_3) solutions for 1 minute prior to drying and evaluated the effects on the drying rate and color of the raisins. Dipping time in the AEEO and PC solutions was around 1 minute under ambient conditions. The grapes were then dried in single layers in batches at temperatures ranging from 50°C to 70°C with an air velocity of 1.2 m/s. Grapes dipped in the AEEO and PC solutions exhibited shorter drying times than untreated grapes. Dipping in AEEO enhanced the drying rate to a greater extent than dipping in PC, and resulted in raisins with higher color values. The highest raisin quality was obtained with grapes pretreated with AEEO and dried at 60°C. Mixed fatty esters were prepared in the laboratory from five vegetable oils (groundnut, safflower, sunflower, cotton seed, and rice bran oil) using the Central Food Technological Research Institute (CFTRI) process, and used as dipping oil for grapes before drying. Drying rates for grapes treated with mixed fatty acid esters were longer than those obtained with the commercial dipping oil (Giridhar et al. 2000).

Doreyappa Gowda et al. (1997) evaluated 17 new grape hybrids consisting of 7 yellow seedless, 5 black seedless or soft seeded, and 5 seeded grapes, and compared them with Thompson seedless and Arkavati grapes to test their suitability for dehydration. Sensory evaluation of the dry product revealed that hybrids E-29/5, E-12/3, and E-12/7 produced raisins that were superior to Thompson seedless and were comparable to Arkavati, with distinctly lower acidity.

Vazquez et al. (1997) described a pilot-scale drying plant comprising a closed-circuit, hot-air convection chamber with a heat pump for drying grapes that were pretreated in various ways.

A novel physical treatment process to enhance the drying rate of seedless grapes has been used as an alternative to the conventional EO-dipping method in the production of raisins. This new process consists of preliminary abrasion of the grape peel using an inert abrasive material such as grapes subjected to either abrasion drying or EO-dipping pretreatments were dried in a convection oven at 50°C (with an air speed of 0.5 m/s) until the average moisture content was reduced to about 20% (w/w). Assessment of the drying rate, drying time, and microstructure of the pretreated grapes and color of the dried samples was used to compare the effectiveness of the two processes. The physical abrasion method was found to be as effective as the conventional dipping method for removing the waxy outer layer of the grapes prior to drying. Although a darker product was obtained with the physical method, it made no use of chemical additives, thus allowing production of safer raisins (Di Matteo et al. 2000).

Seedless grapes of the same clone vines subjected to the hot water and AEEO exhibited average effective moisture diffusivities that ranged from 3.34 to 8.46 $\times$ 10^{-10} m^2/s at 50°C (Esmaiili et al. 2007b). The researchers further found that the increase in the mass transfer coefficients at given moisture content at different temperatures for EO-pretreated samples was two times that for hot-water-pretreated samples during the drying. However, pretreatments had no significant effect on the thermal diffusivity of the grapes during drying.

Factors Affecting the Drying of Grapes

Weather conditions and time of harvest have the greatest influence on the sun drying of grapes, but roll type, tray type, and tray filling also have considerable influence on drying time (Peacock and Christensen 1998). Peacock and Christensen (1998) compared five tray types [(1) standard wet strength (60 $\times$ 90 cm); (2) standard wet strength, extra wide (65 $\times$ 85 cm); (3) polycoated; (4) polycoated with venting; and (5) extra wide with surface sizing] for drying rates over a 16-day period. There were minor differences in the drying rates among the five tray types: raisins in polyvented and extra-wide trays with surface sizing were slightly drier during the last 4 days of drying as compared to those in the standard wet strength and standard wet strength extra-wide trays. Grape berries in flop and cigarette rolls lost about 1.2% of their moisture per day compared to 0.8% for those on biscuit rolls. Similarly, filling with 8.2 kg or less in standard wet strength trays (60 $\times$ 90 cm) reduces the drying time.

Fouskaki et al. (2003) developed a method based on a commercially available water sensor and probe for fast (<5 minutes) and accurate (better than 0.5% error in water content) measurement of water in Sultana raisins without the need for sample weighing.

DRYING TECHNOLOGY

Drying is a simple, widespread processing technology. It involves heat transfer to the product from heating sources and mass transfer of moisture from the interior of the product to its surface and, subsequently, to the surrounding air (Ekechukwu and Norton 1999). Thermal drying, which is the most common method of drying agricultural produce, involves vaporization of the moisture within the product by heat and its subsequent evaporation from the product. Thus, thermal drying involves simultaneous heat and mass transfer (Ekechukwu 1999).

Raisin quality, to a large extent, depends on the drying technology used. Natural drying in sunlight is age old, and the most common and successfully employed drying method practiced in many grape-producing countries (Pangavhane and Sawhney 2002; Fadhel et al. 2005; Li et al. 2009). In this method, bunches of grapes are spread in a thin layer on either the ground or a platform and are directly exposed to the sun until the moisture level in the product is reduced to around 14%. The main methods of natural drying are open-air sun drying without a cover, open-air sun drying with a cover, and natural rack drying. These methods are simple and involve a relatively small capital investment, but they require large areas, involve high labor costs, and take approximately 15–20 days to attain the desired level of moisture in the end product (Basunia and Abe 2001; Doymaz 2006; Jairaj et al. 2009). Furthermore, the final product may be contaminated by dust, stones, leaves, and insects that are hard to remove (Winkler et al. 1974). The exposure to solar radiation also causes the color to deteriorate and raisins produced using these methods rarely meet market requirements (Andritsos et al. 2003). Therefore, traditional sun-drying techniques have now been replaced by industrial drying methods such as hot-air mechanical and solar drying (Ertekin and Yaldiz 2004). The industrial drying methods have also greatly improved the quality of the raisins produced.

Azzouz et al. (2002) evaluated the drying kinetics and moisture diffusivity of convective drying of grapes. Ramos et al. (2004) studied the microstructural changes of grapes during hot-air drying. Fadhel et al. (2005) compared three sun-drying processes and found that solar-tunnel greenhouse drying was the most satisfactory and competitive compared to the natural convection solar-drying process. Bennamoun and Belhamri (2006) investigated the drying kinetics of grapes undergoing solar drying and Esmaiili et al. (2007b) determined the thin-layer drying characteristics of seedless grapes when they were processed using a tray dryer. Margaris and Ghiaus (2007) studied experimentally the hot-air drying characteristics of Sultana grapes.

Introduction of solar dryers can reduce the cost of drying and improve the quality of dried products significantly when compared to traditional methods of drying. In solar dryers, the air is heated by solar energy, as either the sole source or as a supplemental source of energy (Ekechukwu and Norton, 1999). Solar dryers used for the drying of grapes have been broadly classified into (1) direct solar dryers (i.e., grapes are exposed directly to solar radiation or a combination of direct and reflected solar radiation); (2) indirect solar dryers (i.e., air heated by solar energy is passed over grapes spread on a platform or racks); and (3) mixed solar dyer (i.e., grapes are exposed to direct solar radiation and hot air is allowed to flow through them). In indirect solar dryers, air heated by solar radiation can be allowed to circulate through the grapes naturally by buoyant force, as a result of wind pressure, or a combination of the two. Alternatively, a motorized pump and fan can be used to force the heated air to circulate through the grapes.

Various types of solar dryers are employed for drying grapes including direct solar dryers, solar cabinet dryers, staircase solar dryers, glass roof solar dryers, indirect solar dryers, natural circulation dryers, natural conventional dryers, natural convection dryers with chimneys, multipurpose

natural convection dryers, solar dryers with greenhouses as collectors, solar-tunnel dryers with integral collectors, solar air flat-plate collectors with obstacles, multiple-layer solar batch dryers, hybrid solar dryers, and hybrid photovoltaic-thermal greenhouse dryers (Barnwal and Tiwari 2008; Jairaj et al. 2009). Jairaj et al. (2009) compared the various methods used in direct, indirect, and mixed solar dryers with respect to drying time and the quality of the end product. Some researchers have used solar dryers (tunnel greenhouse, indirect convection, and indirect natural convection dryers with storage) to dry untreated grapes (Fuller and Charters 1997; El-Sebaii et al. 2002).

Rack-type solar dryers (shade drying) are used extensively for drying Sultana grapes in Australia and Thompson seedless grapes in India. This is the simplest and most effective type of solar dryer. In this structure, untreated Sultana grapes are dried to a moisture content of about 14% (wet basis) within 10–14 days. In Afghanistan, greenish-colored (amber) raisins with a smooth surface and good texture are produced in special drying houses called *soyagi-hana*. According to Grnacarevic (1969), pretreated grapes shrivel to a certain extent and retain their greenish color within 4 days.

Several types of solar dryers have been tested for grape drying, including solar cabinet dryers (Sharma et al. 1986, 1992), glass roof solar dryers (Nair and Bongirwar 1994), solar dryers with natural ventilation (Sharma et al. 1986), indirect solar dryers (Sharma et al. 1993), multiple-layer solar batch dryers (Eissen et al. 1985), solar dryers with greenhouses as collectors (Fohr and Arnaud 1992), solar-tunnel dryers integral collector (Eissen et al. 1985; Lutz et al. 1987; El-Shiatry et al. 1991), hybrid solar dryers (Tsamparlis 1990), and multipurpose natural convection solar dryers (Pangavhane et al. 1999a, 1999b; Pangavhane 2000). Since drying time and inside temperatures vary considerably in these dryers, the quality of the raisins produced also differs. Solar dryers dehydrate grapes (reducing the moisture content from 34.9% to 17% on a dry weight basis) within 4 days compared to 15 days in shade drying and 7 days in open-air sun drying (Pangavhane and Sawhney 2001).

Freezer and microwave vacuum dehydration have also been tried to minimize the compositional changes in grape berries during the drying process (King 1973; Tulasidas et al. 1993, 1997; Clary and Sawyer Ostrom 1995). Tulasidas et al. (1993) produced Thompson seedless raisins using combined convective and microwave drying in a single-mode, cavity-type applicator at 2450 mHz with varying air temperature, microwave power, density, and superficial air velocity.

Since commercial sun drying of raisins requires a long time (2–4 weeks) and chemical pretreatments are required to enhance the drying rate, Kostaropoulos and Saravacos (1995) assessed the feasibility of improving the sun-drying process for grapes using microwaves. Sultana seedless grapes dipped in an alkaline solution (2.5% K_2CO_3 + 0.5% olive oil) to increase water-permeability of the grape skin were pretreated in a domestic microwave oven and dried by direct solar radiation. Microwave pretreatment reduced the moisture by 10–20% and those grapes dried nearly two times faster than the controls. Blanching in boiling water had the same effect on the drying rate as microwaves. The color and appearance of grapes so treated were comparable to those of commercial products. That study concluded that microwave-pretreated grapes had improved color after drying, due to a reduction in enzymatic browning as enzymes are partially inactivated by the absorption of microwave energy.

Çakmak and Yildiz (2009) developed a new type of air solar collector for drying. Drying in this collector with a swirl flow was uniform, with products reaching the desired moisture level more rapidly. A drying period of 200 hours under natural conditions was reduced to 80 hours with the developed dryer having a swirl-flow element and an air velocity of 1.5 m/s. Air velocity was found to have a greater influence on drying period than air temperature. Drying seeded grapes, with advanced drying techniques will improve their quality and provide conformity with standards.

McLellan et al. (1995) studied the effects of honey as an antibrowning agent to produce light golden raisins without the addition of SO_2 and found that raisins produced using honey without the addition of SO_2 were ranked highest by each of 18 panelists. The results were based on Friedman rank analysis.

Air-impingement drying technology has been successfully used in the paper and textile industries. In this method, the air impinges on the product surface at high velocity, removes the thermal boundary layers, and increases the rate of heat transfer (Anderson and Singh 2006). The heat transfer coefficient was found to be about five times higher than that with cross-circulation dryers (Seyedein et al. 1995). This greatly accelerates the drying rate and reduces the drying time. However, to date, only a few studies have been conducted on air-impingement drying characteristics and the quality of the dried grapes (Yang et al. 2009).

Texture and nutrition are the important components of raisin quality (Esmaiili et al. 2007a). Apart from the variety and growing conditions, the texture and nutritional value of grape and raisins are mainly influenced by drying conditions (Mahmutoglu et al. 1996). Undesirable changes in the texture and nutrition of raisins decrease its quality and marketing value. Usually, if the texture of dried grapes is softer, the quality is better. In hot-air drying, the nutritional quality of the product can be adversely affected by the high temperature and long drying time. Vitamin C has been shown to be a valid indicator of the nutritional quality of Monukka seedless grapes (Lin et al. 1998).

Drying practices for grapes are largely traditional and vary with the variety and geographical location. Certain grapes, such as currants (Zante Black Corinth currants), are usually dried without any preliminary treatment. The DOV method may be used to dry the clusters of Zante Black Corinth grapes. Such DOV currants are more attractive than those dried on trays. California raisins are called loose Muscats if the seeds

are removed. In Spain and Australia, raisins are sold as either Valencia or Lexia, the latter being a rack-dried product. The Sultana is a light-colored, tender raisin made from Thompson seedless grapes, prepared by various processes other than natural sun drying in California.

QUALITY OF RAISINS

Several factors affect the quality of raisins, including the size of the berries; hue, uniformity, and brilliance of the color; condition of the berry surface; texture of the skin and pulp; moisture content; chemical composition; presence of decay (rot), mold, yeast, and foreign matter; insect infestation; and drying time and conditions during the drying process.

Winkler et al. (1974) developed criteria for determining the quality of raisins. Color, taste, and texture are the main attributes for estimating the quality and consumer acceptance of raisins, as judged by sensory evaluation on a 9-point hedonic scale (Guadagni et al. 1978; Ranganna 1986). According to Sharma and Adulse (2007), good-quality raisins should have the following features:

- Good, uniform appearance in terms of color, size, and smoothness.
- Higher pulp content and pleasing taste without any sugar coating.
- Intact skin with the outer layers free of injury, dust and foreign matter.

Chemical Composition

Grapes and raisins are essentially the same fruit, as raisins are dehydrated grapes. The dehydration process induces certain compositional changes at the molecular level, specifically in total proteins, type of carbohydrates, and enzymes such as polyphenoloxidase (Krueger et al. 2003). Raisins have been found to contain hexose furanose, whereas grapes have pentose furanose. Raisins also contain higher levels of total proteins than grapes. The enzyme, polyphenoloxidase, which is present in grapes, does not occur in raisins. One hundred grams of raisins contains 15.4 g of water, 3.3 g of protein, 0.4 g of lipids, 79.2 g of carbohydrates including fiber (5.3 g), 1.8 g of ash, 49.0 mg of calcium, 0.31 mg of copper, 2.08 mg of iron, 33.0 mg of magnesium, 0.31 mg of manganese, 97.0 mg of phosphorus, 751.0 mg of potassium, 12.0 mg of sodium, 0.27 mg of zinc, 3.3 mg of ascorbic acid, 0.16 mg of thiamin, 0.09 mg of riboflavin, 0.82 mg of niacin, 0.25 mg of vitamin B_6, 3.3 μg of folacin, 8.0 IU of vitamin A, 0.70 mg of vitamin E, 4.0 μg of biotin, and 0.05 mg of pantothenic acid (California Raisin Marketing Board 2004).

Nutritional Contribution

Based on a 2000-calorie daily diet, 40 g (1/4 cup) of raisins provides 125 kcal of energy and provides 9% of the potassium, 10% of the carbohydrate, 8% of the dietary fiber, 2% of the calcium, 6% of the iron, and less than 2% of the vitamin A required daily. The addition of raisins to beef jerky lowered the amount of fat in the jerky, and increased the antioxidants and fiber in the product (Mercola 2003).

Grapes and grape products are rich in phenolic compounds, which have demonstrated a wide range of positive biochemical and pharmacological effects on the body; they are anticarcinogenic, antiatherogenic, antiinflammatory, antimicrobial, and antioxidant. Based on total phenols per serving, Karakaya et al. (2004) categorized solid foods in the order of red grapes > raisins > tarhana > dried black plums > dried apricots > grapes > fresh paprika > fresh black plums > *Utrica* sp. > cherries > fresh apricots > paprika pickles > paprika pastes. They also found a high degree of correlation between total phenols and total antioxidant activity ($r^2 = 0.95$). Therefore, regular consumption of grape products would have long-term health benefits. Specifically, raisins have been found to minimize risks of heart disease, colon cancer, and intestinal tumors. Consumption of sun-dried raisin has been found to increase fecal weight and short-chain fatty acid excretion, and decrease fecal bile acids in healthy adults (Gene et al. 2004) in a way that has health benefits.

PACKAGING, HANDLING, AND STORAGE OF RAISINS

Raisins may be stored at room temperature for a few months without noticeable loss of color or flavor. Their stability at room temperature will depend on the moisture levels in the raisins and the relative humidity of the atmosphere. If the temperature exceeds 10°C, the relative humidity should be kept below 55%. In addition, precautions against insect damage are necessary. The optimum relative humidity for storage of raisins is between 45% and 55%. However, raisins can be stored indefinitely in the refrigerator. It is important to provide natural ventilation of air around raisins to avoid condensation, especially when they are stored at higher temperatures and high relative humidity.

A moisture content of up to 18% has been shown to reduce friction in Sultana raisins, but increased that of Zante Black Corinth raisins (Kostaropoulos et al. 1997). Similarly, anti-sticking substances reduced the friction, but increased the stick-slip effects. Similarly, loss of sugar increased the friction of raisins.

Methyl bromide is widely used as a fumigant for dried fruits, including Sultanas and raisins (Hilton and Banks 1997). Johnson et al. (2003) proposed a treatment strategy combining initial disinfestation treatment using low levels of oxygen (0.4%) with protective treatments (storage at 10°C, storage in controlled atmosphere with 5% oxygen or application of Indian meal moth granulosis virus) as alternatives to chemical fumigation to control postharvest insect populations in raisins.

Femenia et al. (1999) studied the effects of temperature on the cell walls of raisin tissue during modified (controlled) atmospheric storage. Raisins obtained from seedless grapes (var. Flame) were stored in a modified atmosphere (60% CO_2 and 40% N_2), at 10°C, 20°C, 30°C, and 40°C. Based on changes in color and cell wall components, it was concluded that the combined use of relatively low temperature and a modified atmosphere helped to preserve raisin color and maintain their cell wall materials at values similar to their initial concentrations.

Aspergillus niger and *Zygosaccharomyces rouxii* are the dominant contaminants of Moroccan raisins. El-Halouat et al. (1998) examined the effects of modified atmosphere and certain antifungal preservatives on the growth of *A. niger* and *Z. rouxii* on high-moisture raisins. A combination of modified atmosphere (40 or 80% CO_2) and either 383/321 ppm sodium benzoate or 417/343 ppm potassium sorbate (for prunes and raisins, respectively) was found to be sufficient to inhibit microbial growth and extend the shelf life for 6 months.

Cabras and Angioni (2000) reviewed data on pesticide residues in grapes and their behavior during grape processing, focusing on research carried out in the 1990s. The individual aspects considered included residues on grapes (fungicides and insecticides), residues on raisins, pesticide residues and fermentative microflora, effect of wine making on residues, wine clarification, and pesticide residues in other alcoholic beverages produced from wine and wine by-products.

FOOD APPLICATIONS OF RAISINS

A new product, baking raisins (BR), which does not require conditioning at the bakery, was described by Bruno (1996). These raisins have uniform moisture content and approximately 8.3% more sugars than conventional raisins. BR are packed in airtight bags with reduced O_2 levels to avoid fermentative changes during storage. BR could be stored in this way under ambient conditions for up to 1 year. Baked products containing BR exhibited a longer shelf life and improved texture.

Fruit anthocyanins provide color and health benefits, and addition of these pigments to breakfast cereals can improve their functional values. The stability and acceptability of anthocyanins from blueberries and Concord grape juice concentrate were tested in a model corn-based breakfast cereal. The overall acceptability was higher for the syrup and grape cereals, sweetness and flavor acceptability being correlated with overall acceptability (Camire et al. 2002).

Raisins have been used as a valuable ingredient in bread and other bakery products. Toops (2002) described these aspects with reference to the healthy image of raisins; consumer demand for healthier bakery products containing natural ingredients; the high levels of natural propionic acid preservatives in raisins; the role of raisins in enhancing the flavor, visual appeal, and shelf life of bakery products; the manufacture of raisin bread; the incorporation of raisin products (e.g., juice concentrate, syrup, and pastes) into other breads; and the role of raisin conditioning in the production of high-quality bakery products.

Processors make raisin juice and raisin paste from part of the crop. To do this, raisins are leached with water to produce a pure extract, which is then evaporated under vacuum to produce a self-preserving concentrate. Raisin juice concentrate contains 70% natural fruit-soluble solids. It is added to a number of foods including dairy, confectionery, and bakery items. It is a natural substitute for preservatives, and it sweetens and colors baked goods naturally. It is also a sugar substitute for confectionery items, and filling for hard candies and molded chocolates. In cookies and crackers, raisin juice helps control breakage and maintains moisture. It is also used as a binding agent for cereal bars. It enhances color and flavor in ice cream and chocolate milk.

Raisin paste is made from 100% raisins by extruding them through fine mesh screens. It is added for visual appeal and flavor in sundae-style yogurt and cottage cheese as well as in frozen novelties and soft-centered candies. It is a stable ingredient that sweetens naturally.

Raisins may soon become an alternative to sodium nitrite, a preservative commonly used in processed meat such as beef jerky. Addition of raisins to beef jerky lowers the amount of fat while providing additional benefits like antioxidant properties, fiber supplementation, sodium reduction, and checking microbial growth as well as reducing incidence of the taste of the jerky being "off."

FUTURE RESEARCH NEEDS

The heated air used to dehydrate grapes induces compositional changes including polyphenoloxidase activity, which changes the color of fresh grapes from light green to dark brown, and then to the purple–black color of the dehydrated product. Sulfur dioxide is used to preserve the color. Since the use of excess sulfur dioxide may cause allergic reactions, alternatives to sulfur dioxide fumigation are being attempted. Researchers are evaluating a variety of drying techniques, such as liquid media dehydration and treating raisins with honey to prevent changes in color.

More research is necessary to further refine and optimize the drying process and prevent undesirable changes in the color, flavor, and composition of raisins. As in other crops, organically produced grapes and raisins have become a leading commodity. Thus, there is a need to develop production practices and certification standards for organic raisins.

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28
Wine Technology

Maite Novo, Manuel Quirós, Pilar Morales, and Ramón González

Abstract: Wine fermentation has been known and practiced by mankind since prehistoric times, long before the underlying microbiological and physiological principles were understood. The present chapter aims to give a general overview of the global winemaking process, focusing on diverse aspects that encompass from grapevine management to the differential technical procedures involved in the production of red, rosé, white, and sparkling wines. Special attention has been paid to the microbial ecology of wine fermentation, where the role and main features of different yeast species (including *Saccharomyces cerevisiae*) and lactic acid bacteria has been extensively approached. The last part of the chapter aims to provide detailed useful information regarding wine faults and their sensorial descriptors. Evidences both on their microbiological or chemical origin and the strategies commonly used in the wine industry for their avoidance have been carefully addressed.

INTRODUCTION

Alcoholic fermentation is considered the oldest biotechnological application of microorganisms (Samuel 1996). The earliest molecular archaeological evidence for large-scale wine production were found, inside pottery residues, in a Neolithic settlement located at Hajji Firuz Tepe, in the northern

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Zagros Mountains (Iran), dated between 5400 and 5000 BC (McGovern et al. 1986). *Saccharomyces cerevisiae*, the yeast species responsible for wine fermentation, has been found in lees inside 3000–5000 years old wine jars (McGovern et al. 1986; Cavalieri et al. 2003).

Winemaking requires the management of several biological species with the three main players being grapevine *Vitis vinifera*, the ascomycetous yeast *S. cerevisiae*, and the lactic acid bacterial species *Oenococcus oeni*. It requires control of interactions between these species and the products resulting from their metabolism (must, metabolic products and by-products), their interactions with other species in the vineyard or the cellar environment, and the control of the physicochemical conditions (temperature, nutrient availability, antimicrobials, etc.) in the cellar. This chapter describes the processing of grapes for wine production with special emphasis on useful and spoilage microorganisms. It also discusses technological aspects from grape harvesting to wine bottling.

GRAPEVINE PRODUCTION

Suitable grapes are indispensable to successful winemaking. The main biotic factor affecting grape production is the vine louse *Phylloxera vastatrix* (the devastator). Although commonly known as *Phylloxera*, its current accepted name is *Daktulosphaira vitifoliae*.

Phylloxera original hosts are the American vines, more precisely those wild vines native to the temperate eastern and southern parts of North America. Millenia of coevolution with this insect have made roots of these species of wild vine able to withstand the damaged caused by the insect. Therefore, grafting scions from *V. vinifera* on rootstocks from wild species enables tolerance to this pest and allows grape production for winemaking. The same scion variety grown on different rootstocks in different soils will present differences in vigor, yield and fruit quality, even though the fruit remains that of the *V. vinifera* variety (Skelton 2007).

The climate is probably the main permanent factor that determines vine development. The vine plant is demanding in heat and sensitive to winter and spring frosts, not just for its vegetative development but also for fruit maturation, which requires light and suitably high temperatures.

Viticulture has traditionally been developed in regions around the world characterized by nonextreme or Mediterranean-type climates. These regions are located between parallel 30° and 50° of north latitude and between 30° and 40° of south latitude. Nowadays, these regions have been extended with the addition of the so-called *tropical viticulture* (Hidalgo 1999).

Since the domestication of wild grapes 6000 years ago, numerous cultivars have been generated by spontaneous or deliberate crosses, and up to 10,000 are still in existence today (Vouillamoz and Grando 2006). Until recently, genetic relationships between cultivars were mainly deduced from leaf morphology (Levadoux 1956; Bouquet 1982; Bisson 1999), and the origins of grape cultivars have been the subject of much speculation. The advent of PCR-based microsatellite markers in the 1990s revolutionized grape cultivar identification and parentage analysis (Sefc et al. 2001). For instance, parentage analyses using 30-polymorphic microsatellites allowed the identification of the parents of a traditional cultivar for the first time: "Cabernet Sauvignon," the noble Bordeaux variety that gives some of the world's finest wines, was shown to be a progeny of two other Bordeaux cultivars, "Cabernet Franc" and "Sauvignon Blanc" (Bowers and Meredith 1997).

What variety should be planted in a specific vineyard depends on many biological, climatic, and economical factors. Indeed, optimization of grape quality with appropriate management of the inherent variability of crops has been one major aim of winegrowers. In this respect, a new concept, called Precision Viticulture (PV), was developed during the last decade; the aim was to differentiate between zones of different quality within the same parcel. PV is beginning to have an impact on the wine-growing sector, not only in Australia, Argentina, Chile, South Africa, or United States but also in European countries (Spain, France, and Portugal in particular) (Arnó et al. 2009). The most relevant aspects that PV takes into consideration include efficient use of inputs, differentiation of various grape qualities at grape harvest time, yield prediction, and greater precision and efficiency of samplings conducted at parcel level (Bramley 2001; Bramley and Lamb 2003; Martínez-Casanovas and Bordes 2005).

Determining the optimal time for grape harvest (vintage) is one of the key aspects in wine production. Grape ripening is a key phase for determining the quality of wine grapes, as it immediately precedes harvesting.

The first step of maturation is known as "veraison," and is related to the onset of skin color-change in red cultivars due to accumulation of anthocyanin pigments. This pigment accumulation continues throughout the ripening period. Besides color development, ripening is associated with softening, increase in grape size, and cell expansion resulting in water and sugar accumulation in the mesocarp cell vacuoles (Kanellis and Roubelakis-Angelakis 1993; Coombe and McCarthy 2000). High sugar content, weight of berries, lower acidity, rich color (anthocyanin), and full varietal fruitiness are the main criteria for harvesting the ripe fruit (Boulton et al. 1998).

According to technological maturity, harvest time must also take into account the type of wine to be produced (Hidalgo 1999). In general, *sparkling wine* grapes are harvested first, to ensure lower sugar levels and higher acidity. Next, most of the *white wine* grapes make their way to crush. *Red wine grapes* are typically next in the harvest line, as they take longer to reach full maturation. This will influence the accumulation of anthocyanins in the berry skin and the composition of stems and seeds. However, the appropriate degree

of ripeness depends on the desired winemaking style. Finally, grapes used in the production of ice wines and late-harvest wines are ready to be harvested after undergoing some dehydration on the vine, this resulting in a raisin-like grape with highly concentrated sugars, perfect for dessert wines.

In order to monitor ripening evolution and to determine the optimum moment for the harvest, a random sampling of grape berries is performed. Determination of berry weight, pH, total acidity, density of the must, and phenolic compounds in red varieties (anthocyanins and total amount of polyphenols) are the parameters employed for decision-making. Once the time to harvest is chosen, two main objectives must be pursued during grape picking: getting the highest amount of safe and complete grapes as possible and having them transported to the winery as quickly as possible.

Two kinds of harvesting methodologies can be performed: manual and mechanical harvesting. Manual harvesting has some advantages over mechanical harvesting, especially for thin-skinned cultivars that break open easily. It also allows the selection of the grapes on the vine that can be picked, thus it is a more selective harvesting procedure. However, manual harvesting is slower than mechanical harvesting and it is normally stopped during inclement weather. It is also less cost-effective. Mechanical harvesters apply a mechanical force to one or more parts of the vine, inducing a rapid and abrupt swinging that detaches the berries or fruit clusters (Jackson 2008). This operation allows a rapid collection and transport of grapes to the winery for processing. In addition, mechanical harvesting can be performed during the night, minimizing grape heating and microbial development on berry surfaces in contact with juice released during harvesting.

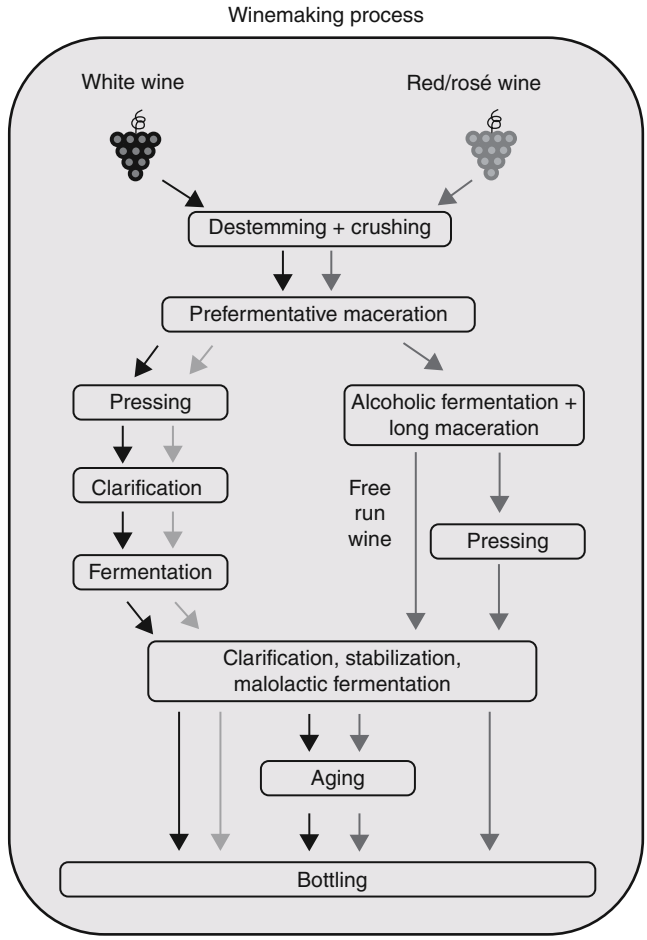

Figure 28.1. Outline of white, rosé, and red winemaking processes. Lines represent the different steps of the winemaking process. Green lines refer to white wine production, red to rosé, and purple to red wine production.

WINEMAKING TECHNOLOGY

Different enological practices applied in winemaking play a role on the final quality of wines. Among others, they include mechanical and chemical procedures such as destemming, grape pressing, clarification, and filtration of the final product. These practices cause a modification of the wine composition and thus influence its organoleptic properties, clearly affecting its flavor and color. Though very different in these properties, white, rosé, and red wines share some common steps in their production processes. These steps (Fig. 28.1) will be tackled in depth in the following sections.

Prefermentative Processes

Destemming and Crushing

Upon arrival of grapes at the winery, the stems are removed from the berries in a process called destemming. The destemmer removes the fruit with a minimal rupture of the grape skin. Depending on the ripeness of the stems, the winemaker will choose the amount of stems, if any, to be included in fermentation. When green, stems can impart vegetal notes and accentuate bitter tannins. However, when used correctly, stems can add complexity to some wine styles. Associated to this first procedure, we usually find crushing of grape berries. During crushing, breakage of the berries allows the release of some grape juice from the pulp and the opening of the skin. These two phenomena are very important because they allow the contact between the free juice and the inner face of the skin, which results in an increase of the extraction of skin compounds, leading to increased concentration of polyphenols and molecules responsible for the wine aroma (Flanzy 2003).

Cold Maceration

A prefermentation process, which has been spread out in many producing areas, is prefermentative skin contact, also

known as cold maceration. During this treatment, must is held for several days at low temperatures (usually between 10°C and 15°C) prior to fermentation. Skin contact technique is able to improve the quality of wines due to both an increase of the flavor extraction from the skins and a greater extraction of phenolic compounds (Gómez-Míguez et al. 2007). Grapes must be sufficiently ripe because skins of unripe grapes can increase the herbaceous character of the wine, mainly due to an excessive amount of C-6 compounds (Ferreira et al. 1995).

Rosé wines are made from red grapes exposed to a short prefermentative maceration. Grapes are crushed or gently broken, and the juice left on maceration at cool temperatures until enough color has been extracted (generally between 12 and 24 hours). The free-run juice is subsequently drawn off and fermented similarly to that of a white wine (Jackson 2008).

In red wine production, this technique is also designed to improve the extraction of pigments from grape skins to the wine. Nevertheless, it is important to point out that color extraction by cold maceration is only effective in the presence of SO_2 (Feuillat 1996; Heatherbell et al. 1996).

Anthocyanins and tannins are the compounds most directly responsible for the color in red wine. Anthocyanins are soluble in water and are dissolved from the moment maceration begins, whereas tannins are more soluble in alcohol. So, their extraction depends on the performance of the fermentation (González-Neves et al. 2004). Another alternative technique to increase color extraction before fermentation consists of freezing the mixture of grapes and must. The freezing of must leads to the breakage of cell membranes and the release of anthocyanins. The use of solid carbon dioxide confers an additional advantage. While it freezes the berries, it sublimes and blankets the must, creating a layer that protects the berries from oxygen before fermentation (Sacchi et al. 2005).

Flash Release

Another technique to increase the polyphenol content in red wines is flash release (FR). This technique consists of a quick heating of the grapes at atmospheric pressure (>95°C) followed by a strong vacuum, which causes an instant vaporization. This vaporization induces an increase of the cell wall fragility and a cooling of the treated grapes (Mountounet and Escudier 2000). FR treatment results in a faster extraction of all classes of phenolic compounds, although their concentration drastically decreases throughout fermentation when pressing is achieved immediately after FR (Morel-Salmi et al. 2006).

Pressing

Grapes used in the production of rosé wine are pressed prior to fermentation, while those used for the production of red wine are pressed after fermentation and a prolonged maceration take place. The pressing systems can be: continuous, horizontal, vertical, and pneumatic presses. However, a relevant issue during pressing is the possibility to fraction the must in the different cycles of pressing. Because the free- and press-run fractions obtained during pressing possess different physicochemical properties, winemakers can use press design to influence wine character. Free-run fractions are clearer and possess lower levels of suspended solids, phenolic content, and flavorants derived from the skins. Subsequent press-run fractions contain increasing amounts of suspended solids, anthocyanins, tannins, and skin flavorants. These fractions are more prone to oxidation (possess more polyphenol oxidase), possess lower acidity (higher potassium contents), and have higher concentrations of polysaccharides, gums, and soluble proteins. Most wines are a judicious blending of both free- and the first press-run fractions. Depending on the intentions of the winemaker and the characteristics of the grapes, a portion of the second and possibly third pressing may also be incorporated (Jackson 2008).

"Pumping-Over" and "Rack and Return"

Phenolic compounds are an important group of molecules that are responsible for major red wine sensorial characteristics such as color, astringency, and suitability for aging. Anthocyanins, flavanols and their polymers, and polymeric pigments resulting from the reaction of anthocyanins with polymeric flavanols are the phenolic compounds having the greatest sensory impact in red wines. While anthocyanins and polymeric pigments give red wines their color, flavanols and their polymers are responsible for bitterness. The polymeric flavanols are also referred to as tannins. Although phenolic compounds are present in grape juice, their amount is increased along wine fermentation because of their greater solubility in ethanol than in aqueous solution. Anthocyanin extraction reaches a maximum early in fermentation whereas tannin extraction continues to increase with continued skin and seed contact (Sacchi et al. 2005).

Many winemaking techniques have been developed to enhance the extraction of these compounds during winemaking. During fermentation, due to the CO_2 production, all solid parts of grapes (skins and seeds) are pushed up to the top of the tank, leading to the formation of a cap (Fig. 28.2), which hampers the extraction of phenolic compounds. However, different techniques, such as pumping-over and rack and return, have been developed in order to solve this handicap.

Pumping-over is achieved by pumping the fermenting wine over the cap in the same tank. Must/wine from the bottom part of the tank is pumped to the surface, where cap has been formed (Fig. 28.2). Cap is broken up by hosing it down with the must, increasing the liquid/grape contact.

The "rack and return" technique, also known as *délestage*, originated in the French producing area of Côte du Rhône though it is nowadays used in wineries all over the world,

Figure 28.2. View of a cap during the fermentation of red wine, and hose used for pumping-over. © Museo de la Cultura del Vino Dinastía Vivanco.

especially in Anglo-Saxon wine-producing countries (Zamora 2005). This procedure mainly consists of the total drainage of the tank to a new container once the cap of solid parts of grapes has been formed. After 2–3 hours, the must/wine is returned to the original tank, falling in from the top while spraying and breaking down the cap. Rack and return is not only interesting to improve extraction of phenolic compounds but also allows the controlled elimination of seeds, which is really interesting when grapes are not ripe enough. Specifically, the elimination of seeds considerably decreases the body, astringency, and bitterness of the wines, while the addition of seeds increases their body and astringency (Canals et al. 2008). In addition, the aeration caused by racking from one tank to another contributes to wine yeast survival and metabolism during fermentation.

Clarification

White must is typically clarified before fermentation to favor the retention of its fruity character. Fruitiness may be masked by the excessive production of fusel alcohols, associated with juice containing high levels of suspended solids. Studies of juice on white wine quality indicate that wines prepared from clarified juice present a higher quality (Williams et al. 1978), with higher ethylic esters and fusel alcohols acetates levels and less fusel alcohols levels (Kechagia et al. 2008). Although large amounts of suspended solids are generally undesirable, excessive clarification is equally inappropriate. Filtration and centrifugation can remove more than 90% of the fatty acids from must (Bertrand and Miele 1984), as well as much of its sterol content (Delfini et al. 1993). This fact can seriously affect the later development of yeast and lactic acid bacteria (LAB). White juice is commonly allowed to settle spontaneously for several hours (12 hours) before racking. Bentonite or potassium caseinate may be added to facilitate settling and subsequent protein stability. When used, bentonite is commonly added after an initial period of spontaneous settling. This minimizes the production of voluminous loose sediment and the associated loss of juice (Jackson 2008).

Clarification can also be accelerated by centrifugation. By removing only suspended particles, centrifugation has minimal impact on the chemical composition of the juice as compared to other commonly used clarification techniques. Although the equipment used in centrifugation is expensive, minimal juice loss and speed have made it particularly popular. In contrast, an alternative technique as vacuum filtration tends to remove solids excessively, resulting in longer fermentation times and higher volatile acidity (Ferrando et al. 1998). Filtration with diatomaceous earth can also be used to promote prefermentative clarification.

Control of Oxidation

The control of must oxidation, caused by the dilution of oxygen air, is another relevant aspect in order to obtain quality wines. The evolution of winemaking technology has allowed a continuous grape protection from undesirable oxidations by several SO_2 additions through all the steps of winemaking process: harvest transport, grape reception, and pressing. This spread addition all along the process optimizes the blockage of the oxidation reaction chains in the must. For instance, in the case of grapes attacked by *Botrytis cinerea,* the addition of 8 g/hL of SO_2 in three or four steps limits the earthy flavor, consequence of the action of this mould grape infection (Flanzy 2003). The second aspect of the application of SO_2 is the inhibition of microbial activity, which allows the control of the fermentation start-up and the possibility to perform natural clarification.

Enzymes in Winemaking

Winemakers use enzyme in order to improve: (a) juice yields; (b) filtration and clarification of must and wine; (c) extraction of aroma precursors as well as phenolic compounds responsible for the color of red wines; (d) release of aroma compounds from their glycosylated precursors; (e) release of yeast compounds; and (f) to obtain microbial stability (http://www.oiv.int/uk/accueil/). One common feature of the preparations of commercial enzymes used in the food industry, including winemaking, is that they are usually partially purified enzyme extracts obtained from the culture medium of microorganisms, grown under inducing conditions. Because of the composition of the raw materials typically used to prepare food-grade enzymes, and the nonexhaustive downstream purification procedures, most of these preparations carry detectable or even important amounts of other

enzymatic activities. Some of them might be desirable or synergic for the intended application, while other side activities would be eventually detrimental to the quality of wine (van Rensburg and Pretorius 2000). The bulk of these commercial preparations are pectinases produced by filamentous fungi. Indeed, pectic enzymes were the first-enzyme preparations introduced in the field of winemaking. Pectins are structural constituents of plant cell walls, consisting mainly of α-D-1,4-linked galacturonic acid residues or its methyl esters (acid pectic substances; homogalacturonans, rhamnogalacturonans), with regions of neutral pectic substances (arabinans, galactans, arabinogalactans) as side-chain substituents, mostly concentrated in rhamnogalacturonate regions (van Rensburg and Pretorius 2000). Pectic substances, together with cellulose and hemicelluloses, contribute to the turbidity and viscosity of musts and wines, and are responsible for technological problems in their processing. Colloidal pectins can clog filters and retard the spontaneous settling of suspended particles, thus hampering filtration and racking procedures. By partially degrading the negatively charged pectins that may surround positively charged grape solids, small particles self-attract and precipitate, favoring the clarification of the juice. In addition to the technological interest, pectic enzyme preparations, including those carrying plant cell wall degrading side activities (cellulases or hemicellulases), contribute to improve the yield of grape juice (Ducruet et al. 1997), as well as to the extraction of varietal aroma precursors and color, by catalyzing the skin cell wall breakdown. Among the side activities, glycosidic enzymes (glucosidases, rhamnosidases, arabinases, etc.) are especially interesting because of their contribution to the release of odor-active molecules from their glycosilated precursors.

A very specific application exists for β-glucanases (cellulases), a related class of enzymes. β-glucanases from *Trichoderma harzianum* are usually required for the production of wines from botrytized grapes (either because of a poor management of *B. cinerea* in the vine (see later), or for the production of noble rot wines). This fungus secretes large quantities of linear β-glucans, conferring a high viscosity to musts and wines. Other specialized enzyme preparations in enology are those mainly carrying β-glucanase activities used to improve extraction of yeast cell wall polysaccharides (mannoproteins), as they positively contribute to several quality traits of wine (Caridi 2006), or those presenting invertase activity, which are used to improve the microbial stability of wines, including the prevention of unwanted malolactic fermentation (MLF).

The International Oenological Codex (http://news.reseau-concept.net/images/oiv_uk/Client/CODEX_2009_EN.pdf) establishes the allowed usages of enzymes in winemaking, including accepted sources of enzymes (especially those produced by microorganisms), labeling, side activities, applications, and conditioning substances. All this normative is based on the recommendations from FAO/WHO on "General specifications and considerations for enzymes used in food processing" where, far from being restrictive, it is stated that "all enzymatic preparations with activities presenting a technological interest duly proven in practice and meeting the conditions and criteria mentioned earlier, are accepted for the treatment of grapes and their by-products."

Microbial Ecology of Alcoholic Fermentation

Wine fermentation is a complex microbiological process involving the activity of several yeast species, bacteria, and filamentous fungi. Traditionally, grape must was allowed to undergo a spontaneous fermentation process, driven by the natural microbes (Amerine and Kunkee 1968). The origin of these microorganisms can be found in the vineyard, and in the harvest and cellar equipment and instruments. The kinetics of the spontaneous wine fermentation is somewhat haphazard. The speed of the fermentation and its degree of completion depend on the indigenous strains that are present in the must. This is the reason why the microbial ecology of vineyards and grapes has been the subject of scientific studies from the 1950s. Some recent studies on this topic are those by Cocolin et al. 2000, Mills et al. 2002, and Lopandic et al. 2008. In general, ripe sound grapes present microbial populations at levels of 10^3–10^5 CFU/g. These populations are mainly composed of different species of yeast, LAB, and filamentous fungi (Fleet 1999).

It was reported in early studies that *S. cerevisiae* (Fig. 28.3), the yeast species responsible for conducting wine fermentation, is present on the grapes surface in very low numbers (Fleet 2003). Some authors have even reported that this yeast is present in one out of 2016 berries analyzed

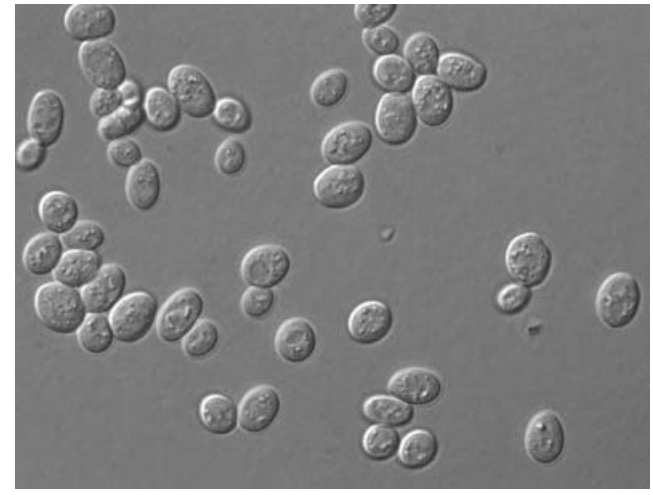

Figure 28.3. Differential interference contrast picture of the wine yeast *Saccharomyces cerevisiae*.

(Vaughan-Martini and Martini 1995). Only when the grape skin is damaged and some juice, rich in sugar, springs onto the surface, fermentative yeasts, such as *S. cerevisiae*, are present in relevant numbers (Mortimer and Polsinelli 1999). In sound grapes, the naturally present biota of ascomycetous yeast is mainly composed of strains belonging to the apiculate yeast species *Hanseniaspora* spp. (mainly *H. uvarum* or its anamorph *Kloeckera apiculata*), even comprising 50–75% of the isolates (Pitt and Hocking 2009), and to other oxidative species of the genera *Candida*, *Pichia*, *Kluyveromyces*, and *Metschnikowia*.

The diversity and size of the consortia of microorganisms present on grapes depend on many biotic and environmental factors. Among the latter, the influence of rainfall and temperature is particularly important, as both factors have a clear impact in the degree of ripeness and therefore on the sugar content of grapes. Rainfall, if abundant, has a washing effect and would cause reduction in the microbial populations.

The phytosanitary state of the grapes also influences microbial diversity of the grape bunch. Microbial loads in mechanically damaged grapes (e.g., by meteorological phenomena such as hail or heavy rain) or grapes affected by phytopathogenic molds are much higher than those present in sound grapes. The use of agrochemicals will also diminish the level of the microbial populations and its diversity.

Wineries represent an additional relevant reservoir of microorganisms, especially yeasts. While the main original source of microorganisms in the winery is the grape harvest, there are secondary sources like animal vectors, being *Drosophila* flies the most relevant ones by far. The clearest and most determining difference between the winery environment and the vineyard is the enormous proportion of *S. cerevisiae* strains in the former. The relationship between *S. cerevisiae* and the wine cellar is so intimate that some authors considered that this microorganism is actually the result of the evolution of a yeast species in such an environment (Loureiro and Malfeito-Ferreira 2003). There are additional studies indicating that the evolution of wine yeast strains has been associated to winemaking even from the origins of this ancient art. Apart from *S. cerevisiae*, yeast species that are frequently isolated from conveyor belts, tables, floors, crushers, pressers, and fermentation tanks correspond to those also commonly associated with grapes, such as *Pichia anomala*, *Pichia membranifaciens,* and species of the genera *Candida* and *Cryptococcus*.

In the spontaneous fermentation of grape must, a sequential replacement of microbial species takes place. The first steps of the fermentation process are dominated by yeast strains coming with the harvest or present in the winery, as described earlier, and belonging to the genera *Candida*, *Debaryomyces*, *Dekkera*, *Hanseniaspora*, *Metschnikowia*, *Pichia*, *Torulaspora*, and *Zygosaccharomyces*, globally known as non-*Saccharomyces* yeasts (Heard and Fleet 1985). Increasing levels of ethanol, combined with CO_2 saturation and anoxic conditions, lead to the death of most of these strains and their replacement by *Saccharomyces* strains, better adapted to ethanol toxicity, anaerobiosis, and the presence of sulfites.

Sulfites are universally used in winemaking for antimicrobial and antioxidative properties, and confer an additional selective advantage to *S. cerevisiae* wine strains. Being unconsciously selected for sulfite resistance over the years, an adaptation to such conditions has caused common chromosome rearrangements in wine yeast strains (Pérez-Ortín et al. 2002). Sulfite levels used in winemaking are permissive for these wine yeast strains, but limit or completely avoid the development of most natural must microorganisms, either yeast or bacteria. The persistence of each specific strain would be also influenced by the actual must composition (nutrient availability), fermentation temperature, or competing microbiota (Lambrechts and Pretorius 2000).

It is important to point out that, despite their short survival time in the fermenting must, non-*Saccharomyces* yeast species can have a deep impact on wine quality through the production of a variety of enzymes and metabolites (Lema et al. 1996; Ferreira et al. 2001; Rojas et al. 2001). However, the main species responsible of alcoholic fermentation of grape must is *S. cerevisiae*. Similar to the succession of species described earlier, a sequential replacement of *S. cerevisiae* strains takes place in most spontaneous fermentations, accounting for up to 20 different strains in a single fermentation process (Querol et al. 1992, 1994). *S. cerevisiae* strains found in natural fermentations differ in actual adaptation to fermentation and winemaking conditions.

In order to ensure the complete fermentation of the sugars present in the must with appropriate kinetics, and prevent spoilage due to the development of unwanted microorganisms, selected wine yeast strains are frequently employed to inoculate wine fermentations, usually in the form of active dry yeast (ADY) (Fleet and Heard 1993). Wine fermentations inoculated with the appropriate ADY strain still experiences a first fermentation step dominated by non-*Saccharomyces* strains, though most of the fermentation process is directed by the inoculated strain (Querol et al. 1992, 1994).

Yeast Strain Selection

Besides the transformation of the glucose and fructose present in the must to CO_2 and ethanol, yeasts contribute to the modification of the chemical composition of the fermenting must by producing other small molecules, including glycerol, acetate, succinate, pyruvate, fatty acids, several esters, volatile aldehydes, and sulfur compounds (Fleet 1993), as well as macromolecules released from the cell wall, like mannoproteins. Most of these compounds have an impact on wine aroma and tasting quality. In addition, some enzymes released by wine yeasts would contribute to the release of varietal aroma compounds from their glycosylated precursors, also influencing wine aroma properties (Swiegers et al. 2005).

The selection criteria originally employed for wine yeast strains were simple: suitable fermentation kinetics and undetectable production of off-flavors. However, they have evolved to more sophisticated requirements, once the differential impact of each selected strain on wine quality and/or the technological suitability of the fermented must became apparent. Among the currently accepted selection criteria for ADY, we can mention the fermentative power, considered as a combination of fast fermentation kinetics, short lag phase, and ability to completely consume must sugars. This is directly or indirectly related to other factors like low nutrient (nitrogen) requirements, sulfite resistance, resistance to several stress factors-like ethanol, osmotic stress, thermal stress, low temperature, or oxidative stress, or killer phenotype. More specific selection criteria include the influence of the yeast strains on the primary (grape derived) and secondary (fermentation related) aroma of wine, glycerol production, and low production of volatile acidity, hydrogen sulfide or ethyl carbamate (EC). These criteria are modulated by the specific type of winemaking (red, white, sparkling, etc), the predominant chemical features of the must, the fermentation conditions in the specific production area, and the enologist preferences, being professional tasting the final step in any selection procedure for wine yeast strains.

The dominance of the fermentation process by a single, inoculated, and well-characterized yeast strain opens the possibility of modulating quality of the final product through the selection of yeast strains and/or improvement thereof. The search for useful yeast strains using the aforementioned criteria has traditionally relied on the isolation and screening of new yeast strains from spontaneous fermentation samples. This is indeed the origin of the majority of wine yeast strains currently on the market. Even though the search for new natural strains keeps going in different wine producing regions, it is now clear that most of the features selected so far would be difficult to improve just by screening new or already available isolates. The genetic improvement of strains already in use would offer new possibilities in terms of characters to be improved as well as creating combinations of interesting features not easily found in nature.

The main available technologies for the genetic improvement of wine yeast are sexual hybridization, random mutagenesis, and genetic engineering. Sexual hybridization allows researchers to combine interesting technological and quality features from two or more strains. The two main limitations for the application of this technology are the lack of genetic markers and the genomic structure of industrial wine yeasts (Bakalinsky and Snow 1990; Dunn et al. 2005) that limits sporulation efficiency as well as spore viability (Gimeno-Alcañiz and Matallana 2001). Nevertheless, there are a few examples of genetic improvement of wine yeast strains by isolation of homozygous single-spore derivatives (Ramírez et al. 1999). However, the genomic simplification resulting from this process can lead to the loss of some of the industrially interesting traits of the mother strain (Gimeno-Alcañiz and Matallana 2001). Sexual hybridization has been used for the elimination of deleterious or undesirable features, as well as for introduction of desirable properties like flocculation (Eschenbruch et al. 1982; Thornton 1985). There are a few commercially available strains resulting from sexual hybridization (http://anchorwineyeast.com).

An alternative to the sexual cycle in industrially important microorganisms is protoplast (or spheroplast) fusion. Protoplast fusion can be intraspecific (for strains of the same species) or interspecific (strains of different species). Interestingly, it has recently been found that several industrially important strains are the result of natural interspecific hybridization events (Masneuf et al. 1998; de Barros Lopes et al. 2002; Belloch et al. 2009). Like for sexual hybridization, protoplast fusion is hindered by the lack of suitable genetic markers in industrial wine yeast strains.

Random mutagenesis using chemical or physical mutagens is a simple way to improve industrially relevant microorganisms. Its applicability for wine yeast improvement is limited by their genomic structure (Bakalinsky and Snow 1990; Dunn et al. 2005), since recessive mutations would be difficult to select, and the lack of suitable selection procedures for most technologically relevant features. There are only a few examples of the genetic improvement of wine yeasts by random mutagenesis, including a series of works cited by Snow (1983), and more recently, improvement of the autolytic behavior of sparkling wine yeast strains (Gonzalez et al. 2003; Martinez-Rodriguez et al. 2004; Nuñez et al. 2005) or nitrogen assimilation and fermentation kinetics (Salmon and Barre 1998).

Finally, genetic engineering approaches to wine yeast improvement have benefited from the role played by *S. cerevisiae* as a model organism in many biological disciplines. In a pioneering work, Pérez-González et al. (1993) assayed several methods for the physical introduction of transforming DNA in an industrial strain and concluded that the more suitable method was lithium acetate transformation (Gietz et al. 1992). The construction of most recombinant wine yeast strains afterwards has also been performed using different variations of the lithium acetate procedure. Although most pioneering works in this field employed autonomously replicating vectors based on the natural 2-micron plasmid of *S. cerevisiae*, the most recent attempts to generate recombinant wine yeast strains are based on the insertion of the recombinant construction into the yeast nuclear genome. In *S. cerevisiae*, insertion is easily directed at a specific *locus* by incorporating homologous fragments into the transforming DNA (Klinner and Schafer 2004). Natural wine yeast strains are generally prototrophic and diploid or aneuploid, which hampers the possibility of obtaining auxotrophic derivatives easily. Most recombinant wine yeast strains were transformed using dominant selection markers, conferring resistance to different antibiotics or other growth inhibitors. Cycloheximide resistance, a semidominant marker encoding a mutant allele of a ribosomal protein, previously employed for the

transformation of brewing yeasts, was one of the first transformation markers used in this field (Pérez-González et al. 1993). The second most popular selection marker for genetic transformation of industrial wine yeast has been resistance to the antibiotic G418 (Wach et al. 1994) and more recently, phleomycin (Coulon et al. 2006). The most popular promoters to control the expression of the genes of interest in transgenic wine yeasts were initially those from *ACT1*, coding for actin, or *ALDH1*, coding for aldehyde dehydrogenase, and currently promoters of genes coding for glycolytic enzymes such as *TDH3* or *PGK1*.

In spite of the enormous effort made by research groups from several winemaking countries to develop recombinant wine yeast strains improved for a variety of characters, only two recombinant wine yeast strains have gone through the whole process and got the approval from the health authorities (and this only for the United States and Canada). One of the main concerns with most other transgenic wine yeasts is the presence of bacterial sequences, especially when part of these sequences code for antibiotic resistance. Strategies to overcome this hurdle have ranged from the construction of auxotrophic wine yeast strains, also by recombinant methodologies, the use of alternative dominant selectable markers from yeast origin, or cotransformation as a way to simplify the procedure of getting rid of the selection marker (Fig. 28.4). The last alternative is the one employed for the construction of these two commercially available strains. The first of these strains, ML01, expresses two heterologous genes, one from the yeast *Schizosaccharomyces pombe* and another from the lactic acid bacterium *Lactobacillus plantarum*. This strain is able to simultaneously perform the alcoholic and malolactic fermentation (Husnik et al. 2006). Besides avoiding delays in malolactic fermentation, a matter that has traditionally worried enologists, this strain avoids the uncontrolled growth of LAB, as well as the associated risk of sensory defects or production of biogenic amines (BA). The second commercially available transgenic wine yeast strain was constructed in order to minimize the formation of the suspected carcinogen ethyl carbamate in wine. The main pathway of ethyl carbamate formation in wine is a spontaneous reaction between urea and ethanol. This strain overexpresses the gene coding for urease, a subproduct of arginine metabolism. In this way, urea is hydrolyzed by the recombinant strain and ethyl carbamate levels are reduced by more than 80% as compared to wines fermented with the unmodified strain (Coulon et al. 2006). Both strains were constructed by simultaneously transforming the recipient strain with a linear DNA fragment that was inserted into the yeast genome, and a circular, autonomously replicating plasmid carrying the selection marker. The ratio of strains carrying both constructions is high enough to allow for an easy identification of transformants carrying the construction of interest. This strategy makes the most of the genetic instability of the strains carrying this kind of replicating plasmids. By selecting for strains losing the plasmid after several generations without a selective pressure, a recombinant strain free of *Escherichia coli* and antibiotic resistance genes, but still carrying the desired construction, is easily obtained (Fig. 28.4). Unfortunately, it seems to be very difficult to obtain reliable data on the actual sales of this recombinant strains.

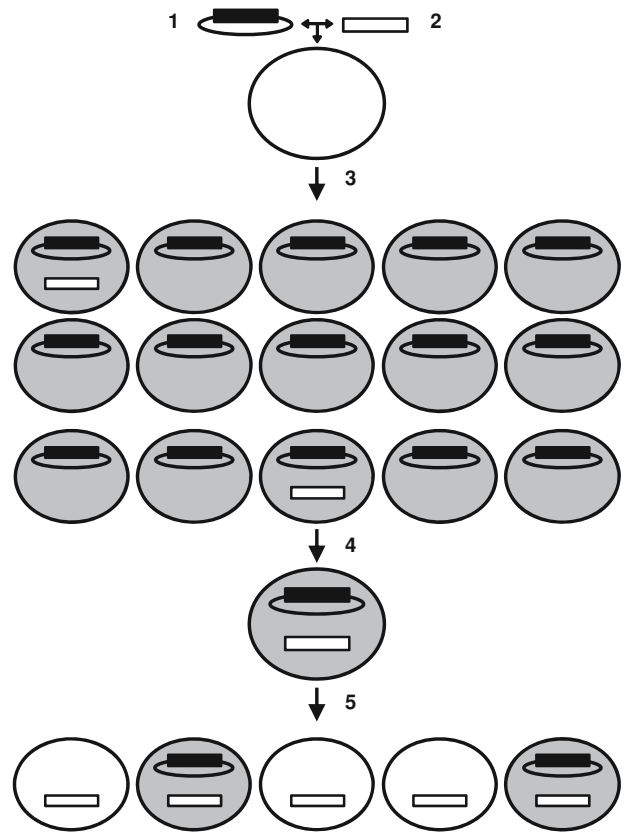

Figure 28.4. Genetic engineering of wine yeast strains by cotransformation. Yeast cells are simultaneously transformed with two DNA fragments, a replicating plasmid carrying a dominant selection marker (antibiotic resistance) (1), and a nonreplicating linear DNA fragment carrying the construction of interest (2). Selection (3) of antibiotic resistant colonies (gray) identify both single and double transformants. Double transformants, carrying the selection replicating plasmid as well as the linear fragment homologously integrated in the yeast nuclear genome, are then identified by PCR or DNA hybridization analysis (4). Growth of these strains in the absence of antibiotics (5) allows recovering sensitive colonies (white) where the selection plasmid has been lost. These transformed cells carry only the construction of interest integrated in the yeast genome, and are devoid or unwanted and/or genetically unstable sequences. These strains are genetically stable and no selective pressure is required to maintain the transgenic character.

Control of Alcoholic Fermentation

The control of alcoholic fermentation is critical to obtain optimal aromatic and sensory characteristics in quality wines. Fermentation is usually carried out in wooden or stainless

Figure 28.5. Wooden tanks for alcoholic fermentation in Bodegas Dinastía Vivanco (La Rioja, Spain). © Museo de la Cultura del Vino Dinastía Vivanco.

steel tanks (Fig. 28.5). It can be monitored by several parameters such as density, pH, heat generation, differential pressure, or CO_2 evolution (Martínez et al. 1999). However, the monitoring of alcoholic fermentation under enological conditions is currently poor due to the lack of sensors for online measurements. Such monitoring is currently limited to the measurement of CO_2 production or changes in density (Sablayrolles 2009). In fact, must density is commonly used in wineries as the parameter to easily control the evolution of wine fermentation, considering that wine is usually racked when its density reaches a value of about 1000 g/L. However, the final concentration of glucose and fructose should be analytically determined in order to confirm the end of wine fermentation. This is considered to be completed when the level of both sugars is below 2 g/L.

The temperature of the fermentation is an important technological parameter that influences wine quality. The range of temperatures used in must fermentations is quite broad, ranging from around 15°C for white and rosé wines to around 30°C for red wines. Since alcoholic fermentation is an exothermal process (23.5 kcal released per mole of sugar fermented; Sablayrolles 2009), fermentation tanks are equipped with cooling systems aimed to compensate for the heating released during the process.

In the production of white and rosé wines, temperature may have a direct impact on the aromatic characteristics of the resulting product, favoring either fermentative or varietal aromas. Low temperatures result in an increase of the production of volatile compounds derived from yeast metabolism (esters, acetates, and medium-chain fatty acids; Torija et al. 2003). However, low temperatures may also result in sluggish or stuck fermentations. Therefore, the right choice of the yeast strain is important, and a final increase of the temperature might be necessary.

In the production of red wines, the aroma compounds produced as a result of the metabolic activity of yeasts during the alcoholic fermentation have a much lesser impact. In this case, the temperature during the fermentation is mostly regulated to favor the transfer of polyphenolic compounds from the grape to the wine.

To avoid any possible risk of incomplete or stuck fermentations, grape juices are inoculated with ADY at a concentration of 15–20 g/hL or 10^6 cells/mL of juice immediately after clarification (Ribéreau-Gayon et al. 2004). Throughout the fermentation process, yeast cells have to cope with a suite of stress factors in order to survive and grow. Some of them are more or less constantly present along the process (pH, sulfites, anaerobiosis, and suboptimal temperatures (either high or low)), while other evolve with fermentation time (osmotic pressure, nutrient depletion (nitrogen, vitamins, lipids), and ethanol content). Despite considerable improvements in fermentation control, stuck and sluggish fermentations are still a major enological concern. The principal mechanisms involved in deficient fermentations have been fully elucidated: nitrogen deficiency, thiamine depletion in the must, lack of oxygen, excessive clarification of the juice, and inhibition of yeast cells by fermentation by-products (especially octanoic and decanoic acids), killer toxins and pesticides (Blateyron and Sablayrolles 2001).

Depending on the winemaking process, other stress factors can also be found: high temperature, cold stress, and high levels of CO_2, particularly in sparkling wine fermentations. These problems can be minimized by the addition of nutritional supplements, usually inorganic forms of nitrogen such as ammonium salts combined with thiamine. Another strategy consists in the addition of inactive yeasts (Blateyron and Sablayrolles 2001). As previously mentioned, oxygen is another essential nutrient, principally to maintain cell viability by the end of the fermentation, since it is required for the biosynthesis of essential membrane lipids (Sablayrolles et al. 1996). In case of white wine, the maintenance of sufficiently high turbidity (50–150 NTU) is essential to minimize stuck fermentations. Solid particles act as a source of lipid compounds, since unsaturated fatty acids or sterols compensate, at least partly, for oxygen deficiencies (Sablayrolles 2009).

Physiology of Wine Yeasts

In quantitative terms, the main result of alcoholic fermentation is the transformation of grape must sugars into ethanol and CO_2 following the glycolytic pathway. In this metabolic pathway, some steps are energy consuming, while others are energy yielding. The energy yield of the overall reaction is 2 ATP moles per mol of sugar consumed. There are also oxidation and reduction steps, but these are internally balanced, since, in fermentation conditions, there is no external electron acceptor available. Apart from energy, glycolytic reactions are also a source of metabolites for the biosynthesis of

other molecules required for yeast development and biomass production.

Backhus et al. (2001) studied the effect of different amounts of an assimilable nitrogen source under conditions mimicking wine fermentation. The high-nitrogen condition resulted in high expression of genes involved in biosynthesis of macromolecular precursors. In contrast, expression of genes involved in translation and oxidative carbon metabolism increased in low-nitrogen conditions. The exponential growth phase is also characterized by a transition from a nitrogen catabolite-repressed (NCR) state to a corresponding nitrogen catabolite-derepressed state as the nitrogen source becomes exhausted (Beltran et al. 2004). As the culture progresses into the stationary phase, a general stress response is triggered. This is characterized by the induction of the common environmental response (CER), the environmental stress response (ESR), and a few heat-shock genes (Rossignol et al. 2003; Beltran et al. 2006). This fact partly results from nitrogen depletion, but mainly from the response to the increasing ethanol concentration, as shown by the high expression of genes encoding proteins involved in proton homeostasis, such as HSP30 and PMP2 (Varela et al. 2004). Marks et al. (2008) identified a group of 223 genes dramatically induced at various points during fermentation and proposed this transcriptional changes to constitute a specific fermentation stress response (FSR).

Transcriptional adaptation to fermentation at low temperatures has also been studied (Beltran et al. 2006). A cold-stress response was expressed at the initial stage of the fermentation at low temperature, followed by an upregulation of genes involved in the progression of the cell cycle, growth control, and maintenance in the middle and late stages of the process. These expression patterns were correlated with a higher cell viability at low temperature. In addition, several genes involved in cytosolic fatty acid synthesis were downregulated, while those involved in mitochondrial short-chain fatty acid synthesis were upregulated in fermentations at low temperature. Pizarro et al. (2008) have characterized the effect of growth temperature on laboratory and wine strains grown in chemostat. Their results showed that temperature mostly affected nitrogen metabolism and the heat shock response, with a decreased general stress at lower temperatures (15°C). Differential responses among the strains were centered not only on sugar uptake and nitrogen metabolism, but also in some genes that would affect the sensory properties of wine.

Malolactic Fermentation

After alcoholic fermentation has taken place, a second microbial process that affects the characteristics of the final product usually occurs. This process, called malolactic fermentation (MLF), is driven by LAB and receives its name from the main transformation that occurs during the process: the decarboxylation of malic acid to lactic acid. The three main consequences of MLF are: (a) an increase in the microbial stability of wine due to the removal of malic acid and other nutrients that can be used as a carbon source by other microorganisms; (b) deacidification of wine and a decrease in the titratable acidity; and (c) sensory changes affecting the complexity of the aroma and palate of the wine.

Figure 28.6. Wooden barrels employed to carry out malolactic fermentation in Bodegas Dinastía Vivanco (La Rioja, Spain). © Museo de la Cultura del Vino Dinastía Vivanco.

Malolactic fermentation is favored by winemakers because it improves the organoleptic properties of wines (Fig. 28.6). Traditional practices have relied upon the growth of naturally occurring LAB microbiota to induce MLF spontaneously, with a moderate increase in wine temperature (either natural or induced), as the main control parameter. However, the harsh conditions of wine (low pH, high ethanol content, depletion of nutrients, and presence of SO_2) create a stressful environment for the growth of microorganisms, and a failure of MLF is not uncommon. This fact has motivated the development of starter cultures of LAB, a topic that will be addressed later.

Ecology of LAB in Winemaking

LAB are present both in the vineyard and in the cellar environment. Crushed grape must contains 10^3–10^4 CFU/mL of LAB, most of them belonging to the species *Lactobacillus plantarum*, *Lactobacillus casei*, *Lactobacillus hilgardii*, *Leuconostoc mesenteroides,* and *Pediococcus damnosus*, and to a lesser extent to *O. oeni* and *Lactobacillus brevis*. As alcoholic fermentation progresses, the ethanol content increases and the number and diversity of LAB decrease to reach 10^2 CFU/mL at the end of this process, being *O. oeni* the dominant LAB species. However, strains belonging to the genera *Lactobacillus* and *Pediococcus* may also survive to alcoholic fermentation. It is important to point out that

while LAB species belonging to the genera *Lactobacillus*, *Leuconostoc*, and *Oenococcus* are heterofermentative (one molecule of hexose is converted to ethanol, lactic acid, and CO_2), those belonging to *Pediococcus* are homofermentative (one molecule of hexose produces two molecules of lactate).

After alcoholic fermentation, bacterial population remains stable for a variable period of time due to the harsh environmental conditions (low pH, inhibitors, ethanol, SO_2), and the best adapted strains, generally belonging to *O. oeni*, start to grow to reach a population of around 10^6 CFU/mL. It is at that point that malolactic fermentation starts.

Some procedures as a prolonged residence of grape skins and yeast lees in wine after the completion of alcoholic fermentation have been shown to favor the activity and growth of LAB during malolactic fermentation. The effect of yeast lees seems to lie on the ability of LAB to use those compounds released during yeast autolysis as metabolic substrates for their growth. Other factors such as wine aeration and CO_2 pressure also seem to favor LAB growth.

After malolactic fermentation has occurred, LAB are inactivated by the addition of sulfite. The number of *O. oeni* cells rapidly decreases after the degradation of malic acid, though *Pediococcus* and *Lactobacillus* strains may survive if the pH is high and sulfite levels are low.

Metabolism of LAB

Malic Acid Metabolism The concentration of L-malic acid in grape juice varies depending upon the climate of the region where the grapes are produced, being higher in cool climatic regions. The conversion of malic acid into lactic acid with the concomitant release of CO_2 is carried out by the malolactic enzyme in a single step that takes place in the cell cytoplasm. The reaction itself is not energy producing. At low pH (3.0–5.0), malic acid is monoprotonated. LAB cells use malic acid in this form and quickly transform it into lactate in a proton consuming reaction. The undissociated form of lactate escapes from the cell by passive efflux (Konings 2006). This results in a net transport of H^+ to the outer cell environment against gradient and is useful to cells in two ways. On one side, this transport helps to maintain internal pH between 5.8 and 6.3, and, on the other, membrane ATPases can produce ATP through the import of H^+. At wine pH, glycolysis in LAB cells seems to be switched off, and this is the only possible alternative to produce energy.

Production of Flavor Compounds Several studies on the effect of malolactic fermentation on wine's sensory properties by GC–MS and olfactometry have concluded that malolactic fermentation adds complexity to the aroma and palate of the wine (McDaniels et al. 1987; Rodriguez et al. 1990; Henick-Kling 1993; Sauvageot and Vivier 1997; Delaquis et al. 2000). Bacterial metabolism during the performance of malolactic fermentation contributes to wine flavor by the formation of additional compounds and the modification of grape-, yeast-, and oak-derived compounds. However, these effects are strain dependent.

LAB strains belonging to the genera *Oenococcus* and *Lactobacillus*, unlike *Pediococcus*, are able to metabolize citrate, present in grapes in lower concentrations than malic and tartaric acids. The initial concentration of citric acid in wine is about 250–300 mg/L, and it is metabolized more slowly than malic acid. Nevertheless, it is generally exhausted by the end malolactic fermentation. As previously explained for malic acid, the utilization of citric acid is also associated to the generation of proton motive force in LAB.

Among the products derived from the metabolic utilization of this organic acid, acetic and lactic acid, diacetyl, acetoin, and 2,3-butanediolare are probably the most important compounds. An excessive amount of acetic acid would result in an increase of the volatile acidity of the wine and would therefore affect wine aroma negatively. Diacetyl produces a pleasant, desirable buttery flavor when found in a balanced concentration. Factors affecting its formation are oxygen availability, citrate and sugar concentration, and temperature while the SO_2 levels would affect its perception. Acetoin and 2,3-butanediol are two compounds related to diacetyl, but with little effect on wine aroma.

Ethyl esters have been related to fruity aromas of wine (Ebeler 2001). There are some evidences of the formation of ethyl acetate, ethyl lactate, ethyl hexanoate, and ethyl octanoate during malolactic fermentation (de Revel et al. 1999; Delaquis et al. 2000). Most of the wine LAB strains studied possess esterase activity (Davis et al. 1988), though the complete biosynthetic pathways involved in the production and hydrolysis of esters by LAB are still unknown.

Malolactic fermentation can also contribute to the reduction of the herbal aroma of wines. These aromas are generally associated with volatile aldehydes present in wine. Among these, acetaldehyde, characterized by its apple-like and nutty aroma, is the most abundant aldehyde in wine and is mainly originated by yeast metabolism. An excess in the concentration of this compound is traditionally compensated by the addition of SO_2 though some strains of *O. oeni* and *Lactobacillus* can metabolize it to ethanol and acetic acid (Osborne et al. 2000). The production of volatile sulfur compounds derived from methionine has also been described in strains of *O. oeni* (Pripis-Nicolau et al. 2004).

Grape-derived flavorless glycoconjugates constitute a pool of volatile aglycones. As an example, almost 200 different aglycones have been detected in Chardonnay musts before fermentation. *O. oeni* possesses various glycosidase activities that are able to liberate aroma compounds bound to sugar moieties though these activities are affected by wine conditions of pH, ethanol and sugar content (Grimaldi et al. 2000). Species of *Lactobacillus* and *Pediococcus* also seem to possess similar glycosidase activity (Grimaldi et al. 2005).

It is important to mention that LAB are also responsible for the production of certain compounds commonly related to aroma defects.

Changes in Color and Texture Besides its effect on flavor, acetaldehyde also plays a key role in color development of red wines by promoting a rapid polymerization between anthocyanins and catechins or tannins, forming stable polymeric pigments resistant to SO_2 bleaching. Depending on the wine style, it may be beneficial to use an efficient acetaldehyde-degrading strain. So, in a white wine, degradation of acetaldehyde by LAB strains would reduce the amount of SO_2 needed to mask the grassy flavor, while its presence for color development of red wines is desirable (Osborne et al. 2000). In the same way, colored monoglucoside anthocyanins can be deglycosylated by LAB glycosidases to the corresponding anthocyanidin, less stable and readily converted into a brown or colorless compound.

Polysaccharides present in grape juice can affect the clarification step, and therefore the quality and mouthfeel of the wine through changes in clarity, and viscosity. Apart from improving juice yields and wine processing, enzymes degrading polysaccharides also allow a better extraction of color and aroma precursors. Though an extracellular $\beta(1\rightarrow3)$ glucanase activity has been found in *O. oeni* (Guilloux-Benatier et al. 2000) future studies to characterize the glycanolytic activities of wine LAB and their relation to changes in the aroma and palate of wine associated with malolactic fermentation are needed.

Strain Selection for Malolactic Fermentation To overcome the difficulties in triggering malolactic fermentation, microbiologists have been working on the selection of strains to be used as starters from the late 1970s. Most of the work performed in this field has been done on *O. oeni* due to two main reasons. First, *O. oeni* is usually the LAB species found in wine after malolactic fermentation and, for this reason, it is considered to resist hostile conditions found in wine better than other LAB species. Second, this species has been rarely associated to wine spoilage.

Criteria for selection of *O. oeni* strains are based on their resistance to common stress factors found in wine, such as ethanol, low pH, sulfites and medium or long-chain fatty acids, and on their metabolic capacities: malic acid degradation kinetics, and production of volatile acidity, biogenic amines and arginine degradation products.

Although there are already some starters in the wine industry market, their use is not as extended as starter cultures of yeast used for the performance of alcoholic fermentation.

As mentioned previously, MLF is considered to be desirable in red and in some white wines. Wine spoilage due to an increased titratable acidity is, in some cases, related to a bacterial growth before the completion of alcoholic fermentation, when a big amount of fermentable sugars are still present. It would therefore be desirable for MLF to start right after alcoholic fermentation had been completed, therefore inhibiting the growth of undesired bacterial species. However, recent works have indicated that a coinoculation with both selected yeasts and LAB strains can lead to a successful alcoholic and malolactic fermentation in a shorter time without compromising the quality of wines (Jussier et al. 2006; Massera et al. 2009).

Postfermentative Processes

Once alcoholic fermentation is completed, wines to be marketed as young wines or wine of the year, are protected from oxidation and microbial spoilage by the addition of sulfite, and then racked into a new tank. This type of wines is treated prior to bottling in order to avoid fatal chemical and biological instabilities that might arise once they are in the market. The most common problems winemakers have to deal with after fermentation processes are completed concern potassium bitartrate instability, protein and microbiological stabilization and clarification. Stabilization and clarification involve procedures designed to produce a brilliantly clear wine with no flavor faults. Because problems might also arise due to these treatments, it is essential to use them discreetly, and to adjust the level or intensity of them to the minimum required for stabilization of each batch.

Potassium Bitartrate Stabilization

Potassium and tartaric acid concentrations can be found in grape juices at very different levels. Much smaller variations are found in the calcium content. Juice is typically supersaturated with potassium bitartrate at crushing. As the alcohol content rises during fermentation, the solubility of bitartrate decreases, inducing the slow crystallization of potassium bitartrate and calcium tartrate. With time, the salt crystals precipitate spontaneously. To achieve a rapid and satisfactory stability of bitartrate salts, wine is usually refrigerated and seeded with potassium bitartrate crystals, which would result in the acceleration of the precipitation (Boulton et al. 1998). Another strategy to achieve the stabilization of bitartrate instability is by chilling the wine at temperatures close to the wine's freezing point, a technique called cold stabilization. Perin (1977) proposed the following relationship to determine the temperature needed for potassium bitartrate precipitation:

$$\text{Temperature } (^{\circ}\text{C}) = -[(\%\ \text{ethanol}/2) - 1]$$

Wine has to be kept under suitable temperature for several days or weeks. At the end of conventional chilling, the cooled wine is filtered or centrifuged to remove the crystals that have formed.

Although less frequent than precipitation of potassium bitartrate, calcium tartrate precipitation is more problematic because it cannot be readily stabilized by low temperatures. This type of precipitation is particularly troublesome in fortified wines, where calcium salts have been used to treat wines. Because the formation of crystal nuclei requires more free energy than crystal growth, seeding circumvents the main limiting factor in the development of calcium tartrate

stability. For that purpose, a racemic mixture of calcium tartrate seed nuclei, containing both L and D isomers, is preferred. The racemic mixture is about one-eighth as soluble as the naturally occurring L-tartrate salt. This may result from the more favorable (stable) packing of both isomers together in crystals (Brock et al. 1991).

Protein Haze Stabilization

Heat-induced protein haze is a common problem during the elaboration of white wine. This type of spoilage is caused by the aggregation of grape pathogenesis-related proteins, namely thaumatin-like proteins and chitinases, with the resulting formation of light-dispersing particles. Although wine containing protein haze is safe for consumption, it severely affects consumer acceptability. Haze formation is currently prevented by the removal of wine proteins thanks to their adsorption onto bentonite (Høj et al. 2000; Tattersall et al. 2001; Ferreira et al. 2002). The adsorption of wine proteins onto this type of montmorillonite clay is due to its cationic exchange capacity. Wine proteins are positively charged at wine pH, and thus can be exchanged onto bentonite, which carries a net negative charge (Ferreira et al. 2000). Beside bentonite, other fining agents commonly used in winemaking are proteins of animal origin such as egg or blood albumin, casein, isinglass (a form of collagen obtained from the dried swim bladders of fish), and gelatins.

Some alternative techniques to bentonite fining such as ultrafiltration (Flores et al. 1990), addition of proteolytic enzymes (Waters et al. 1992), flash pasteurization (Francis et al. 1994; Pocock et al. 2003) and the use of other adsorbent materials such as resin (Sarmento et al. 2000), metal oxides (Pashova et al. 2004), zirconium oxide (Salazar et al. 2006), or even polysaccharides extracted from seaweeds (Cabello-Pasini et al. 2005) have also been studied. The addition of yeast cell wall-derived polysaccharides (mannoprotein rich preparations) has also been proposed as an alternative to reduce protein haze in white wine (Waters et al. 1994). The use of immobilized phenolic compound such as proanthocyanidins (Powers et al. 1988) has also been tested. However, the results obtained so far have not been successful on an industrial scale. Thus, the use of bentonite still represents the main commercially acceptable practical solution to avoid protein haze in bottled white wine (Waters et al. 2005). It has recently been shown that wines fermented with recombinant, high mannoprotein releasing, yeast strains require lower amounts of bentonite for clarification (Gonzalez-Ramos et al. 2009).

Filtration

Once the wine is chemically stable, it is racked to a new tank, where microbiological stabilization will be performed by filtration. In order to reach a complete retention of microbes (approximate size, 0.5–1.5 μm of diameter), wine is filtered by perpendicular flow though polymeric membranes. The terms *rough, polish, tight,* or *sterile* will often be used to distinguish the porosity of the filter membrane that has been using in this treatment (Boulton et al. 1998). The greater the retentive property, the greater is the likelihood of plugging. This is a main issue for winemakers, since the plugging of the filtration system has fatal consequences in terms of time, money and wine sensory quality. Thus, the election of the suitable filtration system for every step during clarification and stabilization is critical.

Several filtration systems can be applied in winemaking, the most commonly used being diatomaceus earth filters (such as pressure leaf filters and rotary vacuum-drum filtration apparatus), and pad, cartridge, and membrane filters. Diatomaceus earth is used to provide structural support in a developing filter cake by a continuous addition during the filtration that allows the settlement of a porous cake. The commercial grades of diatomaceus earth used for wine filtrations have median particle sizes ranging between 14.0 and 36.2 μm. Those with a smaller size can be used instead of tight pads prior to a membrane filtration while those with a bigger size would be use to perform a coarse filtration of juice or following fermentation. A simpler filtration method, currently used in many small and medium-sized wineries, would consist on the use of preformed sheets or pads of cellulose and diatomaceus earth. Finally, perpendicular flow membranes such as cartridge and membrane filters are used for the sterile filtration of wines just prior to bottling (Boulton et al. 1998). Once the wine is completely stable from both the chemical and microbiological points of view, is ready to be bottled.

Wine Aging

Oxidative aging, wine storage and aging in wood barrels followed by a period of bottle aging have been common practices in famous winemaking areas, from where they have spread to most wine producing areas in the world. The capacity of wines to improve its sensory properties is not only exclusive of red wines, since white wines produced from varieties such as Chardonnay, Riesling or Sauvignon blanc also present a good aging potential.

Oak barrels have been traditionally used in wine aging. Among the positive effects that this type of wood has on the final quality of wine color stabilization, spontaneous clarification, and greater aromatic complexity could be highlighted. Oak wood has a slight porosity that allows a slow oxygen transfer during the aging period, favoring the oxidation of wine compounds and a set of physicochemical phenomena that improve the color and flavor of wines. Small quantities of oxygen are usually present during oak barrel maturation. Barrel micro oxygenation profile can be assumed to require a long aging time during which the wine consumes practically all the oxygen it absorbs. The natural rate of permeation of oxygen into new French oak barrels ranges between 1.66 mL/L per month and 2.5 mL/L per month, and

is lower in American oak barrels (Nevares and del Alamo 2008). However, it should not be forgotten that the age of the barrel will also affect the oxygen diffusion rate. As wood pores will be clogged with wine deposits along time, the older the barrel, the slower the resulting oxygen diffusion rate.

Color is intensified mainly due to reactions between tannins and anthocyanins, though other reactions involving acetaldehyde are also important. As a result, free anthocyanin concentration decreases and the tannin structure evolves, which causes a reduction in the astringency of the wine. The increase in wine aromatic complexity is mainly due to the accumulation of certain volatile compounds derived from oak wood, which are released during the aging process inside the barrel. The species and the geographical origin of the oak used in the manufacture of the barrels have also an influence on the concentration of these aromatic compounds (Marco et al. 1994; Ancín et al. 2004). In addition, the several treatments that wood undergoes during the barrel manufacture, such as the drying (Chatonnet et al. 1994; Doussot et al. 2002) and the toasting (Chatonnet et al. 1989; Cadahía et al. 2003) will modify the initial content of these volatile compounds in wood.

Wine aging is a costly process that requires prolonged periods of time. In order to make the process more cost-effective, new and cheaper techniques have been developed. Through the so-called "industrial aging," a technique that combines the use of oak chips and controlled microoxygenation inside a tank, sensory properties similar to those of wines aged in barrels can be achieved. This technique is a common practice in several new winemaking countries, such as Chile, Argentina, South Africa, Australia, and the United States, and has been recently approved and legislated by the European Community (CE 2165/2005 and CE 1507/2006). There are a great number of different oak chips available in the market. The characteristics of the resulting wine depend on several factors such as chip size, botanical and geographical origin of the oak, type of toast, doses, contact time, moment of application, variety, and the usage of woods other than oak (Parish et al. 2000). To perform wine micro-oxygenation, oxygen dosage has to be carefully managed in order to obtain the desired effect without oxidizing the wines. Micro-oxygenation should be carried out at subsaturation doses of oxygen during short periods of time.

When wine has reached the expected evolution inside the oak barrels, it is the time for bottle aging, the second part of the maturing process. After aging in barrels, red wines are stable and limpid. However, a slight filtration with 5 μm filters could be used to remove remaining solid particles. Once bottled, wine evolves in a closed and reductive environment, which leads to important sensory changes. The aging capacity of a wine, maintaining its properties inside the bottle for long periods of time, is a criterion of quality. In general, wines inside the bottle pass through three phases: maturation, fullness, and decline. Sensory quality is improved during the maturation phase, reaching the maximum quality level at fullness. After that, wine slowly loses the features that originally defined its quality (Zamora 2003).

MICROBIAL SPOILAGE OF WINE

Microbial spoilage can be sometimes difficult to detect and to define (Loureiro and Malfeito-Ferreira 2003). This fact is especially true in the case of a fermented beverage like wine, where the oxidative and fermentative metabolism of several yeast species on grape juice generates a complex "cocktail" of compounds that contribute to the generation of flavor, aroma, and mouthfeel in the resulting product.

As in any other food industry, it would be advisable for all wineries to identify the potential spoilage organisms that are isolated from their final products and to get an insight into their conceivable sources of contamination in order to design optimal strategies to prevent product deterioration and its associated economical losses.

Bacterial Spoilage

Increased Acidity

Increased acidity of wines can occur both during the winemaking process and during maturation and bottle aging. The problem normally arises just after a stuck alcoholic fermentation, which can be motivated by a high sugar concentration or a low acidity of the must. Both factors would hamper the metabolic activity of yeast while the remaining sugars would allow an early development of bacteria.

Two kinds of bacteria are linked to this undesired increase of the acidity in wines: acetic and lactic acid bacteria (AAB and LAB, respectively).

AAB are ubiquitous microorganisms that are well adapted to environments rich in sugar and ethanol. Present on sound berries in low numbers (10^2–10^3 cells/g), they can even exceed 10^6 cells/g on damaged grapes. Though their efficiency in converting ethanol into acetic acid through acetaldehyde is exploited in vinegar production, their metabolic activity also constitutes a major concern for the wine industry. The genera of AAB mainly associated with wine spoilage are *Acetobacter*, *Gluconobacter*, and less frequently *Gluconacetobacter*. *Gluconobacter* is the species better adapted to must conditions. While species belonging to this genus cannot oxidize ethanol further than acetic acid, those belonging to *Acetobacter* are able to oxidize it to CO_2.

Populations of AAB decrease as alcoholic fermentation takes place, reaching 10^2 cells/mL when this finishes. At this stage *Acetobacter* species are prevalent.

Acetic acid is the main constituent of the volatile acidity of wine. This acid is considered to be undesirable in dry wine at concentrations exceeding 0.4–0.5 g/L, while in sweet wines this range increases to 1.0–1.5 g/L (Bartowsky and Henschke 2008). From a sensory point of view, acetic acid is perceived as a sour flavor and, at high concentrations, as

a sour, bitter flavor with vinegar-like aroma. It should not be forgotten that this acid is also produced at low concentrations, usually below the detection threshold, during alcoholic fermentation.

Apart from acetic acid, other metabolites that result in unpleasant sensory characteristics of wine such as acetaldehyde, associated with nutty, sherry-like aromas, and ethyl ester, associated with nail polish remover, solvent-like aromas are also produced by AAB if this type of spoilage occurs.

AAB are considered obligate aerobic microorganisms, but they are able to survive without oxygen for long periods of time. The practice of micro-oxygenation of red wine, generally performed to enhance color stability and intensity, to soften astringency due to tannins or to decrease reductive and vegetative aromas, can induce the proliferation of these bacteria. Therefore, the risk of must spoilage must be considered when this technique is applied (du Toit et al. 2006).

On the other hand, LAB causing this type of spoilage generally belong to the species *L. hilgardii* and *Lactobacillus fructivorans*. The main products are acetic acid and D-lactic acid.

Ropy Wine

Ropiness of wine is characterized by a viscous and thick texture of the beverage. While the taste of the product remains unchanged it is that oily feel that spoils it. This type of spoilage was first described by Pasteur in 1866 and was linked to the presence of different microorganisms in wine. This kind of spoilage also occurs in beer and cider. *P. damnosus* is involved in a vast majority of the cases (Lonvaud-Funel and Joyeux 1988) but strains of *L. hilgardii*, *Lactobacillus collinoides,* and one strain of *O. oeni* have also been associated with this problem (Walling et al. 2004). The viscosity generated is due to the production of an exopolysaccharide (high molecular weight β-D-glucan) by using residual sugars present in wine (Llaubères et al. 1990). The deterioration may occur when wine is still in vats. In this case, it is possible to recover to normal viscosity by the use of mechanical treatments. However, in most cases, the ropiness develops very slowly and becomes evident several weeks or even months after bottling. Bacterial species responsible for this type of alteration are difficult to eliminate, perhaps because the exopolysaccharide protects cells from damage. Rigorous cleaning of all the winery equipment is the only way to avoid this problem.

The *dps* gene, coding for a putative glucan synthase, has been detected in all *P. damnosus* and *O. oeni* strains related to ropiness, but not in strains belonging to *L. hilgardii* or *L. collinoides* (Walling et al. 2004). This fact may be related to differences in the mechanism of production and polysaccharide structure and composition among the different genera, species, or strains.

Acrolein Production and Bitterness

The glycerol present in wine as a result of the metabolic activity of yeast during alcoholic fermentation can be degraded by several species of LAB via glycerol dehydratase to 3-hydroxypropionaldehyde. This compound can be converted to acrolein by a chemical spontaneous dehydration during storage in acidic conditions. Acrolein reacts with wine phenols to form a bitter complex. Glycerol dehydratase has been detected in *L. brevis*, *L. hilgardii*, and *Pediococcus pentosaceus*. As glycerol clearly contributes to the body and flavor of the wine, its degradation to acrolein is a two-sided problem.

Mannitol Production

Heterofermentative LAB can produce mannitol as a side-product to compensate the red-ox balance during fermentation. In the typical balanced reaction for energy production under anaerobic conditions, glucose is converted to equimolar amounts of lactic acid, ethanol, and CO_2, with a net production of 1 mol of ATP. Under aerobic conditions, net production of ATP can be increased to 2 mol per molecule of glucose, with the conversion of acetyl-P in acetic acid instead of ethanol, using oxygen as the electron acceptor. Under anaerobic conditions, the amount of ATP produced by mol of glucose can also be increased to 2 instead of 1, if an electron acceptor is found: pyruvate and fructose can be used for this purpose. Fructose is transformed into mannitol by the action of mannitol dehydrogenase, in a reaction consuming NADH, and acetic acid is produced instead of ethanol. Mannitol tainted wine is usually perceived as having a slimy texture with vinegar-like aroma.

Production of Off-Flavors

Animal Odor This off flavor is due to excessive amounts of the volatile phenols 4-ethyl phenol, 4-ethyl guaiacol, 2-ethyl phenol, and 2-ethyl guaiacol in red wines. These compounds are the result of the decarboxylation and subsequent reduction of *p*-coumaric and ferulic acids, naturally occurring in grapes. This type of spoilage usually arises during storage in barrels and is due to *Brettanomyces* strains, a yeast species that is sensitive to SO_2. *L. plantarum* and several *Pediococcus* species have also been shown to produce these ethyl phenols.

Mousy Flavor Mousy flavor is due to the presence of nitrogen volatile heterocyclic compounds, including the tautomers of 2-acetyltetrahydropyridine (ATHP, 2-acetyl-1,4,5,6-tetrahydropyridine and 2-acetyl-3,4,5,6-tetrahydropyridine), 2-ethyltetrahydropyridine (ETHP), and 2-acetyl-1-pyrroline (APY) (Costello and Henschke 2002). Sensory descriptors for these compounds include “cider,” “clovelike,” “spicy,” “horsy,” “wet wool,” “plastic,” “smoky,” “band aid,” and “mousy” (Chatonnet et al. 1992; Snowdon et al. 2006).

Both LAB and AAB can be responsible for this type of spoilage. Different species of *Lactobacillus* and *O. oeni* have been shown to produce these compounds. Costello et al. (2001) have concluded that this ability is restricted to heterofermentative bacteria, and that the pathway of sugar metabolism may play a key role in the occurrence of this spoilage. Costello and Henschke (2002) also demonstrated that *L. hilgardii* produces these compounds in a medium containing ethanol, fructose, and L-lysine or L-ornithine, in the presence of divalent metal ions, and that fructose was not necessary for the production of ETHP. It has also been hypothesized that oxygen favors the formation of this type of nitrogen heterocyclic compounds.

AAB have also been linked to the generation of mousy flavor. All 27 strains of *Acetobacter aceti* used by Vaughn (1938), produced a mousy flavor when grown in sterile grape juice.

Formation of Toxic Compounds

Ethyl Carbamate Ethyl carbamate (EC), also known as urethane, is a well-known animal carcinogen. The formation of EC takes place due to a chemical reaction occurring between ethanol and a N-carbamyl substance such as urea, citrulline, and carbamyl-P. While urea and ethanol are found in wine at high concentrations due to yeast metabolism, the presence of citrulline and carbamyl-P derives from the arginine metabolism of LAB via the arginine deiminase pathway (Liu et al. 1995). In this reaction, 1 mol of ATP is produced for every molecule of arginine that is consumed.

Arginine is one of the amino acids present in grape musts at higher concentrations. While most of it is metabolized to urea and ornithine by yeast during alcoholic fermentation, some arginine is still present in wine by the end of alcoholic fermentation in amounts ranging from below 0.1–2.3 g/L, being therefore available for the metabolism of wine LAB during MLF. Although formation of EC is favored at low pH, development of LAB forming precursors is favored at high pH.

Due to the fact that EC represents a hazard for human health, the maximal amount of ethyl carbamate in wines has been limited in different countries. A feasible way to reduce its concentration would be to reduce the amount of those compounds involved in its formation. While ethanol must be present in wine, a reduction in the concentration of the nitrogen compounds involved in the spontaneous reaction could be achieved. Therefore, on one side, a reduction of the ability of LAB to degrade arginine via deiminase pathway would positively contribute to this goal and, indeed, is nowadays a criterion of strain selection. On the other, urea levels could be lowered thanks to wine yeasts metabolism but the presence of other nitrogen sources in grape must leads to the transcriptional repression of genes involved in its catabolism, being then exported out of the cell.

Genetic engineering of *DUR* genes, responsible for urea utilization in *S. cerevisiae*, has been shown to reduce the levels of urea in the medium and the potential to produce ethyl carbamate (Coulon et al. 2006; Dahabieh et al. 2009).

Another strategy to reduce EC concentration is by the use of a commercial product based on acid urease from *Lactobacillus fermentum*.

Biogenic Amines Biogenic amines (BA) have been implicated in food poisoning incidents. Adverse physiological effects of these compounds are headache, nausea, hypotension or hypertension, and cardiac and anaphylactic shock. The formation of these compounds is due to the metabolism of LAB, and takes place in a single step by decarboxylation of the corresponding amino acids. The most frequent BA found in wine are histamine, tyramine, and putrescine, which derive from histidine, tyrosine, and ornithine decarboxylation, respectively. However, a maximum of 25 different BA have been described.

Histamine production by LAB seems to be a survival mechanism in a hostile environment such as wine. Import of histidine and export of histamine in a low pH medium would help cells to maintain internal homeostasis by secreting a H^+ against pH gradient (Molenaar et al. 1993).

Formation of these compounds has generally been associated with a lack of hygiene during the winemaking process. Although the production of histamine has traditionally been associated with the presence of spoilage bacteria, mainly *Pediococcus*, later studies have been able to identify *O. oeni* strains producing tyramine, and putrescine, *L. brevis* strains producing tyramine, and *L. hilgardii* strains producing putrescine. In general, the ability to produce BA is strain dependent and is, as in the case of EC, a criterion for strain selection. Molecular methods to detect LAB producing these compounds have also been developed (Marcobal et al. 2005).

Yeast Spoilage

Dekkera/Brettanomyces

Perhaps the most important spoilage microorganisms in the current winemaking industry are yeasts belonging to the genus *Brettanomyces* (or its teleomorph *Dekkera*), generally associated with the production of phenolic and mousy off-flavors and the generation of excessive volatile acidity.

Although the taxonomy of these species has undergone an important number of changes since the genus *Brettanomyces* was first reported, recent taxonomical reviews have delimited the number of accepted species to five: *Brettanomyces anomalus*, *Brettanomyces bruxellensis*, *Brettanomyces custersianus*, *Brettanomyces naardenensis*, and *Brettanomyces nanus* (Kurtzman and Fell 1998; Cocolin et al. 2004). A perfect state is only known for the first two species, *Dekkera anomala* and *Dekkera bruxellensis*, respectively. Nevertheless, separation of these two genera in the context of winemaking does not represent a big issue, they are often referred to as *Dekkera/Brettanomyces* spp., and

current molecular methods do not allow a clear discrimination between them (Loureiro and Malfeito-Ferreira 2006).

While the isolation of several of these species from wine and winemaking environments has been reported, the ones primarily associated to wine are *B. anomalus* (*D. anomala*) and *B. bruxellensis* (*D. bruxellensis*) (Grbin and Henschke 2000; Stender et al. 2001; Cocolin et al. 2004; Oelofse et al. 2009). Wineries and cellar equipment are commonly regarded as the main sources of *Dekkera/Brettanomyces* spp. Its presence in grapes has been studied extensively and, although these yeasts do not seem to represent a fundamental part of its microbiota, the apparent scarce presence can be explained by the inadequate enrichment techniques and short incubation times used in its detection and quantification (Renouf and Lonvaud-Funel 2007).

One of the main spoilage effects of the presence and development of *Dekkera/Brettanomyces* spp. in wine is the production of phenolic off-flavors, mainly ethyl and vinyl-phenols (Chatonnet et al. 1995, 1997). Among this broad family of compounds responsible for the detrimental aroma profile of wine, vinyl-phenols are normally associated to "medicinal" notes at concentrations above 725 μg/L in wine (Chatonnet et al. 1993) while ethylphenols, particularly 4-ethyl derivates, generate odors described and perceived as "leathery," "medicinal," "barnyard," or "animal" (Chatonnet et al. 1995; Licker et al. 1998; Suárez et al. 2007). The generation of these compounds occurs by *Dekkera/Brettanomyces* spp. yeasts in two different steps. First, a phenolic acid decarboxylase (PAD) catabolizes the free hydroxycinnamic acid precursors present in wine (*p*-coumaric, ferulic, and caffeic acid) into vinylphenol derivates (4-vinylphenol, 4-vinylguaiacol, and 4-vinylcathecol, respectively). In a second step, these derivates are reduced via the activity of a vinylphenol reductase (VPR) into their correspondent ethyl-derivative forms (4-ethylphenol, 4-ethylguaiacol, and 4-ethylcathecol, respectively) (Harris et al. 2009). Although several microorganisms, including different yeast, bacterial, and fungal species present in the elaboration of wine, posses the first decarboxylase activity (Cavin et al. 1993, 1997; de las Rivas et al. 2009; Landete et al. 2010; Mtshali et al. 2010), the reduction step appears to happen less frequently (Barthelmebs et al. 2001) although it is particularly effective in *D. anomala* and *D. bruxellensis* (Dias et al. 2003; Harris et al. 2009).

Apart from the production of phenolic off-flavors, *Dekkera/Brettanomyces* spp. yeast strains can also contribute to the undesired increase of the volatile acidity of wine through the production of acetic acid and important volatile fatty acids such as isovaleric, isobutyric, and 2-methylbutanoic acid. Recent studies have proven that the oxygen availability during winemaking is not only a determining factor for the development and survival of *Dekkera/Brettanomyces* but also for acetic acid production (Aguilar Uscanga et al. 2003). Among fatty acids, it is mainly isovaleric acid that can exert a detrimental impact on the sensory properties of wine. Generally perceived as a "rancid," "sweaty," or "cheesy" taint, its production is directly linked to the degradation of L-leucine while the degradation of L-valine and L-isoleucine play a key role in the production of isobutyric and 2-methylbutanoic acid.

Dekkera/Brettanomyces can also contribute to another insidious off-flavor called mousy off-flavor or mousiness. This spoilage, described as a "peculiarly disagreeable flavor in wine, which is closely resembling to the smell of residence of mice" (Snowdon et al. 2006) is frequently detected in association with other faults such as oxidation and volatile acidity (Grbin and Henschke 2000). This defect is not exclusively associated to the metabolic activity of *Dekkera/Brettanomyces* but also linked to the development of acetic and lactic acid bacteria.

Three different chemical compounds have been associated to this kind of off-flavor in wine as mentioned earlier for LAB (Chatonnet et al. 1992; Snowdon et al. 2006). Factors affecting the production of mousy off-flavor by *Dekkera/Brettanomyces* include the concentration of the amino acid L-lysine, as it stimulates the production of ATHP (Snowdon et al. 2006), ethanol, as it appears to be the side chain precursor of both APY and ATHP, and oxygen, which has been proven to have a stimulatory effect on the production of ATHP and ETHP though mainly explained because its availability stimulates the growth and, therefore, biomass of *Dekkera/Brettanomyces* (Grbin 1998).

Last, but not least, *Dekkera/Brettanomyces* spp. can also generate color loss in red wines and contribute to the formation of BA. The first phenomenon can be explained either by the hydrolysis of glucose from the main red pigments extracted from the grapes, that is, monoglucosylated-anthocyanins, which are then converted to its correspondent uncolored pseudobase, or by reducing the formation of vinylphenolic anthocyanins due to its aforementioned hydroxycinnamate decarboxylase activity (Edlin et al. 1998), adducts that contribute to color stabilization.

Production of Biogenic Amines by Yeasts

BA are produced, as in the case of LAB (Moreno-Arribas et al. 2003; Landete et al. 2007), via the decarboxylation of amino acids. A study performed with several strains of different yeast species involved in winemaking (i.e., *S. cerevisiae*, *K. apiculata*, *Candida stellata*, *Metschnikowia pulcherrima,* and *B. bruxellensis*), proved that *B. bruxellensis* produced the highest amount of BA, followed by *S. cerevisiae*. 2-phenylethylamine was the amine produced in highest amounts, followed by agmatine, putrescine, methylamine, cadaverine, and histamine, reaching a total content of BA of 15 mg/L (Caruso et al. 2002).

Film Forming Yeasts

There are certain yeast species that can represent a threat as spoilage microorganisms when SO_2 management and

oxygen availability have not been carefully controlled. Species belonging to the genera *Candida* (*Candida vini*, *Candida stellata*, *Candida pulcherrima*, and *Candida krusei*), *Pichia* (*Pichia farinosa*, *Pichia membranifaciens*, and *Pichia vini*), and the species *M. pulcherrima* can develop noticeable film layers in the interface wine-air when wine is exposed to air.

The development of this film layers does not only represent an obvious cosmetic problem but is also generally linked to the formation of undesired volatile compounds. So, *Candida* species can oxidize ethanol leading to high concentrations of acetaldehyde, volatile acids, and esters (Fleet 1992, 1998; du Toit and Pretorius 2000). In turn, the aforementioned species belonging to the genus *Pichia* can contribute to the formation of acetaldehyde (Zoecklein et al. 1995) while *M. pulcherrima* can contribute to wine taint by producing both ethyl acetate and acetaldehyde (Sponholz 1993; du Toit and Pretorius 2000).

It is noteworthy to mention that, in the production of some particular wines as, for example Sherry, the formation of such films, known as "Flower of yeasts" or "Flor" and mainly consisting of particular *S. cerevisiae* strains, is considered desirable (Martínez et al. 1998; Moyano et al. 2002).

Esters Forming Yeasts

Yeast strains belonging to the species *Hanseniaspora uvarum*, or its anamorph *K. apiculata*, *M. pulcherrima,* and *P. anomala* can be responsible for the ester taint of faulty wine (Sponholz 1993; Loureiro and Malfeito-Ferreira 2003). This fault is mainly linked to the presence of high concentrations of ethyl acetate, though methylbutyl acetate can also contribute to the problem.

Several studies have proven that esters formation is directly related to an excessive growth of strains of the aforementioned species during the early stages of alcoholic fermentation. It has been demonstrated that several *H. uvarum* strains present killer activity against *S. cerevisiae* (Zorg et al. 1988; Radler et al. 1990), which hampers the establishment of this species as the main responsible during the alcoholic fermentation and allows the development of spoilage strains (Zorg et al. 1988; Radler et al. 1990; Sponholz 1993).

Fermentative Yeasts in Sweet Bottled Wine

Though fermentative yeast species play a fundamental role in winemaking, species such as *S. cerevisiae* can be regarded as a spoilage organism if it is found in the wrong place at the wrong time (du Toit and Pretorius 2000). Other yeast strains belonging to the genus *Zygosaccharomyces*, mainly *Zygosaccharomyces bailii*, a yeast species regarded as highly resistant to high doses of preservatives, can represent a major problem for the winemaking sector due to the refermentation of sweet or semidry bottled wine. Its presence in this type of wines is predominantly caused by the addition of grape juice concentrate, generally used to provide some sweetness (Boulton et al. 1998). The problem arises when these juice concentrates are stored for long periods without a strict control of temperature and with low SO_2 levels. As Boulton et al. (1998) indicate, higher SO_2 levels should be maintained for a proper preservation. These high levels will subsequently decrease, as juice concentrates will be diluted when added to the wine.

Being a highly fermentative species, spoilage of bottled wine by *Z. bailii* is characterized by the production of large amounts of CO_2 and also by the production of turbidity and sediment, that can gradually become yellowish or brownish, a decrease of L-malic acid and an increase in the concentration of acetic and succinic acid and esters (Boulton et al. 1998; du Toit and Pretorius 2000).

Other yeast species frequently associated with this type of spoilage are *S. cerevisiae*, *Schizosaccharomyces pombe*, which is also able to produce deacidification through the degradation of malate, and *Saccharomycodes ludwigii*, also producing high levels of acetaldehyde and slimes at the bottom of the bottles (du Toit and Pretorius 2000). Table 28.1 summarizes those yeast species commonly associated to wine spoilage.

Control of Microbial Wine Spoilage As described in the previous sections, wine can be altered by a considerable number of microorganisms at several critical stages. The design of a rigorous quality control strategy in the production system is therefore of great importance in order to assure the microbiological stability of the whole process. Grapes are, in addition to the winery equipment, the main source of microorganisms, including yeasts, molds, and bacteria during the wine-making process. In order to minimize the microbial load that might represent a future threat for the stability of wine in the different stages of production, vines and bunch grapes should present an optimal phytosanitary condition. Several studies have reported the contribution of damaged grapes affected by sour-rot or *B. cinerea* to the microbial populations of wine (Mills et al. 2002; Barata et al. 2008). Therefore, an outstanding preventive measure to avoid future spoilage is the performance of a selection of the grape prior to crushing.

Loureiro and Malfeito-Ferreira (2003) have suggested that rotten grapes, *Drosophila* spp., and wine residues are foci where *Dekkera*/*Brettanomyces* can be found. Therefore, grapes that are discarded in the selection process together with piles of husks and yeast lees should be correctly handled and properly destroyed in order to avoid the entrance of spoilage species by *Drosophila* flies into the winery.

An important aspect to consider in order to avoid the development of film-forming yeasts in tanks of must is oxygen availability. As previously mentioned, yeast responsible for this type of spoilage (*Candida*, *Pichia*, and *Metschnikowia* spp.) present a fully aerobic or weakly fermentative metabolism, which allows for their rapid growth

Table 28.1. Wine Spoilage Yeast and Their Sensorial Effects

Type of Spoilage	Yeast Species Involved	Effects on Wine
"Brett" character	*Brettanomyces anomalus* *Brettanomyces bruxellensis* (or their respective teleomorphs *Dekkera anomala* and *Dekkera bruxellensis*)	Production of phenolic off-flavors, mainly ethyl- and vinyl-phenols. Production of increased volatile acidity through production of acetic, isovaleric, isobutyric, and 2-methylbutanoic acids. Contribution to mousy-off flavor through the production of 2-acetyltetrathydropyridine (ATHP), 2-ethyltetrahydropyridine (ETHP), and 2-acetyl-1-pyrroline (APY).
Production of biogenic amines	*B. bruxellensis* *Saccharomyces cerevisiae* *Kloeckera apiculata* *Metschnikowia pulcherrima* *Candida stellata*	Production of 2-phenylethylamine, agmatine, putrescine, methylamine, cadaverine, and histamine.
Formation of films	*Candida vini* *C. stellata* *C. pulcherrima* *C. krusei* *Pichia farinosa* *P. membranifaciens* *P. vini* *M. pulcherrima*	Production of undesired films on wine surface. Production of high concentrations of acetaldehyde, volatile acids, and esters.
Formation of esters	*Hanseniaspora uvarum* (or its anamorph *K. apiculata*) *M. pulcherrima* *Pichia anomala*	Production of esters, mainly ethyl acetate, and methylbutyl acetate.
Presence of fermentative yeasts in sweet bottled wine	*Zygosaccharomyces bailii* *S. cerevisiae* *Schizosaccharomyces pombe* *Saccharomycodes ludwigii*	Production of high amounts of CO_2. Production of turbidity and sediments. Production of acetic and succinic acids and esters. Reduction in the concentration of L-malic acid.

and colonization of the surface of must stored in unfilled tanks with low sulfite levels and oxygen availability. Adequate levels of sulfite together with a lowered temperature and wine protection from air contact with nitrogen would drastically minimize this problem (Sponholz 1993).

Once the grapes have been crushed and grape juice has been released, several antimicrobial compounds can be used in order to minimize the development of undesired microorganisms.

Chemical Agents

SO_2 is probably the oldest compound used in the food and beverage industries due to its antioxidant and antimicrobial properties (du Toit and Pretorius 2000). Generally present in wine as a result of the addition of sulfite or bisulfite, it has been proven that only the molecular SO_2 form exerts antimicrobial effect. This is only present at low pH, while bisulfite, and sulfite ions prevail at intermediate and high pH values, respectively. Romano and Suzzi (1993) observed that, at wine pH (3.0–5.0), only 5% of the sulfur added remains in the molecular active form.

Generally added to grape must at the crusher, the dosage of SO_2 is considered a crucial and delicate step. While its concentration must be sufficient to inhibit the development of undesired yeasts and bacteria, such as some spoilage yeast present on grape surfaces and AAB, it should allow the activity of those *S. cerevisiae* and LAB strains responsible for conducting the alcoholic and malolactic fermentation, respectively (du Toit and Pretorius 2000). If the wine must undergo MLF, SO_2 is added after this is completed. If concentrations of SO_2 around 40–50 mg/L are present before MLF starts, the development of *O. oeni* strains can be severely hampered and this may favor growth of SO_2 tolerant *Lactobacillus* and *Pediococcus* spp. (Davis et al. 1985).

Despite the generalized use of SO_2 in winemaking, some yeasts species such as *Z. bailii* and *S. ludwigii* can be especially problematic due to their ability to resist high doses of preservatives (>3 mg/L of molecular SO_2) (Thomas and Davenport 1985; Martorell et al. 2007). In order to avoid the

unintentional selection of more-resistant yeast strains, larger and less frequent additions of potassium sorbate are required (du Toit and Pretorius 2000).

There is a global interest to reduce the levels of SO_2 in wine due to its association with toxic, mutagenic, and antinutritional effects (Stammati et al. 1992). However, the reduction of this antimicrobial and antioxidant agent without a viable alternative would increase the risk of wine spoilage and the economic losses derived from it (du Toit and Pretorius 2000).

Other chemical compounds used in the microbiological stabilization of wine are potassium sorbate, commercialized under the name of Sorbistat®, and dimethyl dicarbonate (DMDC), under the name of Velcorin®. The former is generally used to inhibit mold and yeast growth and secondary fermentation. Besides affecting sensory characteristics, this compound presents several disadvantages. It inactivates the growth of yeasts (behaves as a fungistat) rather than killing them (fungicide). In addition, several bacteria present in wine can metabolize it to give a peculiar geranium-like odor (Crowell and Guymon 1975), and, although not described in wine, yeasts belonging to the species *Debaryomyces hansenii* and *Zygosaccharomyces rouxii* can detoxify it producing pentadiene, a compound reported to have "petroleum-like" odor (Casas et al. 1999, 2004). One positive feature about potassium sorbate is that its activity presents a synergistic effect with the inhibitory activities of $SO_2$and ethanol. The concentration of potassium sorbate cannot exceed 300 mg/L of wine (Boulton et al. 1998).

DMDC is a chemical compound that acts synergistically with alcohol and high temperature. Its mode of action on yeasts is the denaturation of some enzymes involved in the fermentative pathway, such as glyceraldehyde-3-phosphate dehydrogenase and alcohol dehydrogenase (Porter and Ough 1982). *S. cerevisiae* cells seem to be especially sensitive to this compound and indeed, in order not to alter the fermentative ability of this yeast and strains of *O. oeni*, some authors have suggested that its addition should be performed during bottling (Renouf et al. 2008). Many countries permit this procedure, but it has recently been shown that the legal dose of 200 mg/L does not effectively inhibit LAB or AAB (Costa et al. 2008). Concerning *Dekkera/Brettanomyces*, a study suggest that 400 mg/L cannot inhibit its growth, though a concentration of 250 mg/L would inhibit its fermentative metabolism (Suárez et al. 2007). In order to prevent ethylphenol formation due to *Dekkera/Brettanomyces* metabolism during aging, antioxidants such as ascorbic and erythorbic acids can be used, as they diminish oxygen availability and therefore the growth of these yeasts.

Egg white lysozyme is a natural enzyme product that has recently been approved for winemaking. It can be added at different stages to inhibit LAB (Bartowsky 2003), in order to prevent spoilage or unwanted malolactic fermentation. Other natural antimicrobials are bacteriocins. Many strains of LAB produce bacteriocins, small polypeptides inhibiting growth of related species. *O. oeni* is more affected by nisin than *Lactobacillus* or *Pediococcus*. The use of bacteriocins is not still allowed in winemaking, but the usage of bacteriocin producing starter cultures would be legal. Some researchers are exploring the potential of wine-related LAB to produce bacteriocins (Navarro et al. 2000; Knoll et al. 2008).

Physical Treatments

The main physical method employed in the microbiological stabilization of wine is the removal of cells by means of a primary filtration using depth filters, which comes normally followed by a secondary membrane filtration. The first one would allow the retention of a higher amount of thicker particles without the risk of silting phenomena while the second one, generally performed using filters with a pore size smaller than 0.45 μm, would completely remove yeast cells. Although this technique is generally employed, some authors have proven that it can severely affect the colloidal structure and cause a loss of color in wine (Suárez et al. 2007). However, some others consider that, if properly performed, filtration does not necessarily have a detrimental sensory effect on the product (Boulton et al. 1998).

Donnelly (1977) reported that air filters decreased the microorganism count by 89% and suggested the usage of positive pressure and air curtains to reduce the number of microorganisms introduced from air outside to the bottling plant.

Emerging technologies could also be considered for removing spoilage microorganisms from wine. There have been some reports on the potential of some of these technologies in winemaking, including high hydrostatic pressure, ultrasounds, and pulsed electric fields (Mok et al. 2006; Jiranek et al. 2008; Marsellés-Fontanet et al. 2009; Puértolas et al. 2009).

Despite all the physicochemical measures described to avoid the development of undesired microorganisms during the different stages of winemaking, it should be kept in mind that strict hygienic procedures in the winery is the most effective measure to diminish the probability of microbiological spoilage that might result in significant economic losses for the winemakers. Corrective actions requires that all those surfaces that are in contact with fruit, must, and wine, including tables, mechanical harvesters, picking lugs, pipes, hoses, and fermentation tanks receive regular cleaning and sanitizing treatments. First, equipment should be cleaned properly using warm high-pressure water if possible, as it seems to be the most effective way of removing organic debris. If the use of brushes is needed, only those with soft-bristle must be used in order to avoid the scratching of the stainless steel surfaces. After this preliminary cleaning, surfaces should be cleaned using detergents that generally contain acids, alkali or surfactants (Fugelsang and Edwards 2007). Further treatments should include a rinsing step generally performed with phosphoric acid followed by the use of sanitizers, which allow

a reduction of the viable cell population to acceptable low numbers. This sanitation can be performed with, among others, steam, chlorinated solutions, iodophors (solutions containing iodine and an acid), peroxides, quaternary ammonium salts or even ozone or ozonated water, an effective compound against bacteria, fungi, viruses, protozoa, and fungal and bacterial spores (Khadre et al. 2001; Kim et al. 2003; Pascual et al. 2007). For a review of all the compounds, methods, schedules, and documentation used in the cleaning and sanitation of wineries see the review by Fugelsang and Edwards (2007).

Used wooden barrels represent another significant source of contaminant and spoilage microorganisms in a winery. Unlike the rest of the surfaces present, mainly made of stainless steel, barrels employed in wine aging are generally made of French or American oak wood. The natural properties of this material, presenting small pores, cracks, and staves, allow for a gentle aeration of the wine to occur over the aging period. However, these small air channels can represent an optimal niche for the survival of different yeasts, such as *Dekkera/Brettanomyces*. Neither a thorough clean followed by sanitation with burning sulfur inside empty barrels nor a cold water rinse, followed by a 70°C hot-water rinse and steaming under low pressure (0.5 kg/cm^2) seem to be sufficient to ensure complete elimination of microorganisms in wood staves (Laureano et al. 2003).

Cork Taint

Cork stoppers can also be a source of wine contamination with different microorganisms. Cork can harbor different fungi belonging to the genera *Aspergillus*, *Cladosporium*, *Chrysonilia*, *Monilia*, *Mucor*, *Penicillium, Paecilomyces,* and *Trichoderma*, bacteria corresponding to the genera *Bacillus*, *Micrococcus*, *Streptococcus,* and *Streptomyces* and adventitious yeasts belonging to the genera *Candida*, *Cryptococcus*, *Rhodotorula*, and *Sporodiobolus* (Davis et al. 1982; Lee and Simpson 1993; Prak et al. 2007). However, these do not normally represent a serious threat because they do not survive in wine. Contamination of corks with *S. cerevisiae* and *S. ludwigii* strains has also been reported and attributed to an inadequate cork routine treatment before packaging with sublethal doses of sulfite (Loureiro and Malfeito-Ferreira 2003).

However, the major cork-related concern for winemakers is cork taint. Some compounds that might be present in cork stoppers can be transformed by microorganisms and the metabolic products transferred to the wine. Several volatile compounds, such as chloroanisoles, guaiacol, pyrazines, 1-octen-3-ol, 1-octen-3-one, and 2-methylisoborneol have been reported to contribute to this so-called cork taint, normally perceived as a moldy, earthy, or musty off-flavor (du Toit and Pretorius 2000). However, 2,4,6-trichloroanisole (TCA) is the compound more often associated to cork taint, with a very low sensory threshold (1.4–10.0 ng/L). The origin of this compound is attributed to the fungal detoxification of polychlorophenols (Álvarez-Rodríguez et al. 2002), massively used as fungicides and pesticides in cork-oak (*Quercus suber*) forests, or generated during the hypochlorite bleaching of stoppers, a practice that is nowadays abandoned in favor of alternative bleaching methods.

The determination of the origin of TCA in wines is of great practical significance. It is important to find if the TCA in wine is due to its release from the cork stopper or, alternatively, if the wine was tainted prior to bottling.

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29
Processing of Citrus Juices

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Abstract: The chapter on citrus juice processing gives a comprehensive and the latest information related to various varieties suitable for juice production, factors affecting quality of juice, different types of citrus juices, steps in production of juice, advances in pasteurization of juice, bitterness and debittering processes, packaging and storage of citrus juices, production of orange juice concentrate, production of grapefruit juice, lemon juice, lime juice, freeze-drying of orange juice, preparation of beverages from orange juice, by-products utilization from citrus processing industry, and future research needed in this area.

INTRODUCTION

Among citrus fruits, orange, which includes "bitter (sour) orange" (*Citrus quarantium*), "sweet orange" (*C. sinensis*), and "mandarin orange" (*C. reticulata*), is grown in many regions of the world. Nagy et al. (1977) reported over 100 orange varieties of commercial importance. The estimated world production of oranges was 68.5 million tons in 2008 (FAOSTAT 2008). Brazil ranked first in orange production (18.53 million tons) followed by the United States (9.14 million tons); India, Mexico, China, Spain, Iran, Italy, Indonesia, and Egypt were other major producers (Table 29.1). Brazil also accounts for about 80% of the frozen, concentrated orange juice (FCOJ) exported to the world and the United States is the second largest orange juice exporter. Other orange juice-producing countries are Greece, Israel, Italy, Mexico, Morocco, Spain, Turkey, Argentina, Australia, and South Africa. The major markets for orange juice in the world are the United States, Europe, Canada, and Japan.

The "sweet oranges" are classified into four groups: "common orange," "acidless orange," "pigmented orange," and "navel orange" (Hodgson 1967). The "acidless orange" is of minor commercial importance. Among the "common oranges," Valencia, Pineapple, Hamlin, Parson Brown, Jaffa, and Shamouti are grown in various parts of the world. Pera, Corriente, and Bahianinha are some of the "acidless orange" grown especially in Latin America. The "pigmented oranges" are widely grown in the Mediterranean region. The principal cultivars include Doblefina, Eutrifina, Moro, Tarocco, Ovale, Sanguinello Commun, Ruby Blood, and Maltese Blood. "Navel oranges" are primarily grown for fresh market because of their tendency to develop a bitter taste in processed products. The Washington navel is probably the most important cultivar of this group; Frost Washington and Dream are other promising cultivars. Many fine-quality "sweet orange" varieties, including Tien cheng, Lui cheng, Sekkan, Yinkan, and Hwang Kuo, are grown in China.

"Mandarins" are a group of loose-skinned oranges of primary importance in the Far East, but they are becoming popular in the United States. The Satsumas are an important citrus crop in Japan; Dancy tangerine is widely grown in the United States; and Clementine is an important cultivar of the Mediterranean region, especially Algeria. Other commercial varieties are King, Robinson, Page, Ponkan, and Murcott. The cultivar Murcott, according to horticulturists, could be

Table 29.1. Estimated Orange, Grapefruit, Pommelos, Lemons, and Limes Production (Million Tons) of the Top Ten Countries of the World in 2008.

	Oranges		Grapefruit and Pommelos		Lemons and Limes	
Rank	Country	Production	Country	Production	Country	Production
1	Brazil	18.54	United States	1.40	India	2.43
2	United States	9.14	China	0.61[a]	Mexico	2.22
3	India	4.40	Mexico	0.39	Argentina	1.26 F
4	Mexico	4.31	South Africa	0.34	Brazil	0.97
5	China	3.68[a]	Israel	0.24	China	0.92[a]
6	Spain	3.37	India	0.19 F	Iran	0.69
7	Iran	2.62	Argentina	0.18 F	Spain	0.69
8	Italy	2.53	Turkey	0.17	Turkey	0.67
9	Indonesia	2.32	Cuba	0.17	United States	0.56
10	Egypt	2.14	Brazil	0.07 F	Italy	0.52
11	Pakistan	1.72 F	Tunisia	0.07 F	Egypt	0.33
12	South Africa	1.52	Sudan	0.07 F	Peru	0.24
13	Turkey	1.43	Belize	0.06	South Africa	0.23
14	Greece	0.80	Bangladesh	0.05	Chile	0.18 F
15	Morocco	0.78 F	Iran	0.04	Syria	0.14
	World	68.5	World	5.5	World	10.6

Source: FAOSTAT (2008).
F, FAO estimate.
[a]Unofficial figure.

a tangelo, hybrid of mandarin and orange. Temple, which is also believed to be a tangelo, has excellent flavor and is widely planted in the United States, especially in Florida. The most important tangelo cultivars are Orlando and Minneola, both of which are a cross of Dancy tangerine and Duncan grapefruit.

VARIETIES SUITABLE FOR JUICE PRODUCTION

The "sweet orange" varieties, blood, navel, and the common white-fleshed (non-blood) oranges, yield more juice and soluble solids when grown in conditions other than a dry Mediterranean climate. Pera, Hamlin, Parson Brown, and Natal are the main varieties of oranges grown in Brazil. The important varieties, in the United States, Florida, are Temple, Parson Brown, Pineapple, Hamlin, and Valencia (similar to the Pera). The Mediterranean region is a secondary center of diversity in the sweet orange species. Here, many new and improved sweet orange varieties have developed through bud mutations and chance seedlings. These include the high-quality blood oranges (Sanguinelli of Spain) and the high-quality standard sweet orange varieties. The Spanish Sanguinelli, Moro, and Tarocco varieties have a distinct flavor and are more likely to show blood coloration than other blood orange varieties. A comprehensive account of citrus varieties suitable for processing has been reported by Nagy et al. (1977).

All common white-fleshed, round orange varieties are suitable for processing, but some are preferred to others. The Valencia is the most widely grown variety for processing. The early-maturing varieties, such as Hamlin, Parson Brown, Marrs, and Salustiana, tend to produce poorer juice color, lower yields of soluble solids, and more after-processing bitterness (if harvested early) than most mid-season and late varieties. Good fertilization practice may improve processing quality of early-maturing varieties, but it will not convert them to high-quality varieties. The Hamlin, Parson Brown, Pineapple, and Valencia sweet orange varieties are used for the production of processed juice in Florida.

The major deterrents of using Washington navel oranges for processing are after-processing bitterness in the juice and low yields. The new Lane's Late navel variety from Australia is a distinct improvement over the Washington navel. It produces higher yields of soluble solids and juice than fruit grown in Mildura, Victoria. Juice from Belladonna variety has an appreciably higher limonene concentration than Valencia (di Giacomo et al. 1976). Baladi and Succari varieties of sweet orange are also recommended for production of juice (Noaman and Husssein 1973).

Some seedy varieties have good processing quality, but the seeds are an objectionable feature in the juice extraction. The various common round sweet orange varieties of the world are classified according to maturity and seediness. Parson Brown and Mars Early are early seedy, while Hamlin, Diller, and Salustiana are early seedless varieties. Because of mid-to-late season maturity, presence or absence of seeds, and good flavor, Mediterranean varieties Verna, Cadenera, Ovale Calabrese, and Belladonna are good for processing. The Calderon, Tajamur, Natal, and Pera have been used successfully for processing in South America. Shamouti variety, reported to develop after-bitterness, has been processed extensively in Israel.

Valencia is a preferred variety for juice production (Anon 1993a). A selection of "Valencia" produced deeper orange colored juice than from the normal "Valencia" variety (Stewart et al. 1975). The improved color was related to the higher cryptoxanthin (152 μg/mL) pigment in juice compared with normal "Valencia" juice (90 μg/mL). In Australia, Valencia and navel oranges dominate (Chandler and Nicol 1983). However, because of alternate (year) bearing in Valencia and possibility of bitterness development in juice processed from navel oranges, the Australian juice processors have had supply problems. Trials carried out on other varieties show that Hamlins performed well on Rough lemon with good juice yield, high total soluble solids (TSS) content, high TSS:acid ratio, low acidity, negligible bitterness, and good processing quality when harvested after June. Silettas on Rough lemon also performed well, but not as sweet as Hamlins and had lower TSS:acid ratios. Of the other cultivars, Mediterraneans and St. Michaels showed promise. The former gave a very acceptable juice in September, whereas the latter does so if the fruit is allowed to remain on the tree for a longer time. Minimum juice yields of 38.0%, 30.6%, 43.2%, and 42.5% for Washington, Thompson, Chilena, and Valencia cultivars, respectively, are reported to be important for profitability (Erazo et al. 1984; Giannone and Matliano 1977).

Four commercial varieties of Malta oranges, Blood Red, Pineapple, Jaffa, and Valencia Late were analyzed for physicochemical composition and suitability for processing and waste utilization. Recovery of juice, peel, and pomace in Malta variety ranged from 50.8% to 55.4%, 23.2% to 30.9%, and 13.6% to 22.1%, respectively. New citrus hybrid, Ambersweet (1/2 orange, 3/8 tangerine, and 1/8 grapefruit), yields orange juice with good color and flavor, and the fruit is easy to peel and matures early in the season (Wade 1995). The processing properties of three early orange cultivars (NT-18, NT-34, and NT-36) in two successive seasons were studied by Pinera et al. (1995). They concluded that the weak aroma, flavor, and pale yellow color of juice from these early cultivars of Cuban oranges would limit their use for manufacture of fresh and concentrated orange juice, although ascorbic acid content was adequate and yields were high.

Physical characteristics are the most important parameters in developing proper standards for the design of grading, conveying, processing, and packaging systems for the citrus fruits. Omid et al. (2010) have used an image processing technique for estimating the mass of citrus fruits to design and develop sizing systems (Altan 1995). Universal Testing Machine has also been used for assessing the rheometrical

and textural characteristics of citrus fruits in terms of their suitability for processing (Pallottino et al. 2011).

MANDARINS

The Kinnow (King × Willowleaf) was released by H.B. Frost at the University of California Citrus Research Centre at Riverside in 1935. It is commercially grown in Arizona and California in the United States and in Punjab states of India and Pakistan. Kinnow orange has been analyzed for physicochemical composition, and suitability for processing and waste utilization. Recoveries of juice, peel, and pomace in Kinnow were 55.8%, 26.8%, and 17.4%, respectively (Pruthi et al. 1984). The composition of Kinnow juice is reported as total solids, 11.15%; TSS, 10.0%; pH, 3.6; titratable acidity, 1.15%; reducing sugars, 3.2%; total sugars, 6.74%; pectin, 0.29%; ascorbic acid, 12.20 mg; and β-carotene, 1.35 mg (Sandhu and Bhatia 1985). Sandhu and Singh (1999) studied the factors affecting the physicochemical and organoleptic properties of Kinnow juice. Incorporation of additives in the juice considerably improved the organoleptic quality of Kinnow juice.

Several high-quality mandarins (Ponkan, Tankan, and Dancy types) have come out of China. Dancy, Robinson, Orlando tangelo, Nova, Minneola tangelo, Page, and Kinnow juice are suitable for blending with orange juice to improve the color of the finished product. Orlando tangelo juice does not develop postprocessing bitterness, and Minneola tangelo contains no limonin and is suitable for processing. Page and Nova have good processing quality (Scott and Hearn 1966). Dancy, Robinson, Orlando tangelo, and Nova juices do not develop off-flavors and are suitable for blending to the juice of Temple mandarin. Mandarins are susceptible to losing flavor during storage, thus have a short shelf life. Storage temperature and time have been shown to influence sensory quality of mandarins by altering TSS, acidity, and aroma volatile composition (Obenland et al. 2011).

SWEET ORANGE (*C. sinensis*)

Maturity Characteristics and Juice Quality

The maturity of fruit is assessed from color, juice content, TSS, and acidity of the juice. The different varieties of oranges have been reported to produce juice yields of 26.3–59%, 8.8–14.8% TSS, and 0.64–1.77% acid content (Gaetano 1975). Before harvest, fruit for processing must meet certain minimum maturity requirements established by the regulatory agencies. These requirements may vary from one citrus-producing area to another. These requirements are usually based on (1) color break, (2) minimum juice content, (3) minimum acid content, (4) minimum percentage of TSS, and (5) Brix:acid ratio. The single-strength orange juice as per USDA shall have specific gravity (at 20°C) of 1.0473, that is, 11.75°Brix. There is a steady rise in specific gravity at 20°C, soluble solids, reducing and total sugars, Brix, ratio of soluble solids to acidity, ascorbic acid, formol index, and pH, but a decrease in acidity and ash contents of juice obtained from Sanguinella oranges harvested between 9 January and 26 March.

Color scores of Hamlin orange (*C. sinensis* L. Osbeck) juice increase with late harvesting (Wutscher and Bistline, 1988). The effect of time of harvest on alternate cropping yields and fruit quality of Valencia orange trees are subject to the alternate cropping phenomenon. There is a tendency for soluble solids, acid, and juice concentration to decrease, and for fruit weight and peel thickness to increase with delay in harvesting (Gallasch 1978). Chemical structure of carotenoids has been shown to influence the color of orange juice. According to Melendez-Martinez et al. (2010), the carotenoids better related to the hue are not necessarily the same as those mainly related to the chroma. The pigments mainly related to h_{ab} were zeinoxanthin, lutein, and a mixture of violaxanthin isomers, while the ones mainly related to Cab were zeaxanthin, (9Z)- or (9'Z)-antheraxanthin, and zeinoxanthin. As some carotenoids are used as colorants and the color of orange juice affects the consumer choice, these findings have significant importance for the citrus industry. In a later study, Melendez-Martinez et al. (2011) developed a novel, rapid, and simple method for the assessment of the total carotenoid content of foods based on multipoint spectroscopic measurements.

The stage of maturity, variety, and processing affect the chloramine-*T* values and total amino acid content of orange juices (Maraulja and Dougherty 1975). The total amino acid content of the juices increased from the beginning of the "Hamlin" season to the "Pineapple" maturity stage, and declined slightly during the "Valencia" season. All three varieties show higher chloramine-*T* values as maturity increases. Both sets of test results are slightly higher for hard squeeze juices than for soft squeeze juices. The stage of maturity, variety, and processing also affects the color, cloud, pectin, and water-insoluble solids of orange juice (Huggart et al. 1975). "Valencia" juice had the best color, and average color values were higher for soft squeeze-soft finish than for hard squeeze-hard finish juices. "Hamlin" juice showed less cloud than the other cultivars. Total pectin and water-insoluble solids increased in juices with increased extractor–finisher pressures. It has been observed that the concentration of some amino acids in orange juice vary with the harvesting date, while that of others remain practically constant in the samples from Brazil and various Mediterranean countries (Wallrauch 1980a).

Juice produced at Piana di Rosarno from Biondo Comune oranges between December and May when analyzed (di Giacomo et al. 1975a, 1975b) produced the following values: degree of concentration 5.75–6.25; acidity (as citric acid in 10°Brix) 0.90% (May) to 2.15% (December); soluble solids:acidity ratio 5.26:1 (December) to 12.32:1 (May);

formol index (in 11°Brix) 1.53–2.17; ascorbic acid 5.44–7.73 mg/unit Brix; reducing sugars 50.56–74.12% of total sugars; β-carotene 3.0–6.11%; carotene esters 18.58–22.67% of total carotenoids; alkalinity of ash 47.10–57.60%, with 34.80–53.80% K, 0.12–0.37% Na, 1.74–2.91% Ca, 1.95–2.65% Mg, 2.63–4.04% P, and 0.020–0.113% Fe; Na:K ratio 1:114–1:363; flavonoids 1420–1940 ppm. Acidity, total sugars, ash, K, and Cl measured in samples of Israeli orange and grapefruit juices over growing seasons were measured and the total sugars and chlorides were found to be strongly affected by the growing season (Cohen 1982).

The early, mid-season, and late sweet orange varieties are available for processing throughout most of the periods of the year. Specific types are classified according to the time required between blossoming and harvesting, and the time of year when fruit normally gains maturity. Throughout the United States, citrus trees normally blossom at about the same time, between late February and mid-April. Early-season Parson Brown and Hamlin usually mature from October through December in Florida and Texas. Mid-season Pineapple orange matures during the first quarter of the year (January–March). Late-season cultivars (Valencia) mature from around mid-March through June and in some seasons are harvested even up to July depending upon weather (Harding et al. 1940).

Washington navel and Valencia are predominant cultivars in California and Arizona. Washington navel matures from November to May, and Valencia matures from March through October. Because of climatic differences in these two states, times between bloom and harvest are longer there than in Florida and Texas. In California and Arizona, most of the fruits are marketed fresh, but excess fruits or fruits unsuitable for fresh market are processed. In Florida and Texas, most mid-to-late season fruits are processed into products. Although considerable early-season fruits are marketed fresh, more than half of the Hamlins and Parson Browns are processed.

FACTORS AFFECTING THE QUALITY OF JUICE

The juice quality would somewhat vary with growing region and climate, variety, age of tree, rootstock, scion, fertilization, irrigation frequency, harvest date, tree spacing, and position of fruit on the tree, etc. The following describes factors affecting juice quality.

Rootstock

Isaacs (1980) summarized the effects of rootstock on quality of the juice from mandarins. Bitterness development was found to be affected by rootstock; mandarins budded on Rough lemon rootstock produced juices that developed bitterness soon after extraction. Tree spacing and rootstock affected growth, yield, fruit quality, and freeze damage of young "Hamlin" and "Valencia" orange trees (Wheaton et al. 1986). The influence of nine rootstocks on the composition of juice from "Valencia Late" and "Moro" cultivar oranges was studied (di Giacomo et al. 1977), with special reference to limonene contents. The rootstock could be classified into three groups: (1) low limonene contents (less than 10 ppm) in pasteurized orange juice; (2) intermediate limonene content (10–20 ppm); (3) high limonene content (greater than 20 ppm). With respect to juice yield, Brix:acid ratio, and limonene content, best results were obtained with the rootstock mandarino Cleopatra. Hamlin sweet orange trees propagated on 19 rootstocks were evaluated for yield, juice quality, and economic returns by Castle et al. (2010a). The results produced highly significant correlations between type of rootstocks used and the economic returns obtained. In another study, Castle et al. (2010b) evaluated the performance of "Valencia" sweet orange trees on 12 rootstocks at two locations in Florida and indicated the economic returns as the basis for rootstock selection. Castle and Baldwin (2011) have evaluated worldwide scion selections propagated onto Swingle citrumelo rootstock for fruit yield and juice quality. Several early-season selections (Early Gold and Itaborai), and a mid-season selection (Vernia) for their better juice color and flavor qualities were released for commercial cultivation.

Irrigation and Climate

Juice yield, soluble solids, citric acid, suspended solids, and pH of Marrs and Valencia oranges are affected by irrigation plus rainfall (Wiegand et al. 1982). Vitamin C, juice yield, pH, and suspended solids are only occasionally affected by irrigation treatment where rainfall contributes about half of the annual water requirement (Cruse et al. 1982). Citric acid content of "Valencia" orange juice was consistently higher in less frequently irrigated treatments, regardless of rainfall. Irrigation increased fruit production by 39–64% over the no irrigation control (Koo and Smajstrla 1985).

The climate has effect on the quality of Corsican clementines with respect to soluble extract, acidity, and maturity index and these parameters are influenced by rainfall, with low quality associated with high rainfall prior to harvest and vice versa (Sanchez et al. 1978). Fruit quality was not appreciably affected by temperature greater than 12.8°C. Winter drought stress has been shown to delay flowering and avoid young fruit loss during late-season mechanical harvesting without any negative impact on yield or fruit quality of Valencia orange trees (Melgar et al. 2010). Oleocellosis or oil spotting on the peel of citrus fruits is a postharvest injury caused commonly by improper handling (Melgar et al. 2011). According to their results, the winter drought stress did not affect the fruit size, juice content, TSS, acidity, fruit oleocellosis, and fruit drop in April.

Fertilization

The Brix:acid ratio, formol number, total acidity (TA), citric, malic and isocitric acid contents, citric:isocitric ratio, K, PO_4, Mg and Ca, and glucose:fructose ratio are affected by the harvesting time (Wallrauch 1980b). Higher levels of nitrogen fertilization of Satsuma mandarin trees increased fruit weight, peel ratio, Brix of juice, Kjeldahl and amino-N, alkalinity of juice, and levels of the main amino acids in the juice (Kodama et al. 1977). Phosphorus contents decreased, but no effect was discernible on ash and ascorbic acid contents.

Age of Tree

Age (years) of tree and cultivar influence the juice content, TSS, acidity, and ripeness index of oranges (Frometa and Echazabal 1988). The number of years necessary to obtain reliable results on juice characteristics was determined as four for early cultivars of "Hamlin," "Salustiana," and "Victoria."

Position and Fruit Load on Tree

The color of the fruit and juice is influenced by the position of the fruit on the tree (Stewart 1975). The juice color was consistently brighter and deeper from orange fruits growing on the north side of the trees. Peel colors showed similar trends to those of juice. In the Seto Inland Sea area, Satsuma mandarin (*Citrus unshiu* Marc. cv. Sugiyama) fruit quality is expressed in Brix, and titratable acidity is little affected by variations in microclimate depending on the fruit locations within the tree canopy (Daito et al. 1981). Fruit load and fruit thinning influenced the fruit character, shoot growth, and flower bud formation in the following season in young Satsuma mandarin ("Miyagawa Wase") trees (Morioka 1987). The use of near infrared (NIR) spectroscopy as a nondestructive method to compare the quality of intact orange fruits has been proposed (Cayuela and Weiland 2010). They studied various quality parameters, such as TSS, acidity, maturity index, flesh firmness, juice volume, fruit weight, rind weight, juice volume to fruit weight ratio, fruit color index, and juice color index. Their results indicated good performance of the predictive models, especially for the direct NIR prediction of soluble solids and maturity index.

Pretreatments

Peel oil composition and processed juice quality of Hamlin oranges (*C. sinensis* L. Osbeck) degreened with ethylene gas showed no significant differences between control and experimental samples in flavor tests, vitamin C levels, Brix:acid ratios, color scores, or volatile peel oil constituents (Moshonas and Shaw 1977). Forty-three peel oil compounds were identified, 29 of which are reported for the first time specifically as constituents of Hamlin orange peel oil. The internal edible portion of citrus fruit (flesh) often reaches maturity while the external peel is still green. To improve market acceptability of such citrus fruits, degreening practice based on ethylene exposure is recommended, as it favorably affects the fruit internal and nutritional quality (Mayuoni et al. 2011).

Ethephon, gibberellic acid (GA), and light exclusion affect rind pigments, plastid ultra structure, and juice quality of Valencia oranges in green, colored, and re-greened fruits (El-Zeftawi and Garrett 1978). In the early phase of re-greening, an increase occurs in the plastid lamellae in the two outer layers of rind cells, corresponding to decreases in carotenoids and starch. Plastids containing lamellae without grana stacks are most frequent in re-greened fruits. GA inhibits carotenoids and increases chlorophylls at the re-greening stage only, but hastens the loss of starch at the colored stage, whereas ethephon decreases chlorophylls and increases starch contents in the plastids.

Light exclusion slightly decreases flavonoids and polyphenols in juice of green and colored fruits, and carotenoids in colored fruit; however, ethephon increases flavonoids and polyphenols at the green and re-greening stages and carotenoids at the colored and re-greened stages, but carotenoids are decreased at the green stage. GA decreases flavonoids and polyphenols in the juice of green and colored fruits but decreases carotenoids only at the green stage. Six growth regulators (i) GA (10–20 ppm); (ii) Planofix (200–300 ppm); (iii) 2, 4, 5-T (50–100 ppm); (iv) 2, 4, 5-TP (100–200 ppm); (v) Ethrel (200–300 ppm); and (vi) lead acetate (250–500 ppm) were sprayed two to three times on mandarins (Kaula) and sweet oranges (Kinnow, Pineapple, and Dancy) as preharvest sprays, to determine their effect on granulation and bitterness of juice. Treatments (i) and (ii) effectively reduced the bitterness of juice; bitterness was not observed up to 12 hours after juice extraction in treatment (ii). Hot water dipping (HWD) treatment at 41°C for 20 minutes enhanced peroxidase (POX) and catalase (CAT) activities in both fruit peel and juice, including the content of free phenolics in juice. However, HWD did not affect weight loss, juice yield, TSS, TA, ascorbic acid, or reducing sugars contents (Bassal and El-Hamahmy, 2011). A new approach to the control of postharvest pathogens, while maintaining fruit quality, has been the application of citrus peel essential oils containing coatings on the fruits (du Plooy et al. 2009). This technique will eliminate the use of fungicides based on synthetic chemicals.

ORANGE JUICE: TYPES AND THEIR CHARACTERISTICS

Juice is the cell sap present in the cell vacuoles and expressed by squeezing from sound fruits. Orange juice is consumed in a natural cloudy state. The clarification would impair the appearance and flavor of the juice. Different types of orange juices are available in the market. The chilled single-strength orange juice has limited shelf life and requires installation of

expensive refrigerated tanks. The conventional pasteurized single-strength orange juice in cans is widely used, but the FCOJ is a commodity traded worldwide. Concentrated juices are distributed in large containers as a base for the manufacture of a variety of soft drinks. The same is reconstituted to single-strength juice for direct consumption. Comminuted orange products are prepared for use in beverages. Dehydrated juices in powder form are also available in the market.

Fresh Juice

Freshly squeezed, unpasteurized orange juice is desired because of its fresh aroma and flavor, but the shelf life is less than 20 days at 1°C, as it is highly susceptible to microbial spoilage. The manufacturing operations from fruit washing to packaging must be exceptionally clean to minimize product spoilage. Pectin esterase activity in unpasteurized juice results in loss of cloudiness (Wicker et al. 2003). Due to this reason, product has to be maintained near freezing point throughout its distribution; however, cloud separation, flavor changes due to reactions with oxygen, and color instability still occur at a slower rate. Several days after packaging, diacetyl flavor, fused oils, and other microbiologically generated off-flavors make the product inferior to good quality pasteurized juice. There is a risk of food-borne illness from consumption of unpasteurized packaged fruit juice. This includes salmonellosis from consumption of contaminated fresh orange juice. FDA has proposed juice regulations to mandate the use of hazard analysis and critical control point (HACCP) by most juice-producing companies and procedures for implementing HACCP have been published (Schmidt et al. 1997).

The method of juice extraction as well as the time–temperature combination used for pasteurization had significant effect on the quality of Nagpur orange during storage (Pareek et al. 2011). The juice extracted with a screw-type juice extractor and processed at 65°C for 15 minutes gave better quality in terms of TSS, acidity, ascorbic acid, sugars, and nonenzymatic browning during 6 months of storage at room temperature. The contents of naringin and limonin in extracted juice were minimum with the screw juice extractor and the processing at 65°C for 15 minutes. The shelf life of fresh orange juice filled in nanocomposite low-density polyethylene (LDPE) films containing Ag and ZnO nanoparticles and stored at 4°C has been studied by Emamifar et al. (2010). They observed the least degradation in ascorbic acid (80.50 mg/100 g), lesser development of brown pigments (OD = 0.23), and lower loss of color ($\Delta E = 6.0$) in fresh orange juice packaged in pouches containing 0.25% nano-ZnO during storage at 4°C for 28 days. Compared with pure packaging materials, antimicrobial nanocomposite packages with Ag and ZnO as an alternative nonthermal technique can extend the shelf life of fresh orange juice up to 28 days.

The blood oranges are the major cultivated varieties of *C. sinensis* (L.) in Italy. Although fresh blood orange juice has high antioxidant activity because of a rich profile of phenolics, its preservation is usually done by thermal treatments that affect its nutritional and sensory quality. Fabroni et al. (2010) have proposed a milder continuous high-pressure carbon dioxide (HPCD) process suitable for use on a commercial scale. The HPCD stabilized blood orange juice retains its physicochemical, antioxidative, and sensory quality for a shelf life of 20 days. Qiao et al. (2010) have compared the volatile compounds and chemical and physical properties of orange juice obtained from different parts of the Jinchen fruit (peeled juice, pulp juice, and whole fruit juice). The whole fruit juice was found to have the highest amounts of volatile compounds.

The distribution of volatile compounds in pulp, serum, and cloud of freshly squeezed orange juice has no relationship between the retention of aroma compounds in pulp or cloud and their lipid content or composition (Brat et al. 2003). Juice monoterpene and sesquiterpene hydrocarbons are primarily present in the pulp (74.0% and 87.2%, respectively) and cloud (7.3% and 14.9%, respectively). Esters and monoterpene alcohols are mainly found in the serum (90.4% and 84.1%, respectively). Long chain aliphatic aldehydes tend to concentrate in the pulp. The relative proportions of individual volatile compounds are similar in the pulp and cloud. Half of the alcohol insoluble residues in pulp and cloud are made of noncell wall proteins and the rest are made of cell wall materials. Pulp and cloud total and neutral lipids have similar fatty acid distribution, although cloud is much richer in total lipids than the pulp. The composition of orange juice in terms of total solids, sugars, acidity, and pectin is given by Money and Christian (1950) (Table 29.2). Table 29.3 shows the vitamin (USDA 1957) and mineral contents (McCance and Widdowson 2002).

Due to the presence of various bioactive compounds, such as flavonoids, flavones, and furocoumarins, there is a growing interest in sour orange (*Citrus aurantium* L.) products, mainly the liqueurs and marmalades (Barreca et al. 2011). A simple and accurate method has been reported to simultaneously separate and determine bioactive compounds by high-performance liquid chromatography coupled with diode array detection and electrospray ionization mass spectrometry (HPLC–DAD–ESI/MS) in citrus fruits (He et al. 2011). The volatile flavor constituents from different types of orange juice have been characterized. Using solid phase microextraction–GC-MS, Niu et al. (2008) have identified 73 components, including 9 esters, 14 alcohols, 4 ketones, 8 aldehydes, 34 terpenic hydrocarbons, 3 alkanes, and BHT in 4 samples of fresh-sequeezed juice and 5 samples of "not-from-concentrate orange juice" and 2 samples of juice "reconstituted from concentrate." In another study of three samples from "not-from-concentrate orange juice, Zhang et al. (2008) have identified 45, 52, and 51 aroma compounds in orange juices from Spain, Australia, and China, respectively. The major aroma compounds were hydrocarbons, esters, alcohols, ketones, and aldehydes. The aroma compound with the highest content was D-limonene (82%) in Spanish orange

Table 29.2. Total Solids, Total Sugars, Acidity, and Pectin Contents of Oranges

Fruit	Total Solids (%)	Total Sugars (%)	Acidity No. (cc 0.1 N/100 g)	Pectin (% as Calcium Pectate)
Orange (*bitter*)				
Edible portion	13.59	5.49	3.30	0.86
Peel and pith	27.27	5.86	0.46	0.89
Juice	10.72	5.74	3.77	
Orange (*sweet*)				
Edible portion	12.98	7.88	0.79	0.59
Peel and pith	25.52	6.81	0.27	
Juice	11.09	8.47	1.17	0.13

Source: Money and Christian (1950).

juice, 55.03% in Australian orange juice, and 60.96% in Chinese orange juice. The phenolic compounds isolated from pomace of grape cultivars have shown effective antifungal properties in orange juice against *Zygosaccharomyces rouxii* and *Z. bailii* (Sagdic et al. 2011).

Orange juice is the most popular fruit beverage enjoyed for its flavor and nutritional quality all over the world. However, orange juice if contaminated with an acidophilic spore-forming bacterium, *Alicyclobacillus acidoterrestris*, coming from the soil, can results in off-flavors (Bianchi et al. 2010). These researchers developed a rapid and reliable analytical method based on the volatile profile by dynamic headspace extraction followed by GC-MS analysis to early detect the spoilage of orange juice by *A. acidoterrestris*.

Pasteurized Juice

The consumer preference is increasing toward single-strength chilled juice. The necessity for food safety and quality requires pasteurization of juice before packaging and distribution. Many important nutrients in citrus juices including sugar, acid, vitamins, minerals, some flavonoids, and other components are quite heat stable under the conditions of pasteurization. Pasteurization process is designed to inactivate the thermally stable isoenzyme of pectin esterase. The temperature necessary for enzyme inactivation is higher than that required for killing the microbes. At a lower pH, the enzyme inactivation is achieved in a shorter time, thus producing a better quality juice. Juice treatment with carbon dioxide at above supercritical conditions has the advantage of enzyme inactivation without heat, thus preserving the natural flavor. The juice maintains color and cloud stability throughout its shelf life (Lotong et al. 2003).

Aseptic Single-Strength Juice

Now, the technology is available on a large scale to extract, process, and store single-strength juice in bulk aseptic refrigerated tanks, minimizing microbial spoilage and product quality deterioration. This technology enables provision of blended juices to consumers on a year-round basis, when the fruit is not in season. Depending on the processing capacity of the plant, number of tanks of capacity 950–3800 m^3 each, are installed in refrigerated rooms or insulated with refrigeration. With proper nitrogen blanketing and mixing, the juice quality may be maintained for a year or more (Wilke 2002).

Table 29.3. Vitamin and Mineral Contents of Orange Juice

Vitamins[a]	Content	Minerals[b]	Content (mg/100 g)
Vitamin A (β-carotene) (IU/100 mL)	190–400	Na	1.7
Vitamin C (mg/100 g)	50	K	179.0
Thiamin (μg/100 mL)	60–145	Ca	11.5
Niacin (μg/100 mL)	200–300	Mg	11.5
Riboflavin (μg/100 mL)	11–90	Fe	0.30
Pantothenic acid (μg/100 mL)	130–210	Cu	0.05
Biotin (μg/100 mL)	0.1–2.0	P	21.7
Folic acid (μg/100 mL)	1.2–2.3	S	4.6
Inositol (mg/100 mL)	98–210	Cl	1.2
Tocopherols (mg/100 mL)	88–121		

[a]USDA (1957).
[b]McCance and Widdowson (2002).

Single-Strength Juice from Concentrate

A significant amount of orange juice is packaged from reconstituted concentrate as chilled juice. Because of the economics of storing large bulk quantities of concentrated citrus juice and the consumer preference for a ready-to-serve product, the volume of this product is large now. Pasteurized juice is packaged in cartons or glass containers and is microbiologically stable. The flavor of juice from reconstituted concentrate is not comparable with single-strength juice because of the two thermal treatments and the loss of volatiles during the concentration process. Addition of aromas and essences can improve the quality of the finished product (Ranganna et al. 1983).

Frozen Concentrated Juices

Concentrated orange juice with soluble solids content of 65°Brix is now largely produced in the world. The primary water removal technology is high-temperature short-time (HTST) evaporation, although freeze concentration and membrane processes are also used. The concentration process is accompanied by aroma recovery. The concentrate is blended with a small amount (less than 0.01%, v/v) of cold-pressed oil to mask the off-flavors that develop during storage. The small quantity of fresh juice can also be added back to concentrate to make up the losses of flavor during concentration process. The concentrate is chilled to –9°C by passing through heat exchanger and pumped to large stainless steel tanks maintained at desirable temperature in cold rooms. This concentrate is blanketed with nitrogen and carefully monitored for quality characteristics, so that the juice with different characteristics may be accurately blended to produce a uniform-quality finished product. Under these conditions, the concentrate can be stored for over a year with little loss in quality (Ranganna et al. 1983).

JUICE PRODUCTION

Harvesting

Fruits of suitable quality may be harvested manually using clippers or mechanically, depending upon the facilities available. Manual harvesting may be preferred in the countries where cheap labor is available and comparatively small acreage of orchards is managed. In developed countries, mechanical harvesting is practiced and a number of abscission chemicals are applied to facilitate detachment of fruits from the tree. Care should be taken to avoid any damage to fruit during handling. The fruits are packed in bags or bins and transported to the processing factory. A detailed description of types of harvester used and important factors related to mechanical harvesting of citrus fruits is given by Whitney (1995).

Receiving

After reaching the processing plant, the fruit goes through inspection lines for removal of bruised or damaged fruits. The sorted fruits are conveyed to storage bins and sufficient quantity is accumulated for continuous operation of the processing plant. The laboratory draws a small portion of fruit at this stage for testing the titratable acidity, Brix, and juice yield. The tests for fruits have been discussed by Miller and Hendrix (1996) and Kimball (1991). The testing record of individual lots is maintained to determine which bins are to be blended for uniform product quality.

Washing

Fruits from the bins are conveyed to a washer. The fruits are first soaked briefly in water containing a detergent, scrubbed by revolving brushes, rinsed with clean water, and inspected again to remove the damaged ones. Sanitizing is essential for control of spoilage microbes, which may contaminate conveying equipment and juice extractors, and affect the juice quality. Applied citrus plant sanitation requirements have been published (Winniczuk 1994). An HACCP plan should be followed for complete sanitization of fruits during washing (Schmidt et al. 1997). The fruits are then separated automatically depending on their sizes and allowed to enter into the juice extractors.

Extraction

The development of automatic orange juice extractors has been a major breakthrough in the progress of the fruit juice industry. Various types of extractors and finishers including Rotary Juice Press, FMC In-Line Extractor, and various Brown Model extractors have been discussed by different workers (Sigbjoern 1975; Woodroof and Luh 1975; Nagy et al. 1977; Sutherland 1977). The juice extractor and finisher are important to quality and yield of orange juice and concentrate and can be adjusted to control the amounts of pulp, oil, etc., in the final products. According to Florida state regulation, the USDA Grade A orange juice should not contain more than 12% suspended pulp (Braddock 1999). The finishing process removes the excess of pulp, bits of peel, rag, and seeds. The yield is important to the grower who wants the highest return of his fruit, and to the processor who is responsible for the quality of the finished product.

Guintrand (1982) patented an appliance for extraction of orange juice. This appliance drops the orange into hinged hands, cuts the orange into two halves using a circular saw, and presses the fruit interior using a double press. Subsequently, the pulp and pits are separated from the juice in a centrifuge, and the juice is collected in a dispenser. The main advantage of this system is that all these operations are integrated without any human intervention, other than to

introduce oranges into the appliance. The appliance can be used at airports, stations, etc, and in fruit juice factories.

Ohta et al. (1982) compared the juice prepared from Satsuma mandarin by two methods: (i) an FMC In-Line Extractor that extracts the whole fruit and (ii) by a new screw press extractor that extracts peeled fruit. Concentration of 20 volatile components in the two juices are given: the (i) juice had much higher concentration of hydrocarbons (such as D-limonene, γ-terpinene, myrcene, and α-pinene) and linalool than did (ii) juice, but (ii) juice had more favorable linalool:D-limonene and citronellal:D-limonene ratios, that is, for (i) 0.0021 and 0.0003, and for (ii) 0.0048 and 0.0028, respectively.

The performance of a new screw press type of juice extractor has been evaluated by Watanabe et al. (1982) with peeled fruits of natsudaidai (*C. natsudaidai*) and satsuma (*C. unshiu*) oranges. Soluble solids content, amino-N, and turbidity increased with pressure of extraction, and acidity and soluble sugars decreased in the same order. Concentration of naringin, limonin, and monilin were higher in last stage extraction juice from natsudaidai than in first stage juice. The new extractor gave juice yields a few percent higher than an in-line extractor. At each stage, the extractor expressed (% of total juice): first 63%, second 24%, and final 13%. A slit screen was more effective than a punched screen in terms of susceptibility to plugging.

Sunkist Growers' juice processing plant at Tipton, CA, USA, uses up to 1800 tons (t) of oranges per day to produce frozen concentrate, single-strength juice, oil, and cattle feed (Mans 1983). Every step in the plant operation, from the conveyors bringing fruit out of the storage bins to the evaporator feed tanks, is controlled by a computer and operated from a graphic panel. Three computer-controlled FMC extractor lines of orange and one of grapefruit in a FMC Corp/Citrus World-built plant (Lake Wales, FL) handle 4300 t of oranges and 1375 t of grapefruits daily (Anon 1984). Six programmable control computers constantly receive information from numerous sensors on the lines. Information may be fed into any stage or reports requested at any moment in the process by a single operator.

A continuous process system for orange juice, as installed by Farmland Dairies Inc., incorporating an inline refractometer for Brix measurements, is explained by Polizzi et al. (1987). Processing steps are briefly outlined, with special reference to the inline refractometer and an automatic benchtop refractometer to confirm accuracy of the inline unit. An increase of orange juice production by 30% is achieved with the new system.

A machine for extracting juice from citrus fruits, particularly oranges, is described by Antonio (1992). It includes an inclined chute conveying the fruit to be squeezed against a step, a spoon for raising the fruit resting on the step, and two squeezing plates below the step. The front plate is pivoted at the top and is pulled toward the back plate by a spring. The back plate is joined to a connecting rod and crank, which is driven by a speed reducer used to slide the back plate either toward or away from the front plate. As the two plates converge, fruit between them is squeezed. Extracted juice is collected, as it drips from the fruit, in an underlying hopper from which it is collected in a container. After squeezing, as the plates separate, the fruit residue falls down an inclined grill over the hopper and is collected in a drawer.

di Giacomo et al. (1989) determined the color and anthocyanin contents in industrially produced orange juices from Calabria (31 samples) and Sicily (24 samples); the extraction lines used were in general usage (FMC juice extractor, polycitrus machine). Absorption spectra for a model anthocyanin solution and of an orange juice extract in the 400–600 nm range are shown: both the curves are of similar shape, with a maximum at 538 nm. Tabulated data for Calabrian juices obtained between January and April showed range of anthocyanin contents of 91.6–497.0 mg/L (early April), with mean ± SD of 199.7 ± 106.6, and for Sicilian juices obtained in March and April a range of 497–1038.7 mg/L, with mean ± SD of 721.0 ± 153.3 (early April).

Physical and chemical characteristics and volatile constituents of orange juice, as affected by method of extraction, have been studied by Mohsen et al. (1986a, 1986b). They observed slight differences in orange juice characteristics [TSS, ascorbic acid, sugars, free amino-nitrogen (FAN), pulp, and 5-hydroxymethyl furfural content] extracted by pressing or by rotary extractor. Rotary extraction increased content of pulp, pectin esterase, and carotenoids. Extraction by pressing increased contents of limonene and oxygenated terpenes, while rotary extraction increased amounts of esters and water-soluble volatiles in juice. Taste and color were more acceptable in juice extracted by rotary method, but color of pressed juice was preferred. Limonene contents of orange juice are influenced during industrial processing by the Polycitrus juice extractor (di Giacomo et al. 1976). The variations in limonin content of the Italian Sanguinello cultivar juices due to extraction technique (fixed or revolving reamers, FMC In-Line Extractors, rotary extractors), screening and centrifuging treatments, and juice recovery from peel and rag residues by pressing are reported by Trifiro et al. (1983).

The choice of machinery depends upon the capacity, yield, and quality of the product required by the processor. For small-scale work, halving and burring machines, plunger-type press, continuous screw expeller press, superfine pulper, and cup-type extractor can be used. For large-scale commercial production, automatic plants are being used.

Blending

Processors are aware of variations in the color of juice from different varieties and different seasons of fruit. The color of juice obtained from the fruits harvested in early season is poor. The poor color of early season juice can be improved

by blending juice or concentrate from the oranges rich in color. Attention is given to the blending of different lots to achieve a balance of solids, acidity, color, and flavor. After finishing, the juice flows to large stainless steel tanks where it is checked for acidity and soluble solids; and sugar may be added to increase sweetness, if needed (Hyoung and Coates 2003).

Deoiling

Previously, the oil level in juices was controlled only by adjusting the extractor setting or by choice of the type of extractor. The oil content could be controlled by softening the peel by immersing fruits for 1–2 minutes in hot water, but the oil in the juice varied from lot to lot and the control became difficult. Deoilers have been developed to control the peel oil level in citrus juices. Currently, deoiling in commercial operations is done by using small vacuum evaporators where the juice is heated to about 51.4°C and about 3–6% of the juice is evaporated. After the vapors are condensed, the oil is separated by centrifugation or decantation, and the aqueous layer is returned to the juice. With this treatment, about 75% of the volatile peel oil can be removed. The standards for US Grade A orange juice permit not more than 0.035% of peel oil (USDA 1959). For most commercial orange juices produced in the United States, oil content is maintained at 0.015–0.025%. Use of hermetic separators for deoiling (removal of essential oils) of single-strength orange juice is discussed by Puglia and Harper (1996), with special reference to developments in separator design; types of separators for the citrus industry; design of hermetic separators; benefits of hermetic over centrifugal-type separators for juice deoiling; and deoiling of single-strength juice using hermetic separators. A process for commercial debittering of navel orange juice by reducing the limonin content is described by Kimball (1990). The system includes a commercial deoiler to reduce the essential oil concentration in freshly extracted juice from 0.180% to less than 0.015%.

Deaeration

The single-strength juices are deaerated because dissolved oxygen lowers the vitamin C levels and causes flavor deterioration. The current tendency is to recommend that oxygen levels be kept low in all processed citrus juices. Dissolved oxygen disappears rapidly in canned juices, particularly at high temperatures. A definite benefit from deaeration has been a decrease of frothing in the filler bowl. Vacuum deoilers simultaneously deaerate juice and hence modern juice canneries do not have separate deaerators. Deaeration methods are known to affect the quality attributes of orange juice with respect to browning, vitamin C, sensory, and Hunter Lab color values (Mannheim and Passy 1979). Hot filling and storage at less than 15°C gives bottled citrus juices a shelf life of almost 1 year.

Pasteurization

Pasteurization is aimed at inactivating the spoilage organisms, and the enzyme pectin methylesterase (PME) that is responsible for loss of cloud stability and discoloration in juice. Citrus juices are sensitive to heat. Their vitamin content and delicate fresh aroma and flavor may be lost or damaged by undue exposure to heat, so they are usually pasteurized as rapidly as possible. pH plays an important role in pasteurization of juice. Optimization of microbial destruction, enzyme inactivation, and vitamin C retention during pasteurization of pH-adjusted orange juice is reviewed by Uelgen and Oezilgen (1993). The pH–temperature optimum determined by response surface methodology in the ranges 65–75°C and pH 2.5–4.0 has shown that no pectin esterase activity below pH 3.5 is observed. *Leuconostoc mesenteroides* had its maximum and minimum thermal resistances at pH 3.5 and 2.7, respectively. For an ideal theoretical process requiring four-log cycles of microbial reduction, the optimum pasteurization conditions are 12 minutes at 75°C and pH 2.7. The natural pH of juices varies with the variety of oranges. With the aim of optimizing pasteurization temperature for orange juice, thermal death characteristics of *Aspergillus niger* spores, *Saccharomyces cerevisiae*, and *Lactobacillus fermentum* have been studied by Hasselbeck et al. (1992). Thermal inactivation of all investigated microorganisms occurred at about 75°C. *D* values at 75°C were 0.004 second for *S. cerevisiae* and 0.53 second for *L. fermentum* in orange juice. Chemical and sensory tests showed that thermal treatment in the investigated time–temperature regime (65–95°C, 3–30 seconds) did not lower the orange juice quality. Time–temperature relationships are also important for heat inactivation of enzyme pectin esterase in orange juice under different conditions (Lee et al. 2003).

Commercially, the juice is rapidly heated to about 92°C; the exact temperature depends on the type of equipment used and on rate of juice flow. Juice may be in the pasteurizer from a fraction of a second to about 40 seconds. Recent trends are toward the use of HTST pasteurization with either tubular or plate-type heat exchangers that are heated either by steam or hot water. Heating usually takes about 30 seconds or less and the juice is heated rapidly without local overheating. Modern heat exchangers and automatic controls are usually designed so that scorching or underheating of portions of the juice is prevented.

The chemical, physical, organoleptic properties, and volatile components of juice are affected by pasteurization to varying extents depending upon the technique of pasteurization used (Gil et al. 2002; Min et al. 2003). High-pressure homogenization of orange juice has been shown to reduce PME activity by 30% and 80% after five passes at 100 and 250 MPa, respectively (Welti-Chanes et al. 2009). This "cold pasteurization" of orange juice using high-pressure homogenization technique could serve as an alternative to the traditional thermal processing to minimize adverse sensory, nutritional, and physicochemical changes in juice.

Effect of Pasteurization on Physicochemical Properties

Pasteurization of orange juice produces subtaste-threshold levels of p-vinylguaiacol (PVG) and ascorbic acid degradation but has little effect on browning (Naim et al. 1997). Fortification with glutathione, L-cysteine, or *N*-acetyl-L-cysteine at concentrations below 4.0 mM has no effect on PVG formation and browning, but inhibits ascorbic acid degradation during pasteurization and improves juice acceptance. The ascorbic acid concentration, density, cloud, and fructose levels of the juices are significantly influenced by the processing method when unpasteurized orange juice is bottled and frozen at –18°C; pasteurized juice is either bottled and frozen at –18°C or stored in plastic bins at 1°C for 9 months (Farnworth et al. 2001).

Pigment loss and potential visual color changes are associated with thermal processing of Valencia orange juice, which is quantitatively the richest in carotenoids amongst sweet oranges (Hyoung and Coates 2003). Orange juice was pasteurized at 90°C for 30 seconds and then rapidly chilled. Color values were determined spectrophotometrically, and carotenoids were analyzed by RP-HPLC. Fresh unpasteurized juices contained (mg/L) 0.574 violaxanthin, 0.387 luteoxanthin (one of two HPLC peaks), 0.810 *cis*-violaxanthin, 0.819 antheraxanthin, 0.67 lutein, 0.582 isolutein, 0.662 zeaxanthin, and 0.337 β-cryptoxanthin, as well as several other carotenoids at lower concentration. Pasteurization significantly reduced concentration of violaxanthin, luteoxanthin, *cis*-violaxanthin, and antheraxanthin to 0.308, 0.351, 0.655, and 0.616 mg/L, respectively, whereas concentration of lutein was increased to 0.76 mg/L. Pasteurization also significantly reduced the concentration of neoxanthin and an unidentified peak, and increased concentration of luteoxanthin (the other peak) and mutatoxanthin. Isomerization of the major 5,6-epoxide carotenoids to 5,8-epoxides probably caused the perceptible color changes on pasteurization, which involved juices becoming lighter and more color saturated. Recently, the use of proper microwave treatment of citrus mandarin pomace has been reported to be an efficient technique to liberate and activate bound phenolics and to enhance their antioxidant activity (Hayat et al. 2010).

The effect of pasteurization on volatile components has been widely studied. Pasteurization of orange juice extracted by the two methods caused a slight decrease in limonene and oxygenated terpenes, a noticeable decrease in esters and water-soluble volatiles, and a slight increase in carbonyl compounds (Mohsen et al. 1986a, 1986b). Major volatile components were δ-limonene, linalool, α-terpineol, and terpinen-4-ol. Taste and color were more acceptable in juice extracted by rotary method, but color of pressed juice was preferred. Pasteurization decreased acceptability of taste and odor of juice prepared by the rotary method. Yield of flavor compounds from fresh juice compared with heated juice from Satsuma mandarin were 4.0 and 5.2 mg/kg, respectively (Araki and Sakakibara 1991). The comparison of hydrocarbons and oxygenated compounds in fresh and heated juice has shown that β-terpineol and β-damascenone were found only in heated juice. β-Damascenone had an odor similar to overripe fruit and seemed to contribute to the characteristic odor of the heated juice.

Volatile flavor compounds present in fresh and heated juices of Satsuma mandarin and three cultivars of sweet oranges (Hamlin, Pineapple, and Valencia) were studied by Araki et al. (1992). δ-Limonene, linalool, octanal, and ethyl butyrate decreased and α-terpineol increased after heating the juices. Heat-related changes in these compounds were smaller in sweet orange juices than in Satsuma mandarin juice. Moshonas and Shaw (2000) evaluated flavor quality of pasteurized orange juice during a normal shelf-life period by analysis of sensory quality and qualitative and quantitative changes in 46 volatile flavor compounds. Farnworth et al. (2001) found that while unpasteurized juice contained the highest levels of acetaldehyde, ethyl acetate, α-pinene, β-myrcene, limonene, α-terpineol, 1-hexanol, 3-hexen-1-ol, and sabinene, and the lowest concentration of valencene, compared with pasteurized juice. They suggested that unpasteurized orange juice should be frozen rapidly to be more acceptable to consumers than the pasteurized juices. Jordan et al. (2003) reported that generally the pasteurization did not further modify the aromatic profile of deaerated orange juice with the exception that the concentration of δ-3-carene decreased significantly after pasteurization ($P < 0.05$) and neryl acetate, the concentration of which decreased significantly after a combination of deaeration and pasteurization.

ADVANCES IN PASTEURIZATION TECHNOLOGY

Thermal processing operations such as pasteurization, sterilization, drying, and evaporation are still commonly used by the food industry to guarantee the microbial safety of citrus juices. Currently, the food industry is looking at replacing the traditional well-established preservation techniques with novel thermal and nonthermal technologies that may produce high-quality food products with improved energy efficiency and to be more environment friendly. The newer technologies, such as dielectric heating, ohmic heating, pulsed electric fields, and high hydrostatic pressure processing, have been reviewed by Pereira and Vicente (2010).

Pulsed Electrical Field

It is the latest development in the field of food processing that has found a number of applications in the recent past (Min et al. 2003). This technology relies on the lethal effect of strong electric fields for inactivation of microorganisms. By using this technique, the undesirable changes, such as protein denaturation and vitamin losses during processing

are avoided. The technique is effective against only vegetative cells while spores are not affected. A pilot plant scale pulsed electric field continuous processing system was integrated with an aseptic packaging machine to demonstrate the efficacy of pulsed electric field technology as a nonthermal pasteurization method for fresh orange juice (Qiu et al. 1998). Major system components include a 40,000 V/17 MW high-voltage pulse generator, a set of multiple stage cofield flow pulsed electrical field (PEF) treatment chambers, a fluid handling system for flow control and a Benco Aspack/2 aseptic thermal form packaging machine. Orange juice is processed at a 75–125 L/h flow rate and packed aseptically into 200 mL plastic cup containers. Microbiologically enhanced orange juice tests validated the microbial inactivation effect of this integrated pulsed electric field system. The PEF treated and aseptically packaged fresh orange juice demonstrated the feasibility of pulsed electric field technology to extend the product shelf life with very little loss of flavor, vitamin C, and color.

Pasteurization of fresh orange juice using low-energy PEF was conducted by Hodgins et al. (2002). Low energy PEF of orange juice was optimized with respect to effects of temperature, pH, and number of pulses on microbial contamination. In addition, the effect of PEF combined with addition of nisin, lysozyme, or a combination of two antimicrobial agents on the decontamination of orange juice was also investigated. Optimal conditions were determined as 20 pulses of an electric field of 80 kV/cm, at pH 3.5 and 44°C with 100 U nisin/mL. Using these conditions, a greater than six-log cycle reduction in the microbial population occurs. Following treatment, 97.5% retention of vitamin C along with a 92.7% reduction in pectin methyl-esterase activity is obtained. The microbial shelf life of the orange juice also improved, and determined to be greater than or equal to 28 days when stored at 4°C without aseptic packaging. GC revealed no significant differences in aroma compounds before and after PEF treatment. Panelists found no significant difference in any of the sensory attributes of orange juice processed by thermosonication (TS) (for 10 minutes at 55°C) in combination with PEF (40 kV/cm for 150 μs) or exposed to HTST pasteurization (Walkling-Ribeiro et al. 2009a). No significant change in the physical properties (pH, °Brix, and conductivity), microbiological activity (microbial counts stayed within safe limits of <1000 CFU/mL), and color stability of orange processed by TS/PEF or HTST occurred during storage at 25°C for 168 days. In another study, the shelf life and ascorbic acid content of orange juice-milk beverage treated by PEF was found to be similar to that of heat pasteurization (90°C, 20 seconds) during storage at 4°C for seven weeks (Zulueta et al. 2010).

PEF treatment was applied to unpasteurized Valencia orange juice using a bench-top PEF system to study its effects on pectin methyl-esterase (Yeom et al. 2002). Electric field strengths up to 35 kV/cm were applied to orange juice at a constant water bath temperature of 30°C. An increase in the electric field strength caused a significant inactivation of pectin methyl-esterase with an increase in orange juice temperature. An electric system using a high AC electric field can inactivate *Bacillus subtilis* spores in orange juice (Uemura and Isobe 2003). Higher degree of inactivation of *B. subtilis* spores can be achieved with electric field at 121°C than at 100°C with reduced loss of ascorbic acid and more acceptable product aroma. Electric field-treated samples of Satsuma mandarin juice has more acceptable flavor than those subjected to conventional heat treatment.

Thermosonication applied (for 10 minutes at 55°C) in combination with PEF (40 kV/cm for 150 μs) resulted in a comparable inactivation of *Streptococcus aureus* to that achieved by HTST (94°C for 26 s) without adversely affecting the nonenzymatic browning index or ascorbic acid content (Walkling-Ribeiro et al. 2009b).

High-Pressure Treatment

High pressures in the range of 500–10,000 bar at the ambient temperatures have been known to have lethal effect on microorganisms. However, the technology is not totally effective in destroying bacterial spores and many enzymes. The combination of high pressure with moderate temperature may have a desirable effect. Combination of high pressure with chilled storage and distribution may also be desirable if quality deterioration by enzymes is to be prevented. Addition of CO_2 during high-pressure processing (HPP) of fresh orange juice increased the rate of pectin methyl-esterase inactivation beyond that achieved by pressure alone (Truong et al. 2002). This technology is also compatible with existing range of semirigid and flexible packaging materials (Parish 1998; Sellahewa 2002). High-pressure treatment may provide an adequate alternative to thermal pasteurization for minimally processed citrus juice products. Bioactive compounds present in freshly squeezed orange (*C. sinensis* L.) juice were more stable in high-pressure treatment than the conventional heat processing (Sanchez Moreno et al. 2003). Application of 350–450 MPa of high-pressure treatment of orange juice not only increases the extraction of flavanones but also enhances potential health-promoting attributes of the juice that are retained during cold storage.

Microwave Heating

Microwave heating could be used for continuous pasteurization of citrus juice (Nikdel and MacKellar 1993). Orange juice is pasteurized by pumping it through a coil of Teflon tubing in an oven heated with microwave energy (at 2450 MHz). Juice temperature (95°C) is controlled by varying the flow rate at 100% microwave power. Over 90% of the 570 W microwave power is absorbed by the juice. Pectin methyl-esterase activity is reduced by more than 99.9% by pasteurizing for 15–25 seconds at 95°C. Bacteria are also rapidly inactivated at either 70°C or 90°C. Microwave

pasteurization of juice does not cause any flavor change compared with fresh unpasteurized juice.

Gamma (Γ) Radiation

While safety of food processed by using γ-irradiation up to 10 kGy has been well established, feasibility of gamma radiation for pasteurization of orange juice has been ruled out due to its adverse effect on quality of juice (Spoto et al. 1993). The adverse changes in flavor of irradiated samples are described as "oily," "cooked," and "medicine" notes. While irradiation is effective in destroying pathogens such as *Listeria monocytogenes* and *Salmonella* spp. in fresh orange juice, off-flavors generated preclude its use as an alternative processing technology (Foley et al. 2002).

BITTERNESS IN JUICE

The postprocessing development of bitterness is a common problem in orange juice, which is the main deterrent in the utilization of many orange varieties for juice production. Roughly 15–20% of navel oranges harvested in a given season are not used directly and is processed into a juice that is bitter and requires processing or back blending with other sweeter juice. The bitter fraction of the orange juice arises from a tetracyclic triterpenoid called limonin. The limonin is produced over time from limonic acid or limonin monolactone, which is found in the seeds and membranes of most citrus fruits. Because of low solubility of limonin, heating or prolonged storage increases its concentration in juice. A concentration of 2 ppm of limonin imparts a definite bitterness to the juice (Kefford 1959).

Limonoids

The nonbitter precursor in citrus fruits is identified as limonin monolactone, which after acid-catalyzed conversion forms limonin (Maier and Beverly 1968). Limonin monolactone is stable in the tissues of intact fruit (which is not bitter) because it is apparently not in direct contact with the acidic juice. It slowly converts into limonin (and the juice becomes bitter) when fruit tissues come in contact with the acid in juice, after the juice is expressed from the fruit. The limonin content of the fresh mature Valencia oranges fruit is 2–3 ppm after extraction, rising to 11–13 ppm after pasteurization, but undergoes little subsequent change during storage (Tariq et al. 1974). The majority of the limonin is formed from its non-bitter precursor limonate A-ring lactone. N and K fertilization have significant effects on limonin content of Washington navels, the limonin contents falling at higher N and K doses (Rodrigo et al. 1978). Average limonin and nomilin concentrations in orange juice have been reported to be 0.75 and 0.03 ppm, respectively (Rouseff and Fisher 1980). The early Marrs and Hamlin oranges from five locations in the south Texas citrus have less limonin (6.2 ppm) by mid-November, which reaches a minimum of 1.8 ppm in January (Albach et al. 1981). Linear correlations between limonin and time of harvest were much better than between limonin and Brix, percentage of acid, or the Brix:acid ratio. Rodrigo et al. (1985) reported strong correlation between limonin and acid content in juice of Washington navel oranges.

Limonin content varies with the Navel orange cultivars and could range from 15.37 to 25.02 ppm (Navarro et al. 1983). A lower limit of detection of 1 ppm for limonin on a 2.1 mm internal diameter micropore column and 2 ppm on a 4.6 mm internal diameter analytical column by high performance liquid chromatography can be achieved (Shaw and Wilson 1984). Limonin concentration (5–6 ppm) in the juices from Italian Tarocco and Sanguinello oranges is not affected by maturity and is lower in juices from first than from second pressing; it could be reduced by removing the peel immediately after juice extraction and by low-temperature processing (Trifiro et al. 1984). The addition of hydrocolloid to Kinnow juice has been reported to decrease the limonin content (Aggarwal and Sandhu 2004a). Nomilin found in orange has been shown to have anticarcinogenic properties and to induce detoxifying enzymes in animals (Herman et al. 1990).

Removal of bitterness in citrus juices below the threshold for better consumer acceptability has been attempted using a number of chemical treatment, physical separation processes, blending with other sweet juices/sugar, and enzyme treatments. For the debittering of naval orange juice, Fayoux et al. (2007) have optimized a process of limonin sorption on a low mol. wt. PVC plasticized with diocetyl adipate (DOA). With this polymeric film, the debittering efficiency was 1000-fold greater than that obtained using the currently available polystyrene divinylbenzene resin beads, thus showing potential for commercial scale application. The removal of limonin bitterness in naval orange juice by batch adsorption to Amberlite XAD-16HP resin to an acceptable level has been reported by Kola et al. (2010). Amberlite XAD-16HP did not produce any important negative effect on the quality of orange juice, whereas Dowex Optipore L285 resin reduced the titratable acidity, which increased the Brix:acid ratio leading to higher perceived sweetness.

The present-day consumers demand citrus juices with lower bitterness but with the maximum preservation of the endogenous sensory, nutritional and health-promoting qualities. Cavia-Saiz et al. (2011) have investigated the use of naringinase for the removal of bitterness in grapefruit juice or by physical adsorption with Amberlite IRA-400 resin. Both the naringinase-treated juice (N-Pj) and the one processed with exchange resin (R-Pj) were acceptable to the consumers. The total antioxidant capacity, measured by 2,2′-Azinobis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) and ferric reducing antioxidant power (FRAP) assays, was lower in R-Pj sample, but the highest superoxide and hydroxyl radical scavenger activity was shown by N-Pj sample.

In terms of inhibitory effect of grapefruit juice on lipoperoxidation, N-Pj sample exhibited the greatest effectiveness. These debittered juices also showed a protective effect on the DNA oxidative damage. The enzymatic debittering was found to be more effective than the physical adsorption techniques in preserving the antioxidant capacity of the grapefruit juice.

Flavonoids

The principal flavonoids of citrus are the anthocyanins, flavones, flavonols, or flavanones. Certain flavonoids are used to detect the adulteration of orange juice with other citrus juices. The presence of hesperidin is associated with the fouling of heating surfaces. The major flavonoids present in orange are hesperidin, rutinoside of naringenin, isosakuranetin, 4-β-D-glucoside of naringin, 4-β-D-glucoside of naringenin rutinoside, and neohesperidin. The principle of bitter (sour) oranges is naringin in place of hesperidin of sweet oranges.

Amount and distribution of polymethoxylated flavones in juice, peel, and pulp wash vary considerably and may be used to detect adulteration. Flavone content of orange peel is about 100 times higher than that of juice (Heimhuber et al. 1988). The polymethoxylated flavones including 5,6,7,8,4′-pentamethoxyflavone; 5,6,7,4′-tetramethoxyflavone; 3,5,6,7,8,3′,4′-heptamethoxyflavone; 5,6,7,8,3′,4′-hexamethoxyflavone; 5,6,7,3′,4′-pentamethoxyflav one; 5,7,8,3′,4′-pentamethoxyflavone; and 3,5,6,7,3′,4′-hexamethoxyflavone have been identified in Valencia orange juice and peel oil (Hadj Mahammed and Meklati 1987) while another compound, 6,7,8,4′-tetramethoxy-5-hydroxyflavone, is found only in peel oil. Fully methoxylated flavones such as nobiletin, tangeretin, 3,5,6,7,8,3,4-heptamethoxyflavone, tetra-*O*-methylscutellarein, and sinensetin (5,6,7,3,4-pent amethoxyflavone) in FCOJ range from 4.2 to 7 ppm and these substances are not important contributors to the flavor of orange juice (Veldhuis et al. 1970).

The bioflavonoids contents (mg/100 mL) of orange juice determined by GLC method are rutin 0.73, hesperidin 11.17, and naringin 3.72 (Drawert et al. 1980). Hesperidin solubility during production and storage of clarified Satsuma mandarin juice is important to avoid the formation of haze or sediment. In turbid juice (raw material for clarified juice), soluble hesperidin, which comprised about 20% of total hesperidin immediately after extraction and concentration by evaporation, remains soluble during storage at –20°C, but at higher storage temperature, its solubility rapidly decreases. With clarification by ultra filtration (UF) (batch operation), higher operating temperature gives higher hesperidin content in the permeate. These findings may be useful in determining whether clarified juice will develop haze or precipitate during storage. The hesperidin glycosides solubilize hesperidin in canned Satsuma mandarins and in orange juice, and inhibit crystallization of hesperidin for more than 6 months during storage (Nishimura et al. 1998).

Flavonoid glycoside detection has been used to assess the authenticity of orange juice (Pupin et al. 1998). Concentration of narirutin and hesperidin in hand-squeezed juices may vary from 16 to 142 and 104 to 537 mg/L, respectively. Varietal differences in the ratio of narirutin to hesperidin are observed; the ratio is highest for Pera (mean 8.4) and lowest for Baia (mean 3.6). Authentic FCOJ has higher flavonoid glycoside levels than those in hand-squeezed juices (narirutin 62–84 mg/L and hesperidin 531–690 mg/L, after dilution to 12°Brix), while frozen concentrated pulp wash has levels ranging from 155 to 239 mg/L for narirutin and 1089 to 1200 mg/L for hesperidin.

A method based on flavone glycosides and polymethoxyflavone patterns for differentiating sweet orange (*C. sinensis*) juices from other citrus juices by their flavonoid content is proposed (Ooghe and Detavernier 1999). Analysis of a number of fruit juices such as lemon, grapefruit, and pommerans showed that flavone glycosides fingerprints could be used to differentiate *C. sinensis* from other juices such as grapefruit, mandarin, sour/bitter oranges, and bergamot.

Naringin and neohesperidin are flavonoids found only in certain citrus fruits; sweet orange cultivars do not contain these compounds and their presence in orange juice indicates adulteration with juice from certain other citrus fruits such as grapefruit. A method adopted by the First Action AOAC International demonstrated the reliability of the method in detecting the presence of grapefruit juice in orange juice as indicated by a finding of 10 ppm naringin and 2 ppm neohesperidin (Widmer 2000).

DEBITTERING PROCESSES

Efforts have been made to reduce the accumulation of bitter principles during the development and maturing of orange fruit through chemical sprays, agronomic practices, and postharvest treatment of fruits. Many debittering technologies have been developed based on chemical, physical, and microbial processes.

Tree Treatment

Treating Washington navel orange trees after bloom with 200 or 300 ppm of 2-(3,4-dimethyl phenoxy) triethylamine or 200 ppm of 2-(4-chlorophenyl thio) triethylamine is reported to reduce the concentration of limonin in the juice of oranges at the beginning of maturity, compared with untreated control, with a concomitant small decrease in soluble solids and acidity (Casas et al. 1979). However, these differences in limonin contents decreased with advancing maturity.

Microbial Debittering

A study by Brewster et al. (1976) showed that use of 200 munits of the limonoate dehydrogenase of *Pseudomonas* sp.

321–18 per milliliter of navel orange juice reduced the eventual limonin content of 21–3 ppm, a level below the general bitterness threshold, whereas comparable activity levels of the enzyme from *Arthrobacter globiformis* caused substantially smaller decreases in eventual limonin content. This wide difference in activity at low pH is explained by the instability of the limonoate dehydrogenase of *A. globiformis* at pH 3.5 and the relative stability of this enzyme from *Pseudomonas* spp. Naringinase produced by solid-state fermentation of soy meal with *A. niger* ZG86 (2%) at 32°C for 4 days has been used for reduction of bitterness from orange juice. Orange juice extracted from whole orange fruits or peeled fruits with or without centrifugation was mixed with naringinase at 0–32 μm/100 ppm naringin at 50°C for 1–2 hours. Naringin concentration for the enzyme treatment (16 μm/100 ppm) was reduced to 30 ppm compared with the initial concentration of 320 ppm in the orange juice. Bitterness was decreased by 90% by the naringinase treatment.

Adsorption

Cellulose esters in the form of gel beads (2–4 mm in diameter) selectively removed limonin from navel orange juice without significantly affecting the color and flavor constituents or the ascorbic acid content (Anon 1976). Juice is passed upward through the column of beads. It should be pasteurized for optimum results, but it may also be a freshly extracted juice. About 10-bed volume of juice may be passed through the column to achieve the removal of about 40–60% of the limonin before the column requires reactivation.

Chandler (1977) reviewed the processes for overcoming the problem of bitterness with special reference to the development of gel bead sorption process for separation of the bitter principle (limonin) from orange juices. Cellulose acetate as flake or powder is an efficient and selective sorbent for removing the bitter principle limonin from orange juice. Treatment of orange juice serum with cellulose acetate powder (10 g/L) removed 44–70% of the limonin content in less than 1 hour, at the same time removing relatively negligible amounts of hesperidin and ascorbic acid (Chandler and Johnson 1977). Bitter orange juice was successfully debittered by holding for several days in containers with linings of the cellulose esters in gel form, by batch-wise agitation with gel cubes or beads, and by passage through columns packed with these materials (Chandler and Johnson 1979). These processes provide the basis for methods suitable for in-storage, batch wise, or inline debittering treatments on an industrial scale. Cellulose acetate gel beads were used to debitter eight successive batches of juice, the sorptive capacity of the beads being regenerated by washing with water between the debittering treatments. Johnson and Chandler (1978) described the removal of limonin from navel orange juice by passage through a column of cellulose acetate gel beads. The beads may be easily fabricated to a size permitting the passage of whole juice, and the column can be reactivated by simple water washes.

Cellulose acetate gel beads, when used commercially for removing the bitter principle, limonin, from orange juice, may eventually become so loaded with organic matter that simple water washes are no longer adequate to reactivate them. Such exhausted beads may be readily and economically restored to their original activity by washing with a small volume of warm water, which is recycled through a small active carbon bed (Johnson 1981). β-Cyclodextrin (0.3% w/w) can also be used to overcome bitterness of citrus juices due to limonin and naringin (Konno et al. 1981; Shaw and Wilson 1983; Shaw et al. 1984). Other components such as naringenin 7-β-rutinoside, coumarins, and flavonoids were removed, but the TSS (Brix), TA, and ascorbic acid content of the juice were unchanged. The polymer was regenerated by treatment with dilute aqueous alkali or ethanol.

There are significant reductions in limonin, citrus oils, and pulp in California navel orange juice during commercial debittering using a hydrophilic absorbent (Kimball and Norman 1990a, 1990b). Citrus oils and pulp can be replenished without violation of federal standards of identity. Bitter components, such as limonin, may be effectively removed from citrus juices, particularly navel orange juices, by contacting the juices with an adsorbent resin (Norman et al. 1990). Couture and Rouseff (1992) used neutral (XAD-16) and weak base anionic exchange (IRA-93) resins for increasing palatability of juice from four cultivars of sour orange (*C. aurantium*), namely Seville, Bigaradier, Sour, and Bittersweet. Bitter compounds were removed by both resin treatments. Average naringin concentration was reduced by 50–66% in high acid juice and 89% in low acid juice using IRA-93.

With the aim of improving naringin removal from orange juice, the naringin absorption capacity of five resins (A–E) produced in Tianjin, China, was tested (Wu et al. 1997). The selective removal of limonin and naringin from orange juice by batch adsorption to various materials to reduce bitterness was investigated (Ribeiro et al. 2002). Since reducing sugars, pigments, and vitamin C may be removed simultaneously with flavonoids, adsorption of these compounds was also investigated. The highest adsorption efficiency for the bitter compounds occurred with Amberlite XAD-7. Adsorption of sugars and pigments was low and no adsorption of vitamin C was detected for any adsorbent. The bitterness of navel orange juice is reduced with the addition of 100 ppm of neodiosmin (Guadagni et al. 1977). As this treatment suppresses the bitterness, a level of 50–150 ppm is recommended to improve the acceptability of juice.

Enzymatic Debittering

Study conducted on Shamouti orange juice products revealed that the nonbitter limonin precursor is located mainly in the nonsoluble parts of the fruits, that is, albedo, membranes

of segments and of juice sacs, and rags (Levi et al. 1974). An enzymatic activity reducing the limonin monolactone concentration by 50% at the natural pH of 5.4 at optimum temperature (40°C) was observed in aqueous extracts of albedo and segment membranes. Industrial trials showed that 40–50% reduction in limonin content and hence significant reduction in bitterness was achieved by using only 0.04 in. strainers with only minimum production loss (about 2%), thus allowing production of high-quality orange juice earlier in the season.

Immobilized Enzyme

Limonin debittering of navel orange juice serum was successfully demonstrated with *A. globiformis* cells immobilized in acrylamide gel treatment of 30 mL serum (10–27 ppm limonin), for instance, on a 1.5 cm diameter column packed with 1.6 g immobilized cells (16-mL bed volume) reduced limonin content by greater than 70% (Hasegawa et al. 1982). This column was used 17 times without losing its effectiveness. The treatment did not affect juice composition as measured by total acids, TSS, pH, and sugars. Removal of limonin by free and immobilized cells of *Rhodococcus fascians* in a model buffer system and in a real system (orange juice) has been studied using chitin as immobilization support because of its high yield, simplicity, and cheapness (Bianchi et al. 1995). It is concluded that biodegradation of limonin by *R. facians* depends largely on limonin conversion to its acid forms and therefore on the pH value.

Studies were conducted on metabolism of nomilin (a bitter limonoid constituent of citrus juices) in orange serum by immobilized cells of *Corynebacterium fascians* (Hasegawa et al. 1984). The main metabolite of nomilin was identified as obacunone by thin layer chromatography (TLC) and nuclear magnetic resonance (NMR) spectroscopy. The immobilized *C. fascians* system was highly active: nomilin was completely converted when orange serum containing 20–25 ppm nomilin was passed through the column only once; the column was used 15 times without any loss of effectiveness. The enzyme responsible is probably nomilin acetyl-lyase. Cell-free extracts of *C. fascians* also catalyzed the conversion of nomilin. These results are of significance in relation to debittering of citrus juices.

ACID REDUCTION

Resins have been used to process orange juice in two major applications: (i) for the reduction of acid content and (ii) to remove bitter components (Norman 1990). Some orange juice consumers prefer a reduced acid version of the juice. Fresh juice, stabilized concentrate, or concentrates reconstituted back to 15°Brix can be treated this way. First, the pulp is removed from the juice via centrifugation and the pulp-free juice can then be passed through a weak base anion column, which reduces the citric acid content of the juice. The resin will also retain the ascorbic acid (vitamin C) and folic acid portions of the juice. The resin is more selective for the citric acid, so if enough juice is passed, the citric acid portion of the feed juice will displace the ascorbic acid and folic acid held by the resin. This can be monitored by following the pH of the juice effluent coming off the column. Below a pH of 4.6, the ascorbic and folic acid portions are washed through the resin. The processed deacidified juice effluent can then be blended back to unprocessed juice to achieve the right balance of reduced acid and fresh juice tastes. The pulp can also be added back, or the juice can be sold as a reduced pulp juice. Juices from four cultivars of sour orange (*C. aurantium*), that is, Seville, Bigaradier, Sour, and Bittersweet, were treated with neutral (XAD-16) and weak base anionic exchange (IRA-93) resins for increasing palatability of juice (Couture and Rouseff 1992). Average acidity was reduced 57–87% using IRA-93 before depletion, and sensory acceptability of the juice increased.

CLOUD STABILIZATION

Cloud loss is a major quality defect in orange juice. Cloud stability decreases with increasing amounts of pulp. Juices and concentrates containing 3% pulp have been found to be more stable than ones with higher pulp content (PC) of about 9%. Combination of homogenization and pasteurization gives better stability than either of these treatments alone. The combination of pasteurization and addition of stabilizers such as pectin and gum acacia give good stability to both juices and concentrates (Ahmad and Bhatti 1971). TIC Gums, Inc. has produced a gum system TICALOID No. 1004, which suspends fruit pulp without increasing viscosity (Anon 1983). In processed orange juices with original viscosities between 10 and 25 cP, the addition of 0.15% TICALOID No. 1004 provided complete suspension of the fruit pulp and the final viscosity was between 55 and 60 cP. The juice manufacturer has two options: to maintain the original mouth feel of the juice and to provide complete suspension of the pulp or to develop products with a pulpier consistency.

Methods of preserving cloud without the extreme temperature use in commercial pasteurization (techniques) are desirable. HPP is used as a means of preserving cloud in freshly squeezed orange juice (Goodner et al. 1999). Pressures from 500 to 900 MPa have been investigated at dwell times of 1 second, 1, and 10 minutes. Higher pressure and longer processing times are more effective at preserving cloud; all treatments yield a microbiologically stable product. A 90-day shelf life under refrigeration conditions could be achieved using pressure of 700 MPa combined with treatment time of 1 minute.

Pectin is the major component of orange juice cloud and has important role in juice stabilization. In the presence of active PME enzyme, pectin forms calcium pectate complex, which causes precipitation of cloud particles (Croak and Corredig 2006). A thermal treatment in the range of

50–60°C has been found to be satisfactory during minimal heat processing for the retention of cloud stability within the short turnover of freshly squeezed orange juice-like products (Hirsch et al. 2008). Tiwari et al. (2009) while studying the effect of sonication on PME activity suggested that cloud stability of sonicated orange juice depends not only on the PME inactivation but also on particle size reduction. Ellerbee and Wicker (2011) have investigated the role of calcium and pH on the orange juice cloud stability. According to their findings, in addition to electrostatic attraction and calcium binding, cloud particles associate or dissociate through noncovalent and nonelectrostatic interactions. In a recent study, Sentandreu et al. (2011) have obtained a low-pulp well-colored orange juice through homogenization at 20 MPa, but additional treatment is necessary to inactivate the residual PME activity. They obtained orange juices with similar physical characteristics either when the whole juice was homogenized or by applying homogenization only to the pulp fraction obtained by centrifugation and then blending it back with the low pulp fraction.

PACKAGING AND STORAGE OF ORANGE JUICE

Different types of packaging including cans, bottles, cartons, drums, and barrels made up of glass, metal, plastic, or laminates are used for the packaging of orange juice and concentrates. Packaging of orange juice in metal cans is becoming obsolete. The latest trends are toward aseptic packaging in flexible plastic films and laminates.

CANNING

Plain tin cans are used for single-strength orange juice, because they prevent discoloration of juice upon storage and are least expensive. Enamel-lined cans or lids have been used, but appear to be unnecessary. The cans varying in sizes from about 200 mL to over a liter are used for packing.

Hot juice from the pasteurizer is pumped to the large stainless steel filler bowl and filled directly into the cans. The juice is kept in the filler bowl for a minimum time to prevent damage of flavor by the heat. The cans are filled automatically by opening the valve as they pass around the turntable beneath the filler bowls. It is desirable to minimize the amount of oxygen in the final container. Much of the air in the juice is removed by deoiling or deaeration process. Live steam injected into the headspace as the can is closed replaces the air and helps to create a vacuum during closure. They are closed automatically as they leave the filling machine. The cans are inverted for about 20 seconds to sterilize the lid by the heat of the juice, then, while spinning in a roller conveyer, the cans are rapidly cooled to 37.8°C by cold water spray to facilitate drying and prevent subsequent rusting of the outside of the can. High-speed filling and closing machines handle up to 500 cans/min (Kefford et al. 1959).

The type of packaging materials has been shown to affect the orange juice quality and shelf life (Ros-Chumillas et al. 2007). Monolayer PET (polyethylene terephthalate) showed the lowest retention of ascorbic acid during storage compared with multilayer PET and glass. However, this difference in vitamin retention can be minimized by using oxygen scavengers, liquid nitrogen drop in headspace during filling, aluminum foil seal in screw cap, and with the use of refrigeration. Losses in the aroma of orange juice from PET bottles can be lowered with high-density polyethylene (HDPE) closures (Berlinet et al. 2008). The effect of packaging materials on the color, ascorbic acid, and sensory quality of refrigerated mandarin juice has been investigated by Beltran-Gonzalez et al. (2008). The presence of oxygen in the headspace of juice decreased the ascorbic acid and darkening of color during storage. The juice packaged in clear PET bottles when packed in cartons had a shelf life of 90 days to the 54 days in PET bottles when stored at 4°C. In a subsequent study, Beltran-Gonzalez et al. (2009) suggested the use of Tetra pack carton for improved color, ascorbic acid, and consumer acceptance of orange juice stored at 4°C. Low temperature (6 ± 1°C) storage enhances the functional attributes of mandarin-like hybrid oranges containing anthocyanins (Rapisarda et al. 2008). The effect of externally added ascorbic acid on the deterioration of carotenoid pattern and color of orange juices has been studied by Melendez-Martinez et al. (2009). Regardless of the addition of ascorbic acid, the changes in the carotenoid profiles of orange juices were similar and involved mainly the epoxycarotenoids. It is suggested that the location of (9Z)-violaxanthin in orange juice cloud particles could be more accessible to the juice acids than (9Z)- or (9′Z)-antherexanthin. The decrease in carotenoids was higher with the higher amounts of ascorbic acid addition. Evidently, the enrichment of orange juice seems to promote the contact of the carotenoids and acids during their deterioration process.

Storage

Orange juice undergoes various physical and chemical changes, depending on the type of packaging and storage conditions. When orange juices are compared, immediately after canning, with samples of the original juice, changes in flavor and other quality factors during the actual canning procedure are minimal. Changes during storage of canned juice, however, are much more profound. The storage temperature is the major determinant influencing the flavor and vitamin content of the juice. Kefford (1973) summarized studies of ascorbic acid retention and flavor stability in canned citrus juices during storage at different temperatures, and stated that from the point of view of practical nutritionists, canned citrus juices should be stored at the coolest possible temperature.

Some workers reported, in different studies, that over 90% of ascorbic acid was retained and flavor deteriorated little in

canned citrus juices stored at 21.1°C for 1 year or longer (Riester et al. 1945; Freed et al. 1949). Other workers indicated that ascorbic acid retention decreased and flavor deteriorated at higher temperatures (Martin et al. 1995; Petersen et al. 1998). Khan and Khan (1971) found that canned orange juice had better retention of color, better flavor, and higher retention of vitamin C than bottled orange juice. Hashimoto et al. (1995) reported that exclusion of dissolved oxygen before heat treatment and filling into epoxy resin coated cans effectively preserved fresh flavor during storage at 10°C or 23°C for up to 12 weeks. Torres et al. (2011) have used HPP from 400 to 600 MPa for 15 minutes to retain higher amounts of ascorbic acid and anthocyanins in blood orange juice during storage at 4°C for 10 days. Plaza et al. (2011) investigated the impact of minimal processing on the bioactive compounds in orange fruit during refrigerated storage at 4°C for 12 days. There was a significant increase in carotenoids and vitamin A content; however, some losses (but were insignificant) were observed in ascorbic acid during storage. The flavanones content increased in oranges during storage, possibly due to the cold stress.

Some studies have indicated that tin content may reach 150–200 ppm in canned orange juices stored at temperatures approaching 30°C for 6 months or longer (Bielig 1973). The Codex Alimentarius proposed a maximum of about 150-ppm tin in orange juice for infants. Omori et al. (1973) reported that high concentration of tin in orange juice is a major cause of toxicity. They reported that tin in excess of 300 ppm can cause undesirable physiological reactions in large animals and human beings.

Changes in dissolved oxygen concentration, during storage of packaged orange juice were studied by Manso et al. (1996). Single-strength Valencia orange juice aseptically packaged and stored up to 5 months at 4–50°C was analyzed for dissolved oxygen. Dissolved oxygen concentration reached equilibrium in a few days from an initial level of approximately 2 ppm; equilibrium concentration was independent of temperature of storage.

Sorption of food components, particularly volatile compounds, by polymeric packaging materials is an unsolved problem for the food industry. The food itself develops an unbalanced flavor profile (termed flavor scalping), and the pack, if recycled (e.g., PET bottles), can transfer the adsorbed aroma compound to the next product. Sensory properties of orange juices are highly related to their levels of D-limonene. The effect of packaging and storage conditions on the quality of orange juice has been summarized in Table 29.4. Decreases in sensory quality (overall scores for color, appearance, aroma, and flavor) found during storage in glass bottles are greater at higher storage temperature and with exposure to light. Significant deterioration in sensory quality occurred after 3 months at ambient temperature, and after 1–2 months at 30°C. Changes in bitterness were similar to those of oxidized flavor, but less pronounced, while no significant differences were found for sourness. Sorption of D-limonene by plastic packaging was affected by the external factors such as temperature, relative humidity, and other storage conditions. A gradual decrease in several flavor components, 1-penten-3-one, hexanal, ethyl butyrate, octanal, neral, and geranial, was observed during storage. Contents of some volatile components (α-terpineol and ethyl acetate) increased during storage (Moshonas and Shaw 1989a).

Microbial growth and ascorbic acid concentration are sensitive to variations in D-limonene concentration, within the range of values typically observed in commercial orange juice. Consequently, packaging materials that absorb D-limonene potentially influence microbial stability and ascorbic acid content in single-strength orange juices. However, scalping of flavor volatiles by LDPE, PET, polyamide, and ethylene (co)vinyl alcohol did not result in significant differences in flavor of high oil, typical oil, low oil, and thermally abused orange juice samples made from high-quality orange juice concentrate (Sadler et al. 1997).

Off-Flavors

Bielig and Askar (1974) reported changes occurring during bottling (80°C/10 minutes) and storage of orange juice as increase in α-terpineol, *n*-octanal, and *n*-hexanal and increase in *n*-hexanal, *n*-hexenal, and *n*-octanal during 2 months then decrease; increase in *n*-decanal during 6 months; decrease in fatty acids possibly by autoxidation or enzymatic oxidation (causing "cardboard off-flavor"); and increase in α-terpineol at the expense of α-limonene and linalool. α-Terpineol is proposed as an indicator for predicting storage life. Correlation coefficient between flavor scores and furfural from "Hamlin" orange, "Valencia" orange, and grapefruit juices were highly significant, as reported by Maraulja et al. (1973). Rate of flavor deterioration was dependent on both storage temperature and storage time. However, temperature was the more significant factor. Retention of initial flavor quality was much better when the canned products were stored at less than 60°F (15.5°C).

Orange juice (reconstituted from 65°Brix concentrate) with added peel oil (100 or 200 ppm) was packed in polyethylene-lined cartons (Tetra Brik) and stored at 4°C, 20°C, and 32°C, and in glass bottles at 20°C in the dark to study the effect of packaging on aroma quality (Duerr et al. 1981). Samples were analyzed before and after filling, and periodically until 90 days after filling. Limonene was reduced by 40% after 6 days in the soft packages (by absorption into the polyethylene lining), versus 10% after 90 days in glass. There was a linear rise in α-terpineol, formed from limonene, which was much more dependent on storage temperature than on initial limonene concentration. The rise was greater in glass bottles than in soft packages, at the same storage temperature. The juice was described as stale and musty after 13 days at 32°C, or 90 days at 20°C (62 days in glass), but was still acceptable after 3 months at 4°C. The loss of

Table 29.4. Interaction of Different Packaging Materials with Orange Juice During Storage

Packaging Material	Nutrient/Component	Changes	Conditions	Storage Period	Reference
Glass bottles	Ash, Na, Mg, and P	No change	5–30°C	6 months	Martin et al. (1995)
	Titratable acidity and Sucrose	Decreased			
	Vitamin C	Decreased			
	Hydroxymethyl furfural	Increased			
	Sensory quality	Deterioration			
Accelerated storage	α-Terpineol and β-terpineol	Increased	–	–	Petersen et al. (1998)
	Sensory quality	Oxidized flavor appeared			
	Sourness	No change			
Polyethylene/barrier material laminated cartons	D-Limonene	50% reduction	4°C	24 weeks	Pieper et al. (1992)
Laminated multilayered aseptic package	α-Terpineol and ethyl acetate	Increased	21–26°C	5 weeks	Moshonas and Shaw (1989b)
	2-(2-Butoxy-ethoxy)ethanol	Appeared as new compound			
	D-Limonene	40% reduction			
	Vitamin C	26.09% reduction			
	Oil	Reduction from 0.01% to 0.0066%			
Polyethylene-lined cartons	D-Limonene	40% reduction	20°C	6 days	Duerr and Schobinger (1981)
	α-Terpineol	Increased		90 days	
	Neral, geranial, and octanal	Decreased			
Aluminum-lined cartons	D-Limonene	Decreased	20°C	3 months	Mottar (1989)
Aseptic package	1-pentene-3-one, hexanal, ethyl butyrate, octanal, neral, and geranial	Decreased	21–26°C	8 months	Moshonas and Shaw (1989a)
	Oil content	Decreased			
	Vitamin C	Decreased			
	α-Terpineol and furfural	Increased			
Paperboard sandwiched between two polymer layers	α-Pinene, octanal, and D-limonin	Decreased	4°C	4 weeks	Paik and Venables (1991)
	Microbial growth	No growth			
Polypropylene and polyethylene	Flavor compounds	Scalping (absorption) by package	–	–	Risch and Hotchkiss (1991)
LDPE, HDPE, polypropylene, and surlyn	Terpene, sesquiterpene, and aldehydes	Scalping (absorption) by package	–	4 days	Charara et al. (1992)
Aluminum foil/tie resin/LDPE laminate	Free fatty acid content at 1.1–1.4% level	Caused delamination	–	Long-term storage	Pieper and Petersen (1995)

Silica coated PE/PET cartons versus coextruded ethylenevinyle alcohol (EVOH)	Ascorbic acid and aroma	Better retained in EVOH	2°F (–16.6°C)	11 weeks	Lee and Barros (1996)
LDPE and EVOH versus PVDC	α-Pinene and D-limonene	Less absorption in PVDC	–	–	Sheung et al. (1996)
LDPE, PET, PVDC, and EVOH	Ethyl butyrate and octanal	Equal absorption in all four			
PET bottles	Octanol, decanol, and linalool	Decreased	–	–	Will et al. (2000)
	Furfural and hydroxymethyl furfural	Increased	20–37°C	3 months	
	Ascorbic acid	Decreased			
	$L^*a^*b^*$ color	Deteriorated			
	α-Terpineol	Formed			
Hexamethylene tetramine (HMT) containing LDPE film	Lactic acid bacteria	Inhibited	Frozen	–	Devlieghere et al. (2000)
	Yeast growth	Not retarded			
	HMT	Dissolved from film into juice			
Polylactate, HDPE, and polystyrene	Quality retention	All equally effective	–	–	Haugaard et al. (2002)
LDPE	Valence, decanal, hexyl acetate, octanal, nonanone, and D-limonene	Absorbed	20°C	29 days	Willige et al. (2003)
Polycarbonate	Valence	Absorbed			
PET	Decanal, D-limonene, myrcene	Absorbed			
LDPE	Myrcene, α-pinene	Absorbed			
Laminated brick style cartons	D-Limonene	Maximum absorption			Hirose et al. (1988)
LDPE					
Syrlyn 1601					
Syrlyn 1652 with antioxidant and antibacterial agents					

limonene into the polyethylene lining was considered as an advantage, while desirable volatiles were scarcely absorbed.

Oxidation of D-limonene (constituting 90–95% of orange oil) is a major commercial problem, for example, in orange drinks. Nearly all the limonene disappears from oil in air after storage for 9 weeks at room temperature. Autoxidation products were responsible for poor odor and flavor. A major hydroperoxide fraction possessed the typical strong odor of oxidized orange oil, and a 2% addition to fresh orange oil spoiled the taste and odor of orange drinks. The hydroperoxide was highly unstable and decomposed to carbonyl and hydroxy products (El-Zeany 1977).

Walsh et al. (1997) found two major off-flavors in orange juice, PVG and 2,5-dimethyl-4-hydroxy-3 (2H)-furanone (DHMF or Furaneol) by modified chromatographic procedure. In study by Fallico et al. (1996), hydroxycinnamic acids and their corresponding decarboxylation products, PVG and p-vinylphenol (PVP), were determined in two-processed blood orange juices (freshly squeezed or made from concentrate) produced in Italy; samples were analyzed during 4 months of storage at 4°C and 25°C. Phenols (free and total ferulic and *p*-coumaric acids) were determined in the juices by HPLC. Results showed that there was a 35% reduction in concentration of total *p*-coumaric and ferulic acids after 4 months of storage. Juices did not initially contain vinylphenols, but they were observed after 3 months of storage. PVP and PVG concentration were higher at 25°C. The flavor threshold of authentic vinylphenols in aqueous solution and in the blood orange juice was evaluated by sensory analysis. Concentration of these off-flavors in the stored juices abundantly exceeded the threshold values, especially in the juice from concentrate. It is concluded that the content of vinylphenols might provide a reliable index of blood orange juice quality.

A gradual decrease in several flavor components, 1-penten-3-one, hexanal, ethyl butyrate, octanal, neral, and geranial, and an increase in two undesirable components, furfural and α-terpineol, were observed, in addition to other changes in aseptically packaged orange juice during 8 months of storage at 21°C and 26°C (Moshonas and Shaw 1989b). After 2 months of storage, an experienced taste panel found a significant difference in stored juices compared with a control sample, and significantly preferred the starting control juice. Continuous reductions in oil content and ascorbic acid were noted during the 8-month storage period.

ORANGE JUICE CONCENTRATE

Concentration of fruit juices permits economic advantages in packaging, storage, and distribution. It also helps in the economic utilization of perishable fruits during the peak harvest periods, thus stabilizing the market prices of fresh produce. Orange juice contains about 85–90% water; during the concentration step, their bulk is considerably reduced by removing most of this water. Orange juice concentrate is prepared either from freshly extracted and pasteurized single-strength juice or from a stored and pasteurized single-strength juice. The major equipment used in the concentration process is the evaporator.

EVAPORATORS

Orange juice concentrate is a major item of trade. Most of the juice is converted into concentrate in the orange-producing areas of Brazil and Florida. With improved designs of evaporators, it has now become possible to produce high-quality product. The first commercial low temperature orange juice evaporator was built at Plymouth, Florida, by Vacuum Foods Company, which was designed as a result of research carried out at the Winter Haven Laboratories. This company later became Minute Maid Corporation, Minute Maid Division of Coca Cola Corporation, and was designated as the Foods Divisions of the Coca Cola Corporation. The designed evaporator was a falling film type and consisted of a series of vertical stainless steel cylinders with spray device, water heating, and vapor removal system. This could produce concentrate of 42°Brix. Later on, Skimmer Company, Majonnier Brothers, Buflo-vak Division of Blaw-Knox, Kelly, and Gulf Machinery Company developed falling film evaporators for low temperature concentration of juice. The efficiency was improved by developing the multistage and multieffect evaporators. These combinations, however, required long residence time for the product in the evaporator. Sutherland (1977) discussed the evaporators for concentration of orange juice along with the other equipment required for packaging and storage of juices, and their relative advantages.

Modeling of multieffect falling film evaporators was studied by Angeletti and Moresi (1983). The classic mathematical model of multieffect evaporators, operating in forward flow, was combined with an accurate estimation of the overall heat transfer coefficient (HTC) in falling film evaporators. For this, a correlation developed by Narayanamurthy and Sarma (1977) was used. It was possible also to estimate the order of magnitude of the fouling factor (Rd). Finally, design of an orange-juice, double-effect, falling film evaporator system was carried out according to two different strategies.

Concentration of orange juice using an agitated thin film evaporator (ATFE) system was studied by Nongluk et al. (2001). Experiments were performed on a laboratory-scale ATFE system and a pilot plant scale system capable of handling larger flow rates. The effect of PC on the rates of evaporation and the maximum obtainable concentration was studied for orange juice of the Pera variety (Stolf et al. 1973/1974). The PC was between 2% and 10%; the evaporator was a Centri-Therm, Model CT-1B pilot plant, centrifugal manufactured by Alfa-Laval, Sweden.

Thermally accelerated short time evaporator (TASTE) has been designed to use high temperature at first stage, which would simultaneously evaporate, pasteurize, and enzyme

stabilize the juice. TASTEs have relatively low initial cost and ease of cleaning. The principal disadvantage is their relative inflexibility. It is not convenient to blend add-back concentrate with the feed juice, as might be done with other types of evaporators. The high temperatures cause more rapid fouling of heat exchanger tubes and necessitate more frequent cleaning (Chen et al. 1979). Changes in main constituents of orange juice were evaluated by Pino et al. (1987) during concentration on a TASTE. Mean retention of ascorbic acid was 93.5% and concentration caused slight browning of juice, but sugar content was not affected. Viscosity reduction by homogenization of orange juice concentrate in a pilot TASTE was studied by Crandall et al. (1988). Controlling viscosity is critical for the efficient evaporation and pumping of citrus concentrates. Viscosity of an orange (cv. Pineapple) juice concentrate was reduced by installation of a commercial homogenizer between the third and fourth stages of a pilot plant "TASTE."

Possibilities for manufacture of orange juice concentrates by using evaporator equipment (TASTE and a five-stage falling film evaporator from GEA Wiegand); aroma recovery; concentrate manufacture by freeze concentration; manufacture by UF and reverse osmosis; and storage of orange juice concentrate are discussed by Loeffler (1996). Losses of volatile compounds in orange juice during UF and subsequent evaporation by a TASTE were investigated by Johnson et al. (1996). Physicochemical changes during preparation of Kinnow mandarin juice concentrate was studied by Sandhu and Bhatia (1985). Juice was extracted using a superfine pulper and concentrated at 50–55°C under vacuum in rotary glass evaporator. The desirable concentration of juice was 40–42°Brix under the conditions of experiment. The composition of 40°Brix Kinnow concentrate is reported as total solids 44.50%, TSS 40.00%, titratable acidity 4.57%, reducing sugars 14.80%, total sugars 26.90%, ascorbic acid 44.88 mg, β-carotene 5.36 mg, pectin 1.16%, and pH 3.60. The ready to serve drinks prepared from concentrate of 40°Brix after reconstitution were comparable with those prepared from freshly extracted juice.

The economics of using mechanical vapor recompression (MVR) evaporators to concentrate orange juice has been discussed by Kelso et al. (1980). Evaporators using MVR have been operating successfully in various food industries for several years. Energy consumption in a concentrated orange juice plant was determined by Filho et al. (1984). Consumption of electricity and thermal energy for FCOJ and citrus pulp pellets (CPPs) was determined. Thermal energy accounted for 90% of total energy consumption in the plant and its consumption for CPP exceeded that for FCOJ. The kilocalories of thermal energy/kg of water evaporated increased as the feed rate of single-strength juice was decreased. At the design evaporation capacity, the steam efficiency of two tubular evaporators and two plate evaporators was found to be $0.85N$ and $0.82N$, respectively, N being the number of effects of the evaporator. Fouling of the waste heat evaporator was a major reason for the high-energy consumption in the CPP unit.

Orange juice powder has many advantages and economic benefits over the concentrate as it provides a stable, natural, and easily dosable material for many applications in food and pharmaceutical product formulations. A new technique for the spray drying of orange juice concentrate has recently been reported by Goula and Adamopoulos (2010). They used maltodextrins as a drying agent for the spray drying of orange juice using dehumidified air as a drying medium. Jesus et al. (2007) have reported that it is feasible to concentrate orange juice by reverse osmosis, while still maintaining its sensory and nutritional quality.

Essence Recovery

The orange essence is a volatile fraction recovered from fresh juice. The flavor of orange products is enhanced by addition of essence. The quality of essence varies considerably and depends upon the variety, seasonal variation, degree of maturity, condition of fruit, and other factors. Morgan et al. (1953) investigated the recovery of essence from orange juice under vacuum at 110°–115°F (43.3–46.1°C). The volatile oil content of orange juice has been reported to vary from 0.016% to 0.075%. The details of orange aroma compounds are given in Table 29.5 (Nursten and Williams 1967). In many citrus processing plants, recovery of essence during concentration of juice has been incorporated as a part of the process for FCOJ. A method for essence recovery under vacuum has been developed by Wolford and Attaway (1967) and Wolford et al. (1968). In this method, the essence is recovered by evaporating about 15% of juice just before it is fed to the evaporator, and the volatile fraction is concentrated in a series of condensers until the volume is reduced to about 1/100 that of the original juice. The product has been reported to be very fragrant and is used to impart fresh flavor and aroma to FCOJ.

A system in which the vapors are recovered by a pump with a liquid seal has been described by Bomben et al. (1966) and Brent et al. (1968). Currently, the most widely used system is recovery of essence from the first effect of a TASTE. Essence is stripped off the aqueous phase during the first stage of concentration by evaporating 15–25% of the juice. By distillation through a packed column, the fragrant vapor is allowed to pass over to a refrigerated condenser while the heavier fractions and waste are condensed separately. This method can be extended to aroma recovery from peel and juice waste streams (Veldhuis et al. 1972). To economize the process, the essence recovery unit should be incorporated as part of a multieffect evaporator. The blending of large quantities of essence concentrates is recommended to maintain the uniformity of product quality. The essence is extremely sensitive to oxidation; it must be stored in filled containers with no air headspace and often is packed under nitrogen or

Table 29.5. Major Aroma Compounds of Orange Juice

Hydrocarbons: Limonene, *p*-cymene, α-thujene, myrcene, α-phellandrene, α-terpinene, β-terpinene, γ-terpinene, terpinolene, sabinene, α-pinene, β-pinene, car-3(4)-ene, camphene, *p*-methyl-*i*-propenyl benzene, 2,4-*p*-menthadiene, farnesene, ylangene, β-elemene, α-copaene, β-copaene, caryophyllene, α-humulene, α-humulene valencene, and cadinene
Alcohols: Methanol, ethanol, *n*-propanol, *n*-butanol, 3-methylbutan-1-ol, 2-methylbut-3-en-2-ol, *i-butanol, n-pentanol, i*-pentanol, *n*-hexanol, *i-hexanol, n-hex-x-en-1-ol*, *n-hex-2-en-1-ol*, *n-hex-3-en-1-ol*, *n-hept-3-en-1-ol*, *n-octanol*, *n-nonanol*, *decanol*, *linalool*, α-*terpineol*, *i*-pulegol, borneol, *trans*-carveol, geraniol, and terpinen-4-ol
Carbonyls: Acetaldehyde, acetone, 2-butanone, pentanal, *n*-hexanal, hexenal (2 isomers), 2-hexenal, 4-methyl-2-pentanone, *n*-octanal, *n*-nonanal, *n*-decanal, 2-decanone, 2-decenal, *n*-undecanal, 2-dodecenal, geranial, citral, neral, carvone, furfural, and nootkatone
Acids: Formic, acetic, *n*-propionic, *n*-butyric, *n*-hexanoic, *n*-octanoic, and *n*-decanoic
Esters: Ethyl formate, geranyl formate, ethylacetate, *n*-octyl acetate, *n*-decyl acetate, citronellyl acetate, terpinyl acetate, linalyl acetate, bornyl acetate, geranyl acetate, ethyl butyrate, 3-octyl butyrate, geranyl butyrate, methyl *i-pentanoate*, *ethyl i*-pentanoate, *n*-octyl *i*-pentanoate, ethyl hexanoate, methyl 3-hydroxyhexanoate, ethyl 3-hydroxyhexanoate, ethyl octanoate, methyl 2-ethylhexanoate, methyl anthranilate, and methyl *N*-methylanthranilate
Miscellaneous: Ethyl 2-butyl ether and 1,1-diethoxyethane

Source: Adapted from Nursten and Williams (1967).

carbon dioxide. Essence is usually kept at low temperature (about 2°C).

Limonoid glucoside is a potential functional food ingredient obtained from orange juice; however, the presence of juice particulates lowers its value. Breksa et al. (2008) have used centrifugation technique to clarify orange juice concentrate and the centrifugate was passed through solid phase extraction (SPE) columns and then a larger SP-70 Sepabead column to obtain limonoids glucoside. The key aroma compounds in a freshly reconstituted orange juice from concentrate have been characterized by Averbeck and Schieberle (2009), and the most important odor compounds were (R/S)-linalool, (R)-limonene, and (S)-ethyl-2methylbutanoate with odor activity values (OAVs) of >1000. A few other odorants with OAVs of <100 were octanal, (R)-α-pinene, ethyl butanoate, myrcene, acetaldehyde, decanal, and (E)-β-damascenone. In a recent study, Averbeck and Schieberle (2011) have investigated the influence of different storage conditions (37°C for 4 weeks or 20°C for 1 year) on the key aroma compounds of orange juice reconstituted from concentrate. Under these conditions, the breakthrough threshold of α-terpineol and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (4-HDF) were not reached. However, the concentrations of dimethyl sulfide and 2-methoxy-4-vinylphenol clearly exceeded their breakthrough threshold limits. The excessive amount of these compounds confirmed the crucial role these odorants play in producing off-flavor of stored orange juice concentrate.

Freezing and Freeze Concentration

Concentrated orange juice is prechilled by passing it through a slush freezer (e.g., Votator). This model has three cylinders, 15 cm × 122 cm, while newer models have two cylinders, 15 cm × 183 cm. Similar units have been studied for concentration of citrus juice by freezing ice crystals and separating these crystals from the concentrate by centrifuging. A principal advantage of freeze concentration is that it tends to concentrate certain soluble fragrant components in the liquid product. Another advantage is that, theoretically, it should take less energy to separate waste by freezing than by evaporation. However, multieffect evaporators tend to nullify this advantage because optimum engineering design has increased their efficiency. A disadvantage is that freezing water is a relatively slow process in comparison to evaporation, and concepts for speeding it up are not readily apparent. Another principal disadvantage is that suspended matter and soluble solids tend to separate with the ice. Such losses, in most trial runs, became large enough to require partial recovery. This increases the time to reach a desired concentration point as well as the cost. One citrus processing plant used a freeze concentration process to recover partially concentrated juice for blending in the final product to improve fresh flavor. However, the development of equipment to recover high-quality citrus essences made freeze concentration less attractive. Although the freeze concentration can produce a frozen concentrate of superior quality, no commercial production has been carried out due to economical reasons (Muller 1967). Recently, Sanchez et al. (2010) have investigated the cryoconcentration of orange juice using a pilot plant falling film evaporator and achieved a final concentration of 28.8°Brix. As the freeze concentration allows the dewatering of orange juice at a temperature below the freezing point of water, the finished product quality is better than the conventional drying techniques.

Storage of Concentrates

The most desirable temperature for storage of frozen concentrate is −18°C. Cans or bulk storage stainless steel tanks are used commercially. Tocchini et al. (1979) studied

quality of concentrated juice pasteurized as (i) cans sealed under vacuum, followed by spin-cooking and cooling; (ii) as (i), but cans sealed under N_2; and (iii) hot-filling of the cans, followed by spin-cooling. All samples were pasteurized at 74 ± 2°C for 40 seconds. Samples (i)–(iii) were then stored for less than 180 days at 5°C. Frozen samples stored at –15°C were used as a control. The results show that (i) canned samples had the best keeping quality; its organoleptic properties did not differ significantly from those of frozen samples after storage for 90 days.

Distinct differences in Brix:acid ratio, bottom pulp, and apparent viscosity of the concentrates from the control and freeze-damaged samples have been observed (Hendrix and Ghegan 1980). In the freeze-damaged samples, the Brix:acid ratio was initially higher and continued to increase with storage. Bottom PC increased with storage in the freeze-damaged samples, as did the apparent viscosity.

Kenawi et al. (1994) investigated the effects of storage and packaging material on properties of calcium fortified orange juices. Orange juice concentrate was fortified with calcium phosphate to provide the consumer with 20% of the recommended daily intake. Fortified and unfortified juices were aseptically packaged in cans, laminated pouches, or LDPE bags. Quality of orange juices was evaluated in these packaging materials during storage for 10 weeks at room temperature. Vitamin C content of juice concentrate decreased during storage in fortified and unfortified samples. The decreasing trend was similar for all packaging materials. Titratable acidity increased and pH decreased during storage. Color of fortified and unfortified concentrates changed little during storage, Fe contents varied little, but a slight loss in Ca content occurred in all samples (4–4.5%) during the 10 weeks of storage. Acceptability of fortified juice was higher than for unfortified juice; sensory evaluation was affected by packaging material and storage time. Samples in LDPE bags rated poorer than those in laminated pouches or cans.

FREEZE DRYING OF JUICE

Fruit juice powders offer many advantages over their liquid counterparts. Juice powders have reduced volume and weight, reduced packaging, easier handling, and longer shelf life (Shrestha et al. 2007). Koroishi et al. (2009) have developed a high-performance process for the freeze drying of natural orange juice yielding lower operation time, lower costs, and higher product quality. In the freeze-drying process, the moisture is removed from the product by sublimation, and ice is directly converted into water vapor, thus minimizing the quality deterioration during drying. Pereira de Almeida (1974) gave a general account of the production of freeze-dried juice, covering extraction from the fresh oranges and elimination of oil to give a maximum residual content of 0.020–0.025%; concentration by freezing in an inert atmosphere to preferably 18–20% solids; separation of free ice and centrifugation of juice concentrate from pulp solids; vacuum treatment to remove oxygen; homogenization (preferably at 300 kg/cm^2) to disperse fine pulp particles; pasteurization at 95°C for 10 seconds and rapid cooling; freezing and granulation (–50°C); freeze drying at maximum temperature of 35–40°C to give 1.0–1.5% residual moisture content; and packaging with minimum exposure to oxidation. While it is possible to obtain a high-quality product, doubts are expressed on the economic possibilities due to demands on basic technical resources and potential marketing difficulties.

The most important parameters for correct operation of the freeze-drying cycle were evaluated in relation to the original concentration of the juice (Mowzini et al. 1974). Special attention was paid to the relation between the internal temperature of frozen granules and pressure in the freeze-drying chamber, in view of the difficulties of industrial processing caused by melting, puffing, and collapse. To avoid puffing, limiting temperature were –34°C for juice concentration to 40°Brix, –30°C for 30°Brix, –28°C for 20°Brix, and –26°C for natural juice. Maximum tolerable temperature for frozen granule surface was 35°C, for heating plates 90–120°C, and temperature at the condenser surface 8–10°C below that of the heating chamber. The results were used to devise optimal industrial freeze-drying cycles for processing orange juices at different concentrations. To ensure product quality, 30–35°Brix was suggested as a safety limit.

BEVERAGES MADE FROM ORANGE JUICE

Ready-to-serve drinks, cordial, squash, crush, and orange syrup are prepared from orange juice or concentrate, squash being the most commonly prepared product. Both oranges and mandarins are used for preparation of squash. The juice is extracted in the usual way and pasteurized. Sugar syrup is prepared according to recipe, cooled, and filtered. Food grade citric acid is used for acidification of the product. Peel oil or good quality orange essence is used for flavoring. Two recipes based on 25% and 33.33% juice are used for preparation of squash. Squash contains moderate quantity of pulp. Minimum TSS 40% and acidity 1.0% are maintained in squash as per food laws (FPO 1955). Potassium metabisulfite equivalent to 350-ppm sulfur dioxide is permitted in the product. Orange color and essence are added to increase the aesthetic appeal of the product. The product is filled into bottles leaving about an inch headspace. It does not need pasteurization and is stable under ambient conditions. Aggarwal and Sandhu (2004b) studied the effect of hydrocolloids on the quality of Kinnow squash. The addition of carboxymethylecellulose, sodium alginate, and gum acacia individually at a level of 0.6% improved the physicochemical and organoleptic

characteristics of Kinnow squash. Among these hydrocolloids, carboxymethylecellulose had the most desirable effect in improving the flavor, appearance, and cloud stability of the product.

Crush and fruit syrup contains minimum 55% and 65% TSS, respectively, with at least 25% of orange juice content. Cordial is prepared from clarified juice. It is sparkling clear beverage containing 25% juice and minimum 30% TSS. Permitted preservatives and flavor are added (FPO 1955).

Ready-to-serve beverages based on 10% juice are prepared which contain sugar and citric acid to suit the individual taste, generally in the ratio 12:0.3 (Brix:acid ratio 40:1). Permissible amount of potassium metabisulfite (sulfur dioxide 70 ppm) or sodium benzoate (benzoic acid 120 ppm), color, and flavor can be added. The bottled product is processed to increase its shelf life at room temperature. The time and temperature of processing depends upon the size of bottles. The glass bottles of 200 mL capacity require 20 minutes processing in boiling water for sterilization. The aseptic packaging is ideally suited for ready to serve beverages, which permits use of heat labile plastic containers. This product has good consumer demand in the Indian market where there are hot climatic conditions for most part of the year. Ready to serve beverages may also be carbonated (Khurdiya 1990).

The effect of thermal (85°C, 1 minute), pulsed electric field (PEF at 25 kV/cm, 65°C), and high hydrostatic pressure (HHP at 650 MPa, 50°C) processing on PME activity and volatile compounds concentration in an orange juice-milk beverage has been reported to inactivate 90% of the PME activity (Sampedro et al. 2009). Twelve volatile compounds were extracted by solid-phase microextraction (SPME) and were quantified by GC-MS following the application of different treatments. The average loss of volatile compounds was between 16% and 43% after thermal treatment. After PEF treatment, the average loss was between 13.7% and 8.3% at 25°C but increased at higher temperatures of treatment. After HHP treatment, the average loss varied between 14.2% and 7.5% at 30°C and was significantly higher at 50°C. Thus, the PEF treatment showed enormous potential as it achieved higher degree of PME inactivation in an orange juice-milk beverage preserving natural aroma than HHP and thermal treatments.

Garbagnati (1978) described a machine for producing beverages in granulated form of the Vomm-Chemipharma production line incorporating a Turbo-Granulator. Applications include the production of cold orange and lemon beverages. Influence of different packages and incandescent light, on the quality of an HTST-pasteurized single-strength orange drink during ambient storage (25–30°C) was investigated by Sattar et al. (1989). Both in terms of physicochemical and sensory characteristics of the drink, amber-colored packages were found to be superior to the green glass bottles and coextruded wax laminated paper (TetraPak).

Ascorbic acid retention in juice and drinks packaged aseptically into two flexible films (retort pouch and polyethylene) is affected by processing, concentration of added amino acids, and the type of packaging material. Nonenzymatic browning of single-strength orange juice and synthetic orange drinks containing 10% (v/v) orange juice is linearly related to added amino acids concentration and is more pronounced in the presence of high levels of ascorbic acid (Kacem et al. 1987). Deaeration and anaerobic storage resulted in increased retention of ascorbic acid. There was a very little change in the flavor score, browning, color, or amino acid content in aseptically packaged beverages in 250 mL Tetra Brik packs during storage at 24°C for 16 weeks.

Herrera et al. (1979) manufactured a beverage-clouding agent from orange pectin pomace leach water prepared from Valencia and Hamlin oranges. A commercial pectinase was used to hydrolyze pectin in the leach water. Clouding agent solids recovered (as percentage of peel solids) were 29% for Valencia orange peel and 27% for Hamlin orange peel. The stability of the prepared cloud was evaluated at a solids level of 1%. Several food proteins, together with some naturally occurring water-soluble gums (viscosity builders) and lecithin, were evaluated as clouding agents for formulated orange drinks (Garti et al. 1991). Use of these three types of natural products represents a significant advantage over the formulations currently in use consisting of synthetic emulsifiers and wetting agents.

Orange carbonated beverages prepared from orange concentrate were treated with the stabilizers such as sodium alginate (0.2%, 0.4%, and 0.6%, w/v), guar gum (0.25%, 0.35%, and 0.45%, w/v), and gum Arabic (2.3%, 2.6%, and 2.9%, w/v), and their cloud stability was monitored spectrophotometrically during storage at 4.4°C for 45 days (Ibrahim et al. 1990). Best inhibition of cloud separation was obtained with 0.35% guar gum (10 days), 2.9% gum Arabic (8 days), or 0.2% sodium alginate (28 days).

El-Wakeil et al. (1974) reported that the contents of nitrogenous compounds, total ash, Na, K, and P, and the K/Na ratio can be used to differentiate orange beverages prepared from synthetic and natural concentrates. The formol value, while being a useful statistical quality index, cannot be applied as a sole parameter for individual products or for the determination of the orange juice content of beverages (Fogli 1975). Determination of the natural fruit content in orange juices and beverages on the basis of the free amino acid (FAA) content is described by Habegger and Sulser (1974). Empirical formulae are given for determining the approximate percentage content of natural fruit in an orange product, viz., (total FAA $\times$ 100)/3 or total $N \times 100 \pm 20\%$ is given for the former. Benk (1969) described a method for detection of adulteration in orange beverages with soybean extract that contains raffinose and stachyose. Since raffinose and stachyose are absent in orange juice and orange peel, it is possible to detect the use of soybean extracts in orange beverages using circular paper chromatography, but glucose syrup interferes with the detection.

BY-PRODUCTS UTILIZATION

There are many by-products from the manufacture of orange juice. These include peels, pulps, and seeds, which are pressed and dried for cattle feed. The press liquid yields citrus molasses, which is also used for cattle feed as well as terpene oils for paints and plastics. Citric acid, pectin, and essential oils are also recovered from fruit-processing waste.

Citric Acid

Citric acid can be extracted from culled sour oranges or pomace left after extraction of juice. Juice may be fermented first to remove the gums, pectin, and sugars to facilitate the filtration, mixed with filter aids like Kieselguhr at 60°–66°C and then filtered. Calcium citrate is precipitated with the addition of hydrated lime and calcium carbonate, and precipitate is separated and dried quickly to avoid discoloration. For the conversion of citrate into citric acid, the wet paste is treated with calculated amount of concentrated sulfuric acid. The precipitated calcium sulfate is removed and the liquor is concentrated to crystallize the citric acid (Cruess 1997). The composition of orange juice and peel with respect to major organic acids given by Clements (1964) is presented in Table 29.6.

Essential Oils

Orange oil finds uses in the food, beverage, pharmaceutical, perfumes, and soap industries. Mandarin essential oil expressed from the peel is employed commercially in flavoring a number of food products. Mandarin essential oil paste is a standard flavoring for carbonated beverages. The essential oils are obtained from peel by means of scraping the whole fruit and pressing the scrapings in vertical or continuous presses, then separating the essential oil and water by centrifugation. In some factories, the essential oil is extracted at the time of juice extraction in the squeezing machines (FMC In–Line). Essential oils are also obtained in very small quantities by the stiletto systems and by S-fumatric-type presses, which use squeezed half fruits (Lal et al. 1986). The essential oils from green or mature bitter oranges are obtained by a system of scraping, followed by pressing the scrapings and are considered as the products of excellent quality available on the market.

The highest quality natural oils known in the trade are cold-pressed peel oils. The fresh orange peels yield about 0.54% oil by the cold press method. Kesterson et al. (1971) described seven different types of equipment used to express citrus peel oils. The general commercial methods in the production of cold-pressed oils include oil recovery from peel after juice extraction, simultaneous extraction of juice and emulsion from whole fruit, and recovery of oil from peel flavedo following removal from the whole fruit by abrasion or shaving. Natural or phenolic antioxidants may be added to oils to increase the stability under adverse storage conditions. Concentrated or folded oils are prepared by vacuum distillation of cold-pressed oils. Rezzoug and Louka (2009) investigated improvement of oil extraction from orange peels through a thermomechanical process. In their process, peel oil has short contact with the heated zones in the apparatus, thus resulting in a lower heating period of the oil compared with steam distillation. This not only saves energy but also gives peel oil of superior quality. Using a vacuum fractionation column, Beneti et al. (2011) have achieved a complete removal of limonene from the citronella essential oil phase at the lowest operating pressure. The remaining citronella essential oil fraction was mainly composed of citronellol and geraniol. A microwave steam distillation (MSD) of essential oils from fresh orange peels has been compared with conventional steam distillation (Sahraoui et al. 2011; Farhat et al. 2011). MSD had shorter extraction time, cleaner features, and lower energy cost and provided an essential oil with superior sensory quality (e.g., fresh fruit aroma). Grown under

Table 29.6. Organic Acids of Juice and Peel of Oranges and Tangerines

	Juice (g/100 mL)		Peel (mEq/g Dry Weight)			
Fruit	Malic	Citric	Malic	Citric	Oxalic	Malonic
Orange						
Washington Navel I	0.06	0.56	0.02	0.01	0.11	0.02
Washington Navel II	0.20	0.93	0.02	0.01	0.10	0.03
Valencia	0.16	0.98	0.02	Trace	0.13	0.03
Tangerine						
Dancy I	0.18	1.22	0.06	0.02	0.15	0.01
Dancy II	0.21	0.86	0.09	0.02	0.20	0.02

Source: Adopted from Clements (1964).

same agroclimatic and cultural conditions, the peel essential oils from four selected Tunisian Citrus species: sweet orange (*C. sinensis* Osbeck), mandarin (*C. reticulata* Blanco), sour orange (*C. aurantium* L.), and pommelo (*C. grandis* Osbeck) have been analyzed by GC as well as GC-MS (Hosni et al. 2010). The essential oils mainly consisted of monoterpenes hydrocarbons (97.59–99.3%), with limonene (92.52–97.3%) and β-pinene (1.37–1.82%).

Developments in the analytical techniques have lead to the identification of hundreds of volatile compounds in the orange fruit. Essential oils further undergo changes during packing and storage. The most important volatile materials of citrus fruit are those associated with flavor and aroma. These include terpene hydrocarbons, carbonyl compounds, alcohols, esters, and volatile organic acids. They are generally present in peel oil in flavedo but are also found in oil sacs embedded in the juice vesicles. Variable amounts are present in different parts of fruit and their concentration is affected by processing and storage conditions. One compound D-limonene alone accounts for 80–96% of all citrus oils. α-Pinene, sabinene, β-myrcene, and D-limonene play an important role in orange flavor. Linalool and myrcene make a positive contribution and 2-hexanol and α-terpineol have a negative contribution to orange aroma (Pino 1982).

Chemical composition and aroma of orange were investigated by Rodopulo (1988). The results of analysis showed 12 aldehydes, 12 alcohols (usually as esters with organic acids), 5 terpenes, and 3 esters. Referring to these results, recipes were formulated for the manufacture of aromatic essences enriched with vitamins and trace elements and sugar. The following composition was recommended (mg/L): limonene, 125; citral, 0.25; citronellal, 0.26; linalool, 1.2; α-pinene, 0.9; hexanal, 0.08; and citric acid, up to pH of 4.5. Ethanol (less than 1%) can be replaced with glycerol or 2,3-butylene glycol, 3 g/L each. After addition of sugar, 75 mg/L of ascorbic acid and trace elements (B, Mo, Mn, and Zn) are incorporated up to maximum quantities of 0.3–0.5 mg/L. The aroma components of orange as reported by Nursten and Williams (1967) are given in Table 29.5.

Pectin

After the extraction of orange juice, about 50% of the fruit ends up as peel and pomace. Citrus peel is the major raw material for citrus pectin manufacture (Liu et al. 2006). The maximum pectin grade obtainable under optimum conditions may be about 150–250 for orange peel, which is quite low as compared with that of lemon and grapefruit peels. Peel for citrus pectin is used after extraction of peel oil. Pectic enzymes of peel have to be inactivated to prevent the decomposition of pectin during processing and storage. For commercial production of pectin, peel passes through several steps including removal of peel oil, shredding or comminuting the peel to facilitate the washing and extraction, screening or reeling the peel in rotating cages to remove seeds, and rag and leaching the peel with water to remove soluble sugars and other undesirable materials. If the peel is not to be utilized immediately for pectin extraction, it has to be heated for 10 minutes at 95–98°C to inactivate the pectic enzymes. The extraction conditions such as pH, time, and temperature are controlled to maximize pectin extraction. Both organic and inorganic acids can be used for hydrolyzing the protopectin into soluble pectin. Mineral acids like hydrochloric and sulfuric acids are preferred for extraction. Wooden extraction tanks or vats are commonly used. Raw shredded or dry stored peel may be used for extraction of pectin.

Owens et al. (1949) described a continuous process using a countercurrent extractor for the manufacture of pectin from orange peel. Process conditions involved are water to peel ratio of 3:1, pH of 1.3–1.4, and temperature of 90–100°C with heating for 1 hour. After separation, pectin is given several washings in 50–70% solvent and final dehydration/washing in 80–90% solvent. Finally, the pectin is dried to approximately 6–10% moisture content with warm air or in a heated drum. Low methoxyl pectin can be prepared by controlled acid, alkali, or enzymatic deesterification. The pectin is recovered from comminuted orange peels pretreated with (i) fungal crude enzyme (prepared from *Aspergillus terreus*), (ii) yeast crude enzyme (prepared from *Kluyveromyces lactis*), and (iii) Irgazyme M10 (a commercial preparation from cultures of *A. niger*).

Extraction of pectin from dried orange peel was studied by Gentschev et al. (1991). Mechanical composition, water uptake, and swelling properties of orange pomace were studied during initial rinsing; weight and volume of pomace increased by 6× and 2×, respectively, in the first 20–30 minutes of rinsing. Optimum washing conditions were achieved using a hydromodule of 24:1, and three separate washings with a time–temperature combination of 20 minutes at 20°C, 15 minutes at 30°C, and 10 minutes at 40°C. Effect of extraction variables on yield and quality of pectin extracted from dry orange waste with nitric acid was studied by Aravantinos-Zafiris and Oreopoulou (1992). A factorial experimental design was used and effects of temperature, time, and pH of extraction on pectin yield and "jelly units," that is, pectin yield × viscosity of pectin solution, were determined. Optimum conditions for pectin extraction are also discussed. According to ash and methoxyl content determinations, the product can be classified as low ash and high methoxyl pectin. Its purity expressed as anhydrogalacturonic acid content varied from 68.5% to 75.0%.

Hesperidin

Hesperidin can be recovered from the wastewater of orange juice processing (yellow water) by concentration of diluted extracts on styrene-divinylbenzene resin (Di Mauro et al. 2000). Turbid raw material flowing out from centrifuges of essential oil separation contains considerable amount of hesperidin (approximately 1 g/L), mainly associated with solid

particles. Yellow water is treated with calcium hydroxide until pH 12 is reached, to solubilize hesperidin before being filtered, neutralized at pH 6, and loaded on resin up to a saturation point. Desorption with 10% ethanol aqueous solutions at different NaOH concentrations (0.23–0.92 M) is carried out to ensure high concentration of hesperidin in selected fractions (10–78 g/L), from which it is precipitated in high yield and purity immediately after acidification to pH 5. Best results are obtained using 0.46 M NaOH as eluent: 71.5% of the adsorbed hesperidin is desorbed in 300 mL, with an overall 64% yield of isolated product at 95.4% purity.

Coloring Matter

The orange peel is a good source of pigments and yields about 350 mg/kg orange peel (Wilson et al. 1975). The crude extracts and yields from 20-fold concentration of cold-pressed oils of midseason orange, Valencia orange, and tangerine were 116, 95, and 116 mg/kg peel, respectively. A dispersible powder for coloring and flavoring orange drinks was produced from the essential oil and carotenoid pigments of orange peel (Rovesti 1978). Recycling orange essential oil on flavedo from whole oranges produces an extract with 336 ppm of total carotenoids (87.7% xanthophylls). To obtain a highly colored water-dispersible product, color extract is dispersed in an aqueous emulsion containing natural and modified polysaccharides (a mixture of unmodified hydrolyzed starches, enzyme-treated water extract of orange peel, and 3% gum acacia or sodium caseinate) and is spray dried at less than 75°C in a 75% N_2, 21% CO_2, and 4% O_2 gas mixture at a water-soluble:fat-soluble substance ratio of 1.8 and a water:total DM ratio greater than 10, atomizer rotation rate 7000 rev/minute. The product is a deep yellow powder of medium density, easily dispersible in water at 40°C (or in cold water with stirring). About 7% of the carotenoids in the extract are lost in spray drying. No significant changes in carotenoid contents or composition are observed after 120-day storage away from direct light at 35°C. Color changes in prepared drink are prevented by addition of 100 ppm of ascorbic acid. The pigments from orange peels have also been produced by using microbial enzymes (Elias et al. 1984).

BIOACTIVE COMPOUNDS

Phytochemicals, especially the phenolics in fruits and vegetables, are the major bioactive compounds having known health benefits. Plant phenolics, which are known to have antioxidative and antiradical properties, are commonly found in both the edible and nonedible components of fruits and vegetables (Babbar et al. 2011). They have reported the total phenolic contents, reducing power, and antioxidant activity of six fruit residues, such as Kinnow peel (a type of orange), litchi pericarp, litchi seeds, and grape seeds. Scordino et al. (2007) have extracted anthocyanins, limonoids, flavanones, and hydroxycinnamates from pigmented orange pulp, a by-product of orange juice processing, by using a series of resin adsorption and membrane operations. The composition of the final product (28°Brix) was 250 g/L sugars (glucose, fructose, sucrose), 9 g/L citric acid, and 1 g/L pectin and was transparent lightly amber-colored liquid, which could be used as a natural sweetener in food and beverage formulations.

Out of the 22 compounds representing more than 89.5% of the volatile oil obtained from *C. aurantifolia* by hydrodistillation were D-limonene (30.13%) and D-dihydrocarvone (30.47%). The lime volatile oils were shown to produce DNA fragmentation and induction of caspase-3 up to 1.8- and 2-folds after 24 and 48 hours, respectively, which may be due to the process of apoptosis (Patil et al. 2009). Estimation of apoptosis-related protein expression further confirmed the apoptosis induction by the lime volatile oils, thus suggesting the potential benefits of lime essential oils in colon cancer protection. In a subsequent study, Patil et al. (2010) have purified five putative compounds from lime seeds (*C. aurantifolia* Swingle) using soxhlet extraction and chromatographic separation. They determined their structures using TLC, HPLC, and MS as limonin, limonexic acid, isolimonexic acid, and β-sitosterol glucoside and limonin glucoside. They also confirmed the induction of apoptosis of pancreatic cancer cells through annexin-FITC staining of the cells and expression of apoptosis-related proteins.

GRAPEFRUIT (*C. grandis; C. aurantium,* var. *grandis; C. decumana*)

The world production of grapefruit and pommelos is 4.69 million tons. The grapefruit is consumed as fresh fruit, juice, or jam. Igual et al. (2010) suggested use of osmotic dehydration technique at mild temperature to obtain jam with good nutritional quality. The cultivars of grapefruit used for juice production are Marsh seedless and Duncan. Red Blush and Foster are recommended for cultivation in India. Grapefruit juice prepared from pigmented rather than white grapefruit often yields a product with poor color (Lee 1997). It is suggested that a grapefruit juice of good color could be produced through careful selection of highly pigmented grapefruits, controlled blending, and further color enhancement. "Star Ruby," a new cultivar of red grapefruit, was found to have excellent color both in the flesh and in the juice, even in late season (Ting et al. 1980). The color is sensitive to heat, but the juice after pasteurization and concentration retains sufficient color. The juice of the Star Ruby is higher in soluble solids and acid than the Ruby variety (Hensz 1971). Thompson is another pigmented cultivar. Grapefruit is processed both for single-strength juice and frozen concentrate.

Fruit in the processing plant is graded, sampled for analysis, and stored in bins after removal of split and decay fruits. Fruit is given another grading inspection before washing, to remove additional inferior fruit. The fruit is then dumped in

a soaking tank or hot pit, which has multiple purposes of soaking, washing, and oil control.

Juice Extraction and Finishing

The grapefruit juice can be extracted using the same machinery as used for orange juice with adjustment of extractors depending upon the size of fruit. Specially designed extractors are also available for different size fruits. Modern extractors can handle over 2 tons (t) of fruit/minute. Bireley Citromat, Brown, and the Food Machinery In-Line Extractors are used for juice production. The juice yield varies from about 334 L/t fruit at beginning, to a maximum of about 542 L/t at midseason, but dropping considerably toward the end of season. The average yield is reported to be about 480 L/t fruit. Mohsen et al. (1986a) reported that rotary extraction increased PC and pectin esterase in the juice. Pressing extraction increased contents of limonene, oxygenated terpenes, and carbonyl compounds. Rotary extraction increased contents of esters and water-soluble volatiles. Effect of method of extraction and pasteurization on grapefruit juice properties and its volatile components was studied. Taste and color were not affected by the treatment, but odor of juice extracted by pressing was more acceptable than that obtained by rotary extraction.

Mechanically extracted juice contains seeds, pips, and membrane segments, which must be removed quickly to avoid leaching of naringin and limonin from suspended particles into the juice. The juice is finished in the same type of finisher that is used for orange juice. In the case of grapefruit juice, the pressure applied during finishing has marked effect on yield and flavor of juice. The naringin and limonin contents of Florida grapefruit juice have been reported to range from 218 to 340 ppm and 2 to 10 ppm, respectively (Tatum et al. 1972; Barros 1992).

Coloring Pigments

Cruse et al. (1979) reported that juice of the Star Ruby grapefruit (*C. paradisi* Macfad) extracted by commercial machinery and canned during the regular harvest season contained from 0.34 to 0.56 mg/100 g β-carotene and 0.57 to 0.72 mg/100 g lycopene, as compared with the corresponding respective value ranges of 0.09–0.14 mg/100 g β-carotene and 0.04–0.08 mg/100 g lycopene for the Texas Ruby Red variety. Blending with Star Ruby juice at about a 30% level in the early processing season and 40% in the late processing season is proposed as a means of maintaining a desired level of pink color in canned Texas grapefruit juice. In Texas, the processing of pink grapefruit juice is emphasized, as contrasted to white grapefruit juice in Florida and California. The carotenoid composition of the juice of red-fleshed grapefruit is reviewed by Benk and Bergmann (1973). For carotenoids, the ranges reported are total carotenoids, 1.4–3.5 mg/L; β-carotene, 0.6–1.6 mg/L (39–53% of total); lycopene, 0.4–0.9 mg/L (23–38%); and cryptoxanthin, 0.03 mg/L (1.6%).

Deaeration and Deoiling

Deaeration and deoiling are important features in canning of grapefruit juice. The freshly extracted juice contains 2–4% gases (Pulley and von Loesecke 1939). As oxygen has adverse effect on color, vitamin C, and citrus oils, it must be removed immediately. The acid-catalyzed dehydration of the D-limonene produces turpentine-like taste even in the absence of molecular oxygen (Blair et al. 1952). It is a serious problem with canned and chilled grapefruit juice because of its high acidity. Shearon and Burdick (1948) and Scott (1941) discussed technical and engineering phases of deaeration and deoiling of juice. For optimum flavor and storage life, the juice should contain 0.003–0.005% recoverable oil. Sulfur volatiles are the major factors in determining the aroma of grapefruit juice (GFj), and 13 sulfur volatiles have been identified by Jabalpurwala et al. (2010). Canned reconstituted GFj had more total sulfur volatiles and a greater number than the fresh GFj. In fresh GFj, hydrogen sulfide constituted 80% of the total sulfur volatiles, but only 5% in canned GFj.

Debittering

Debittering of grapefruit juice has been achieved with β-cyclodextrin polymers or XAD resins in a fluidized bed process (Wilson et al. 1989), polystyrene divinylbenzene adsorbents (Manlan et al. 1990), polyvinylpyrrolidone (Nisperos and Robertson 1982), naringinase entrapped in cellulose triacetate fibers (Tsen and Yu 1991), naringinase immobilized in packaging films (Soares and Hotchkiss 1998b), active packaging (Soares and Hotchkiss 1998a), enzymes (Prakash et al. 2002), and Amberlite IR 120 and Amberlite IR 400 and alginate entrapped naringinase enzyme (Mishra and Kar 2003).

Ribeiro and Ribeiro (2008) have developed a fast and effective HPLC method for the simultaneous determination and control of naringin and naringenin in commercial grapefruit and orange juices. This method is useful in debittering process when using naringinase enzyme. Ferreira et al. (2008) used high pressure with naringinase enzyme immobilized in calcium alginate beads to remove bitterness in grapefruit juice. This enzyme hydrolyzes naringin (a flavanones glycoside and major bitter component of GFj) to naringenin, which is tasteless. At a pressure of 160 MPa at 37°C for 20 minutes, they were able to remove 75% of the bitterness from grapefruit juice. Recently, Kranz et al. (2011) reported use of XAD-7HP resin for debittering of grapefruit juice, but they observed a selective shift in reduced flavor profile. Reduction of naringin to 51.28% of its original value led to decrease in α-terpineol (which gives off-flavor) to 43.05%, whereas other flavor compounds were also reduced by 76.27% (β-myrcene) to 92.76% (β-caryophyllene). This technique indicates a promising potential to selectively remove the off-flavor component during debittering of processed citrus juices.

Deacidification

Optimum conditions for use of chitosan in deacidification of grapefruit juice and effects of chitosan treatment on the composition and sensory properties of the product have been studied (Rwan and Wu 1996). Chitosan with a particle size of 40–60 mesh and a degree of deacetylation of 90% showed superior deacidification properties. Deacidification carried out by adding chitosan into juice at 0.015 g/mL with stirring at room temperature for 30–60 minutes gave deacidified juice with a Brix:acid ratio approximately 13.4; total acid content was reduced by approximately 52.6%; contents of citric, tartaric, L-malic, oxalic, and ascorbic acids being reduced by approximately 56.6%, 41.2%, 38.8%, 36.8%, and 6.5%, respectively. Sugar, amino acid, mineral, and naringin contents and Hunter L, a, and b color values were not affected. Deacidified juices had higher scores for total acceptability than the original juice. Chitosan could be successfully regenerated and reused. The economic feasibility of adsorptive deacidification and debittering of Australian citrus juices was studied by Johnson and Chandler (1985). Aspects covered were basis for costing (capital outlay, loan repayment and depreciation, maintenance, and labor cost); deacidification of citrus juice (regeneration of deacidifying resin, replacement of deacidifying resin, evaporation of diluent water, and cost of citric acid removal); debittering of citrus juice (regeneration and replacement of debittering resin, evaporation of diluent water, and cost of debittered navel orange juice); return by saving in sucrose addition; and return by increased value of debittered juice. It was concluded that the operation of both processes for 3 months of the year each should repay capital in less than 1 year.

Sweetening

The relationship between the ratio of Brix to percent acid and sensory flavor in grapefruit juice was studied by Fellers (1991). A significant correlation between ratio and flavor was found; the higher the ratio, the better the flavor. Because of high acidity and tartness, most grapefruit juice is sweetened. For sweetening, calculated amount of sugar or highly concentrated sugar syrup (65°Brix) is added to the tanks containing the juice, so that Brix is increased to a desired level.

Pasteurization and Packing

In the case of grapefruit juice, higher temperature is required to deactivate pectin esterase compared with orange juice. The effect of time and temperature of pasteurization on cloud stability of canned grapefruit juice was studied by Kew et al. (1957). The cloud was stabilized in a high-speed pasteurization at 98.9°C for 1.75 seconds, at 90°C at about 13 seconds, and at 85°C for about 43 seconds. Effects of thermal pasteurization on color of red grapefruit juice have been studied (Lee and Coates 1999). Juices were pasteurized at 91°C using a plate-type heat exchanger. Thermal pasteurization affected color (CIE L^*, a^*, b^*) producing a lighter and brighter color. Thermal pasteurization especially affected CIE b^* values and chroma within the juice. Reflectance spectra within the visible region (400–700 nm) clearly showed changes in spectral distribution of light reflected from juice after pasteurization. There were no changes ($P > 0.05$) in major carotenoid pigments (β-carotene and lycopene) of the juices after pasteurization.

Two new "cold" pasteurization techniques available to the food industry, ultrahigh pressurization pasteurization, and electric impulse poration pasteurization are described (Anon 1993b). With ultrahigh pressurization pasteurization, the pressure treatment destroys the cellular integrity of microorganisms without affecting heat labile flavor compounds, vitamins, and other essential components. With electric impulse poration pasteurization, liquid foods are passed through very narrow orifices across which are passed high-voltage electric pulses. The electric pulses inactivate microorganisms by electroporation.

Pasteurization caused an inactivation of about 94% in pectin esterase and decreased contents of limonene, oxygenated terpenes, esters, and water-soluble volatiles. Carbonyl compounds showed a slight increase after pasteurization. The major volatile components of grapefruit juice, identified by GC, were limonene; terpinen-4-ol; α-terpineol; linalool; methanol; ethyl butyrate; and octanol (Mohsen et al. 1986b). Pasteurized grapefruit juice is filled into cans, closed, and cooled by the same procedures as described for canned single-strength orange juice.

Concentrated Grapefruit Juice

Praschan (1951) has discussed the different types of evaporators and different methods of freezing from engineering and technical angle. After pasteurization, juice is concentrated under high vacuum at temperature below 26.7°C to about fivefold, diluted or cut back with fresh unconcentrated, deaerated, heat-treated juice having a higher pulp and oil content to about fourfold. Often, cold-pressed grapefruit oil is added to replace that lost during the concentration. Product is filled into cans of appropriate size.

Aroma and total volatile compounds composition of a single unpasteurized Marsh grapefruit juice and its 65°Brix concentrate (obtained from juice using a TASTE) reconstituted with water to 10°Brix were examined using GC-olfactometry and GC-FID (Lin et al. 2002). Total volatile compounds (measured by FID) in the reconstituted concentrate were reduced to <5% of initial values, but 57% of total aroma compounds (as judged by GC-olfactometry) remained. Forty-one aroma-active compounds were detected in unpasteurized single-strength juice, whereas 27 components were found in the unflavored reconstituted concentrate. Aroma-active compounds were classified into grapefruit/sulfury, sweet/fruity, fresh/citrusy, green/fatty/metallic,

and cooked/meaty groups. Five of the six components in the sweet/fruity and 14 of 18 green/fatty/metallic components survived thermal concentration. However, only 4-mercapto-4-methyl-2-pentanone in the grapefruit/sulfury group and linalool and nootkatone from the fresh/citrusy group were found in the reconstituted concentrate. Methional was the only aroma compound in the cooked/meaty category found in both juice types. β-Damascenone and 1-*p*-menthen-8-thiol were found only in the reconstituted concentrate. 4-Mercapto-4-methyl-2-pentanol was detected for the first time in grapefruit juice.

Storage

Grapefruit juice is probably the most stable of the citrus group, though the changes in flavor are probably masked to some extend by high acidity and bitterness due to naringin that has not been found in significant amount in other citrus juices. Under normal storage temperature and conditions, properly processed juice should retain its normal flavor and appearance for about 9 months; it should still possess a good flavor for about 15 months, after which definite off-flavor and off-colors develop. The most significant changes in stored canned juice are a decrease in limonene and an increase in linalool monoxide, α-terpineol, and furfural. Canned or bottled grapefruit juice will retain its normal flavor almost indefinitely when stored at 0°C. Changes in aromatic volatile constituents of grapefruit juice were studied during 8 months storage of concentrated juice at –9°C and –18°C (Pino 1986). Results obtained by GLC indicated decreases in terpene hydrocarbon and esters, while other compounds such as α-terpineol, epoxydihydrolinalool, furfural, and aldehydes increased during storage at –9°C. Changes were less evident during storage at –18°C. Alterations in composition corresponded with results of sensory analysis.

Changes in color and pigment composition (β-carotene and lycopene) of red grapefruit juice concentrates during storage at –23°C for 12 months have been studied (Lee and Coates 2002). Concentrate (38°Brix) was packed in both plastic (16 oz) and metal (6 oz) cans. Decrease in red intensity (CIE a^*) in juice color and slight increases in CIE L^*, b^*, and hue values from analysis of reconstituted juices were the characteristic color changes in concentrate during frozen storage. With respect to fresh concentrate, juice color in stored concentrate shifted toward the direction between negative DELTAC* and positive DELTAL*, indicating that the color became slightly paler. A color difference seemed to exist between the two containers, especially for the magnitude of DELTAL*; color changes were more pronounced in concentrates packed in plastic. There were significant changes ($P < 0.05$) in major carotenoid pigments (β-carotene and lycopene) in the concentrates. More than 20% loss of lycopene and approximately 7% loss of β-carotene occurred with plastic containers after 12 months. Regression analysis showed that the rate of decline was approximately 0.291 ppm/month ($r = 0.990$) for lycopene compared with 0.045 ppm ($r = 0.817$) for β-carotene in concentrate stored in plastic. In the metal can, the same trends were observed, but pigment losses were slightly smaller than those with plastic. An estimated shelf life for lycopene was 26.1 months in the metal can compared with 18 months in plastic. Shelf life for β-carotene was >39 months, which was more than twice that of lycopene in the plastic container.

Changes in flavonoid content of grapefruit juice during conventional and microwave processing and 2 months of refrigerated and frozen storage have been investigated by Igual et al. (2011). Naringin, narirutin, quercetin, and naringenin were found to be the most abundant flavonoids in grapefruit juice. Pasteurization treatment caused a significant reduction in flavonoid contents, but the treated samples were more stable during storage. Conventionally pasteurized juice preserved better under refrigerated conditions, but microwave pasteurized juice preserved better under frozen storage, as it retained the highest level of flavonoids. Ferrentino et al. (2009) used continuous dense phase carbon dioxide (DPCD) equipment to inactivate yeasts, molds, and total aerobic bacteria. Although pectinesterase activity was partial (69.17%), but the cloud increased by 91%, and the treated juice showed no growth of microorganisms during 6 weeks of storage at 4°C. The treatment and storage did not affect the total phenolic content of red grapefruit juice.

Roig et al. (1994) studied the possible additives for extension of shelf life of single-strength reconstituted citrus juice, aseptically packaged in laminated cartons. The results show the importance of eliminating oxygen in systems where L-ascorbic acid is present for its nutritional value. Of the additives studied for the purpose of extending the shelf life of the juices, sodium metabisulfite was the most effective. The cold storage (at −18°C) of grapefruit concentrate has been suggested as a viable treatment for achieving a five-log reduction in salmonellae (Parish et al. 2004).

LEMON (*C. limonia*)

Eurekas, Lisbons, and Villa Francas are the commercial varieties. Predominant cultivar in Mediterranean countries is Femminello. The production of lemons and limes is reported to be 12.45 million tons in the world. Lemons are picked by hand according to size rather than color when they meet maturity standards. Lemons are considered mature when they contain 30% or more juice. Very immature fruit that has not gone through the curing process may impart a green-fruit taste, whereas fruit stored for very long time may impart an overmature or stale taste. The blending of fruit may sometimes be necessary to obtain satisfactory, uniform flavor, and acidity. The presence of flavanones, flavones, polymethoxyflavones (phytoanticipins), and scoparone (a phytoalexin) has been suggested to be involved in the defense mechanisms of various citrus fruits, including lemons, against *Penicillium*

digitatum, which is the most damaging postharvest diseases in these fruits (Ortuno et al. 2011). The relative participation of any one group of these secondary compounds in defense mechanism may vary from specie to specie of the citrus fruits.

Lemons used for juice production in commercial operation are graded and brush-and-spray washed with warm detergent solution and rinsed before going to juice extractors (Kieser and Havighorst 1952). Biesel (1951) described in detail the methods for controlling microorganisms in citrus processing plants. The citric acid is the most important single constituent of the lemon and consequently concentrated juices are standardized on the basis of acidity. To counter the variations in acidity, the juice from different lots is blended and stored in concentrated form. The concentrated juice can be manufactured to any desired acid content by adjustment of the ratio between volume and concentration. The lemon juice when added to bonito fish preserved by sous vide packaging had a shelf life of 49 days compared with 35 days for the control (Cosansu et al. 2011).

Juice Extraction

Most of the juice is extracted with automatic machines such as Brown Extractor and Food Machinery and Chemical Corporation machine. Both these machines produce juice free of peel extractives. The amount of peel oil, pulp, and pectic enzyme incorporated into juice during extraction are the deciding factors for selecting the type of extractor for specific products. FMC In-line machine is used for simultaneous recovery of both juice and oil. The Citrus Equipment Corporation unit, the Citromat, and the Elpico machines are chiefly used for peel oil recovery. Juice yield from 36% to 57% is obtained by different methods of extraction (Dupaigne 1971).

The juice should be screened as soon as possible to remove the insoluble solids, which contain leachable substances that may impair the flavor, color, and cloud stability of the juice. For better juice yields, screening in paddle finishers or screw presses is done to remove coarse pulp. Ray et al. (2003) used a UF unit for clarification of lemon juice and reported that the membrane with a molecular weight cut-off of 300 kDa was best suited for clarification of lemon juice. The juice should be chilled to 10°C to avoid undesirable changes at higher temperature due to atmospheric oxidation.

The lemon peel oil content is very important from the standpoint of both flavor and stability. The amount of cold-pressed peel oil in lemon juice is limited to 0.025% because of oil burn as noted by throat feel at higher level. It is necessary to lower the oil content of lemon juice for specific uses. Deoiling may be accomplished by injecting preheated juice into a vacuum chamber, such as Majonnier deoiler. Debittering of by-product of lemon juice extraction has been achieved by a vacuum method, where debittering for 15 and 45 minutes reduced the essential oil by 50% and 88%, respectively, without adversely affecting the ascorbic acid content (Mezaheri Tehrani et al. (2006). The debittered pulp was found to be suitable for use in marmalade and soft drinks.

A process for production of a shelf-stable lemon juice without use of sulfite preservatives is described (McKenna et al. 1991). Lemon concentrate and/or lemon oil, sodium benzoate, and water are mixed; ascorbic acid, sodium acid pyrophosphate, glucose oxidase, or sodium hexametaphosphate are added with stirring; and an inert gas, for example, CO_2, He, or N_2, is bubbled through the mixture, to produce a juice with a shelf life of greater than 9 months.

Donsi et al. (1998) carried out high-pressure stabilization of lemon juice. All the benefits of HPP were achieved at the 3000 bar. It gave high-quality lemon juice with a satisfactory shelf life. Sharma et al. (2004) studied the use of foam mat drying process to produce a beverage powder from the hill lemon (*C. pseudolimon*). They used a 45°Brix juice concentrate after foaming with 2% carboxymethyl cellulose and drying in a mechanical drier (55 ± 2°C) followed by finishing in a vacuum drier (50 ± 2°C) to a moisture content of about 5%. This powder product being hygroscopic in nature had a better shelf life when packaged in aluminum-laminated than the simple polypropylene pouches and stored within a RH of 18–25%.

Pasteurization

The current practice is to heat the juice to a temperature for sufficient time and to assure practical sterility as well as cloud stability by inactivating the natural juice enzymes (Rothschild et al. 1975). A temperature of 77°C for 30 seconds is used in commercial operations. The juice is cooled immediately after pasteurization by passing through the heat exchanger.

Concentration of Juice

The concentration of heat-stabilized juices is carried out in vacuum evaporators. TASTE and AVP rising and falling film plate evaporators are used for concentration. A centrifugal evaporator developed by Alfa-Laval is suitable for concentration of lemon juice to 47.7% TS at 38°C, with no adverse effects on flavor or vitamin contents (Thormann 1972).

A triple-effect plate evaporator for the production of lemon juice concentrate features a novel density-control system for single-pass, nonrecirculatory flow operation, which regulates steam pressure and condenser vacuum (Dinnage 1970). The evaporator has three effects arranged in four stages of evaporation and additional use of steam jet recompression gives overall evaporative efficiency of approximately equal to 4:1 while concentrating lemon juice to 50°Brix. The feed is regeneratively preheated to 54.5°C, with concurrent cooling of the concentrate. Liquid holding time is minimized by use of extraction pumps at each evaporator stage; total holding time is 135 seconds. A feed input of 35,700 lb lemon juice/h (8% solids, 4.5°C) results in 5700 lb final concentrate/h (50% TS, 7.2°C). The final product is standardized on the basis of

grams of anhydrous citric acid per liter, usually about 325 g/L of concentrate.

Packaging and Storage

Plastic or steel drums, glass containers, and cans of different sizes can be used for packing depending upon the storage time and temperature, as well as on the basis of economical considerations. All types of lemon juice products should be stored at lowest possible temperature. Frozen single-strength juice chilled to –1°C is filled into cans and quick-frozen, and stored at –23°C. Frozen concentrated juice after standardization of acid is also frozen at –23°C in drums for storage.

Vandercook (1970) reported that when lemon juice was stored under adverse conditions, the long wavelength peak (323–335 nm) in the UV spectra of the juice shifted to shorter wavelengths. With continued juice deterioration, the peak became a shoulder. The deterioration and spectral changes were proportional to the storage temperature and greatly increased by air.

Effects of adding SO_2, Sn^{2+} (tin), or cysteine to concentrated lemon juice on its color during storage have been investigated (Nunez et al. 1989). The results showed that at 45°C, browning was inhibited by greater than 125 ppm SO_2, and the degradation of ascorbic acid, formation of furfural, and hydroxymethyl furfural by greater than 250 ppm SO_2. Browning rate was reduced by Sn^{2+} (tin) depending on the concentration used: at 1000 mg Sn^{2+} (tin)/kg juice, browning was reduced to about one-third of the initial rate. Cysteine inhibited color formation only slightly at high concentration and affected the aroma of the juice at concentration greater than 500 mg/kg. Use of Sn^{2+} (tin) was promising because of its low toxicity and high legal tolerance levels, especially as its concentration would be reduced when the juice was diluted for use.

Studies were conducted on effects of cysteine on browning of concentrated lemon juice during storage (Tateo and Bianco 1984). The results showed that addition of cysteine before concentration reduces browning during subsequent storage; it also reduced browning under UV or IR irradiation. Addition of cysteine after concentration did not control browning.

LIME (*C. acida; C. aurantifolia*)

The small size Key (Mexican or West Indian) or common lime and the large-fruited Persian (Tahitian) seedless limes have gained commercial importance. The Key is the most important cultivar. Lime resembles the lemon in structure and composition, but it is usually smaller in size. The composition of the lime varies considerably with variety of fruit and the location where the fruit is grown. The fruit weight of Persian lime has been shown to be positively correlated to the juice % recovery, but it had negative relationship with ascorbic acid (Castellanos and Hernandez 1982). The small fruits (40–42 mm dia.) had low juice contents than the bigger fruits (50–55 mm dia.), as the later were found to be more acceptable for fresh consumption.

Juice Extraction

Production of lime juice is described by Seelig (1993) and Anon (1993c). For large size Persian lime, the standard juicing equipment is used, for small size Key lime, conventional extractors are not practical and juice is generally obtained by crushing the whole fruit in a screw press.

The fruit is carefully graded, washed, and sometimes sterilized before passing to the high-speed juice presses or rollers. The juice is screened, analyzed, blended, deaerated, and deoiled before final canning. Lime juice is handled and pasteurized in the same way as lemon juice. The juice from Persian lime is passed through a finisher after extraction with standard juicing equipment. During finishing, it is important to keep pressure comparatively light to avoid extraction of bitter constituents from peel. Pruthi and Lal (1951) observed that deaeration combined with flash pasteurization at 90–96°C gives the best retention of vitamin C and overall juice quality. Study conducted on the factors affecting the keeping quality of lime juice (El-Shiaty et al. 1972) indicated that pasteurization improved cloud stability, had no effect on palatability, percentage of TA or pH, but resulted in a slight decrease in ascorbic acid content. The acid content of juice varies from 4.94 to 8.32 g/100 g of juice for different cultivars. The lime juice may be clarified by passing through a suitable plate and frame or other types of filter presses after mixing with filter aid. The juice may also be clarified by storing in wooden tanks with addition of either sulfur dioxide or sodium benzoate. Shaila-Bhatawadekar (1981) studied the clarification of lime (*C. aurantifolia*) juice by cellulase from *Penicillium funiculosum* at pH 2.2–5.6, using an enzyme concentration of 0.82–3.2 filter paper units (FPUs), with subsequent incubation of the juice at 30°C, 40°C, and 50°C for 2–32 hours. Maximum turbidity reduction (greater than 90%) was obtained at pH 4.0–4.5, temperature 30–40°C, an incubation period of 18–24 hours, and addition of 1.64 FPU enzyme. For freezing, the juice is precooled before filling into cans.

Edwards and Marr (1990) analyzed the volatile components of lime juice oil and lime peel oil by capillary GC and MS. α-Santalene and β-santalene (0.06% and 0.11%, respectively) were found in lime juice oil, while β-santalene and β-santalol were found in lime peel oil (0.03–0.04% and 0.5%, respectively).

Concentration

Askar et al. (1981) described the production of lime juice concentrates using the serum–pulp method. Lime juice was concentrated using four methods: (i) freeze concentration of the juice, (ii) vacuum evaporation of the "cut-back" juice with pasteurized juice, centrifugal separation into pulp and serum followed by (iii) freeze concentration, or (iv) evaporation of

serum and recombination with the pulp. The chemical composition of fresh, pasteurized, and concentrated lime juice has shown that the best quality concentrates were obtained by method (iii), followed by methods (i), (iv), and (ii). Freeze concentration does not markedly affect palatability or cloud stability but results in a decrease in percentage of TA and ascorbic acid (El-Shiaty et al. 1972).

Storage

Under unfavorable conditions, the lime oil in contact with high acid lime juice develops characteristic off-odors and flavors. Ikeda et al. (1961) reported that γ-terpinene is readily oxidized to off-flavored product, *p*-cymene. Pasteurized juice can be stored at 2°C for 15 months without appreciable change in flavor. In untreated samples, changes occur and storage life is limited to about 4.5 months at 27°C.

Sensory and physicochemical stability of frozen Tahiti lime juice, natural and sweetened, have been studied (Pedrao et al. 1999). Samples of natural Tahiti lime (*C. latifolia*) juice and Tahiti lime juice sweetened with 60% sucrose were frozen and stored for up to 60 days. At intervals during storage, ascorbic acid and citric acid concentration, optical density at 420 nm, pH, Brix value, and sensory properties were determined. Optical density at 420 nm increased during frozen storage, indicating darkening; this change was greater for the sweetened than for the nonsweetened samples. The other physicochemical and sensory properties studied were little affected by freezing or frozen storage, and most properties were similar for sweetened and natural juices.

El-Shiaty et al. (1972) reported that the storage temperature, time, and type of packaging material affected the organoleptic characteristics of the lime juice. Plain tin cans were superior to glass bottles and plastics or polyethylene packages. If plastics or polyethylene containers are to be used for packaging of lime juice concentrate, the storage temperature should not exceed 0°C.

The shelf life of lime juice, made from *C. aurantifolia* picked at maturity, was investigated under various pretreatment, packaging, and storage conditions (El-Ashwah et al. 1981). Lime concentrates were pasteurized or pasteurized and treated with 200 or 300 ppm SO_2 before being packed in polyethylene bags. The remaining samples were pasteurized or pasteurized and treated with 200 ppm SO_2 or 200 ppm SO_2 + 10% NaCl and filled into glass bottles. Analyses for TSS, TA, pH, total SO_2, ascorbic acid, FAN, PC, color index, pectin methyl-esterase activity, and sensory quality (taste, odor, and color) were conducted. TSS, TA, and pH were 8.8%, 7.7%, and 1.9, respectively, for all juices and storage did not affect these values. SO_2 levels decreased during storage, with a reduction of 8% after 1 month and 5% at the end of storage. NaCl did not affect SO_2 retention, which was higher in glass bottles than in plastic bags. Ascorbic acid decreased from 30 to 26.7 mg/100 mL although addition of SO_2 enhanced ascorbic acid retention. Ascorbic acid retention in glass bottles was greater than that in plastic bags. FAN increased from 18.7 to 21.3 mg/100 mL during pasteurization, yet storage did not affect this value. PC decreased from initial 6% to 4% after pasteurization and it increased in all samples during storage. Color index decreased after pasteurization and during storage, although in unpasteurized control samples, addition of SO_2 slowed down this decrease especially in plastic bag samples. NaCl accelerated discoloration in a linear manner. PME activity was completely inhibited in all samples after 4-month storage. Organoleptic evaluation showed that pasteurization reduces juice quality slightly, but addition of SO_2 maintained it at acceptable levels for up to 6 months. Juice in glass bottles was unacceptable after 4 months, but addition of NaCl and SO_2 extended its shelf life to 6 months.

El-Ashwah et al. (1974) studied effect of storage on frozen lime juice. Juice was extracted from mature limes with a hand-reamer and strained through a thin cloth. One batch was pasteurized at 76°C for 1 minute, and another was not pasteurized. Three preservatives were applied to subbatches before bottling: (i) 100 ppm sorbic acid, (ii) 1000 ppm sodium benzoate, and (iii) a combination of 500 ppm sodium benzoate and 250 ppm potassium metabisulfite. Storage was carried out at –12.2°C for less than 12 months. Unpasteurized juice retained better flavor for a greater time than pasteurized juice. Partial cloud separation commenced at 6 months for all, except treatment (iii), which remained stable until 12 months; (ii) and (iii) had a better effect on pasteurized juices than (i). TSS and total titratable acidity remained essentially constant throughout, but ascorbic acid was gradually destroyed. Pasteurization and preservative (iii) helped ascorbic acid retention. Amino-nitrogen levels were inconsistent during storage, and volatile oils gradually declined, irrespective of treatment.

A study was made about the effects of different storage conditions on the keeping quality of concentrated lime juice (Heikal et al. 1972). Juice was mechanically extracted from Baladi limes and concentrated under vacuum to 42% soluble solids. The concentrated lime juice was either (i) bottled without any preservative or (ii) treated with 0.15% calcium carbonate plus 0.3% potassium metabisulfite, and then bottled. Bottles were stored at room temperature, 0°C or –10°C for less than 30 weeks. No significant change was observed in pH or TA of the concentrated lime juice during processing or storage. Prolonged storage resulted in increased loss of ascorbic acid, the loss being greater at higher temperature. The samples subjected to (ii) and stored at –10°C retained the highest concentration of ascorbic acid; discoloration and off-flavor development were also satisfactorily retarded by this treatment.

FUTURE RESEARCH NEEDS

It would be desirable to propagate the orange trees with as diverse a genetic makeup as possible of both scion and

rootstock, to minimize the universal problem of postprocessing bitterness and to improve the other quality characteristics. Extraction machinery has greater scope for improvement. Instantaneous extraction processes should be developed that would extract the juice under vacuum preferably by centrifugal forces with minimal incorporation of pulp particles but still keeping a highly acceptable quality of juice.

Consumer demand for orange juice being as natural as possible and without extensive processing is increasing. Problems related to production of freshly squeezed (nonpasteurized) orange juice are mainly microbial, and its stability depends on strict sanitation practices during production and on storage at low temperature during distribution and retailing. Since shelf life and sensory properties of fresh orange juice depend almost entirely on initial bacterial counts and on storage temperature, importance is given to hygiene and sterilization in the manufacturing plant. Good production practices of raw material and product manufacturing technology should be developed throughout the world to meet the quality requirements of unprocessed juice. Safety concerns regarding pesticides and mycotoxins in citrus fruit juices are of utmost importance. Pesticides are likely to enter the food chain from environmental or direct exposure in the fruit groves or from pest control applications. Rapid methods for screening and estimation of pesticide residues in citrus juice should be developed.

Inert packaging material with low cost and desirable quality characteristics specific to fresh and frozen juice is the need of the hour. Efforts should be made to commercialize the technologies such as HPP, pulsed electric field, and the processes using carbon dioxide gas under high pressure. Economically viable technologies should be developed to recover the newer and valuable by-products from the wastes of citrus processing industries. All efforts should be concentrated to promote the natural citrus juices as far as possible, vis-á-vis ensuring the safety of product for human consumption.

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30
Peaches and Nectarines

Muhammad Siddiq, Allan Liavoga, and Ibrahim Greiby

Abstract: Peach (*Prunus persica*) fruits have been historically produced in China, Iran, USA, France, and the Mediterranean countries, such as Italy, Spain, and Greece. In addition to fresh consumption, peaches are processed into various products, such as canned fruit, juice, and jam. Nectarines are smooth skin peaches that have a great potential as minimally processed or fresh-cut form. This chapter provides an in-depth overview of the following topics: fruit history, world production, cultivar types, harvesting, postharvest physiology and storage, physiological and pathological disorders, postharvest treatments, packaging, storage technologies, processing and processed products, nutritional profiles of raw fruit and its processed products, fresh-cut products, by-products, and waste utilization.

INTRODUCTION

Peaches (*Prunus persica*) belong to the genus *Prunus* of Rosaceae (rose) family having decorative pink blossoms and a juicy, sweet drupe fruit. They are categorized as "stone fruit" due to their seed being enclosed in a hard, stone-like endocarp. This fruit originated in China, later introduced into Persia and was spread by the Romans throughout Europe. Early Spanish brought several varieties of peaches to North America. Commercially grown peaches are generally distinguished as "clingstone" (pit adheres to flesh) or "freestone" (pit relatively free of the flesh); the famous 'Elberta' peaches belong to the latter type. Nectarine is smooth-skinned fuzzless peach; the lack of fuzz is due to a single gene (Reiger 2004; Anon 2008). Peach and nectarine fruits are relatively large in size ranging from 2 to 3.5 inches in diameter. Peach fruit is pubescent throughout the growing season, and is usually brushed by machine, prior to marketing, to remove most of the pubescence (Magness et al. 1971). Purple-leaved and double-flowering forms of peaches are cultivated as ornamentals. In China, where the peach flower is largely used in decoration, it is considered a symbol of longevity.

World production of peaches and nectarines has remained steady in recent years, ranging from 16.71 to 18.43 million metric tons (MT) during 2004–2008 periods. As compared to year 2004, 18.43 million MT production in 2008 was about 10% higher (Fig. 30.1). China alone accounted for over 45% of world peach and nectarine production

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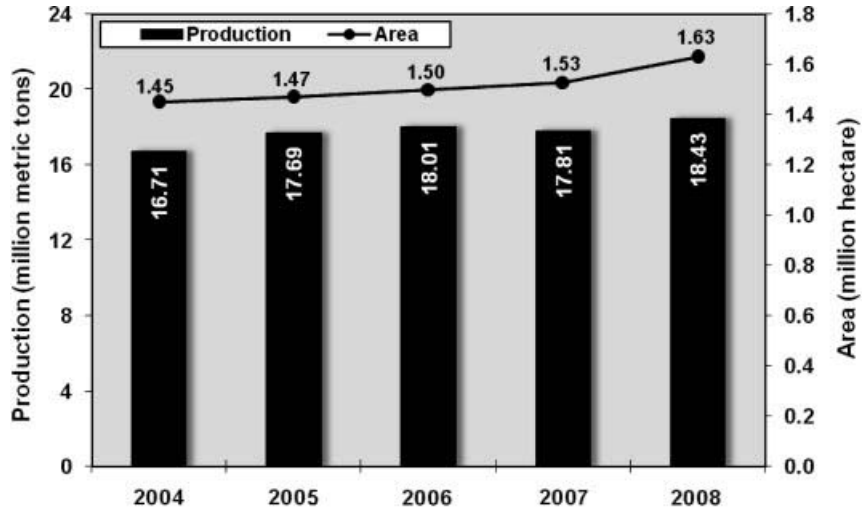

Figure 30.1. World peach and nectarine area harvested and production from 2004 to 2008. (Adapted from FAO 2010.)

(Table 30.1). Other leading producers were Italy, the United States, Spain, and Greece. China also leads in the area harvested for peaches and nectarines, followed by Italy and Egypt (Table 30.2). However, on per hectare yield among major producers, USA leads with 20.6 MT, followed by France (20.0 MT), and Greece (19.9 MT). Higher fruit yields have been reported in Austria and Malta (44.2 and 21.3 MT, respectively), but these countries rank very low on total production basis.

The US commercial peach production is mostly centered in California and in the Southern Atlantic states (South Carolina, Georgia) followed by Michigan, New Jersey, and Pennsylvania. California's climate is ideal for Cling Peach trees, which require a chilling season followed by warmer days combined with rich soil and adequate water to produce the most flavorful fruit. Clingstone-type peaches are used for processing only and are grown exclusively in California. Peaches contribute about $943 million to California's total economy (CCPB 2010).

The per capita consumption of fresh and processed peach products in United States is shown in Table 30.3. Almost half of this consumption is in the fresh form, which has great potential to increase because of the rise in the popularity of fresh-cut fruits in recent years.

Table 30.1. Peach and Nectarine: Production in Leading Countries (2004–2008)

	Production (1000 Metric Tons)				
Country	2004	2005	2006	2007	2008
China	7040.5	7649.7	8243.3	8028.4	8329.3
Italy	1710.0	1693.2	1664.8	1630.4	1589.1
USA	1429.8	1301.9	1132.5	1279.3	1304.4
Spain	987.6	1260.9	1245.5	1221.1	1298.7
Greece	875.5	864.4	767.9	816.0	734.1
Iran	390.0	390.0	390.0	390.0	575.0
Turkey	372.0	510.0	552.8	539.4	551.9
Egypt	360.9	360.0	427.6	425.3	399.4
France	396.7	402.6	394.5	364.9	301.1
Argentina	272.4	272.5	260.0	270.0	270.0
Chile	311.0	310.0	295.0	268.0	268.0
Brazil	235.7	235.5	199.7	186.0	239.1

Source: FAO (2010).

Table 30.2. Peach and Nectarine: Area Harvested in Leading Countries (2004–2008)

	Area Harvested (1000 Hectares)				
Country	2004	2005	2006	2007	2008
China	665.6	679.8	672.2	699.6	782.7
Italy	89.9	87.1	85.8	86.0	86.1
Egypt	31.8	32.0	78.4	80.0	80.2
Spain	78.5	79.1	80.3	80.6	75.4
USA	73.7	71.8	69.3	63.8	63.3
Iran	25.5	25.5	25.5	25.5	51.3
Mexico	35.1	36.9	41.6	41.7	39.8
Greece	43.6	43.3	43.1	43.3	36.9
Turkey	27.3	27.8	27.7	29.4	28.2
Argentina	26.0	26.0	25.0	26.0	26.0
Brazil	23.9	23.8	22.5	22.4	21.3
Chile	20.1	20.0	19.0	21.1	21.1

Source: FAO (2010).

Table 30.3. Peaches: US Per Capita Consumption (in Pounds) for Selected Years (1990–2008)

Year	Total, All Uses	Fresh	Processed			
			Canned	*Frozen*	*Dried*	*Total*
1990	9.83	5.54	3.78	0.45	0.06	4.29
1995	8.93	5.32	2.98	0.55	0.07	3.61
2000	9.96	5.30	3.83	0.76	0.07	4.66
2005	9.12	4.83	3.34	0.72	0.23	4.29
2008	9.06	5.07	2.98	0.73	0.27	3.98

Source: Adapted from USDA-ERS (2010).

PRODUCTION AND HARVEST

Cultivation

The number of peach cultivars commercially harvested far exceeds apple and pear. One of the main reasons for this is the ease with which peaches can be bred; in contrast, apple and pear cultivars result mostly from chance selection. Almost all regions of the world, including the United States, have their own breeding programs to produce peach cultivars that adapt to a particular region. Therefore, there is no single cultivar, which is dominant worldwide, or in individual peach-growing countries (Reiger 2004).

The peach tree grows better in well-drained, loamy soils (pH 6–7). Peach and nectarine cultivars do not require cross pollination and set satisfactory crops with their own pollen. Peaches have been bred to perform in climates from Canada to the tropics, and have the widest range of chilling sensitivity requirements of any tree crop. Peaches bloom relatively early (e.g., mid-March in Georgia), and are less cold tolerant than apple or pear. This is the principal reason that they are generally grown in more southern states in the United States than the apples. Frost can be a problem in most peach-growing areas of the world as open flowers and young fruit can be seriously damaged or killed by brief exposure to –2°C or below. The US peach production in the southeastern states has suffered a decline in the past several decades due to severe late spring frosts (Logan et al. 2000; Reiger 2004).

The pruning of peach trees is done extensively to produce quality fruit. Pruning is either done manually or by mechanical hedgers. However, proper manual pruning is widely recommended since it has proven to be more effective (Westwood 1993). Peaches are heavily thinned for proper size development; this is generally done manually, leaving 1 fruit per 6 inch of shoot length, which makes it an expensive operation. In some cases, chemical blossom desiccants could be used for flower thinning, but no chemicals are widely used for peach thinning. Miranda-Jimenez and Royo-Diaz (2002) reported that peach tree productivity is improved if trees are pruned early; either in full bloom or soon after the fruit has been set. Chemical thinning could reduce the high cost of manual pruning, however, it distributes the fruit irregularly on the shoots.

Fruit thinning can also be used to relieve water stress in peach but it can affect fruit quality (Lopez et al. 2010). Kumar et al. (2010) reported that fruit yield decreased with the increase in level of pruning in ‘Flordaking’ and ‘Saharanpur Prabhat’ peaches, whereas, medium pruning treatment gave highest yield in ‘Flordasun’ peach. Pulp weight, stone weight, pulp-stone ratio, ascorbic acid, sugar–acid ratio, and moisture content were not affected by pruning levels. However, fruit weight, size, soluble solids, sugar and acid content were significantly increased by pruning.

For improving peach quality under field conditions, Fernández et al. (2009) explored a strategy to apply calcium directly to fruits. Since peaches in Spain are typically bagged shortly after thinning, a method based on the application of calcium gels to the fruit surface was introduced and its effect assessed with respect to quality, nutrient balance, and surface deposition. Results showed that calcium-containing formulations increased mesocarp and exocarp calcium, confirming the penetration of calcium through the peach skin thereby improving the quality and storability of bagged peach cultivars. Serrano et al. (2004) reported that the use of foliar spray of calcium had a similar effect on peach and nectarine fruit quality to that of the postharvest applications of calcium.

Ziosi et al. (2008) reported the development of a nondestructive index to monitor the progression of ripening; this method employs the difference in absorbance between two wavelengths near the chlorophyll-a absorption peak (670 and 720 nm). The index of absorbance difference (IAD) was related to the time course of ethylene production during on-tree ripening peaches and nectarines. For each fruit, consecutive stages of ripening, as defined according to ethylene production (preclimacteric, climacteric, postclimacteric) occurred in the same ranges of IAD over two growing seasons. Infante et al. (2008) reported that electronic nose analysis was useful for discriminating between freshly harvested peach cultivars (‘Ryan Sun,’ ‘Autumn Red,’ ‘September Sun,’ and ‘Tardibelle’), even at an early preclimacteric phase. Results from electronic nose analysis showed that peach flavor was significantly correlated with texture, juiciness, and sweetness but not with aroma or acidity. The use of electronic nose was also reported for monitoring quality changes during postharvest storage (Benedetti et al. 2008).

Fruit Classification, Maturity, and Harvest

Peaches can be classified according to appearance and sensory characteristics as: round, flat, or beaked; pubescent or smooth-skinned; freestone or clingstone; white, yellow, or red fleshed; sweet, sour, or astringent; and melting-fleshed or nonmelting-fleshed (Brovelli et al. 1999). In most cultivars, horticultural maturity for harvesting both peaches and nectarines is determined based on changes in skin ground color from green to yellow. In California, a color chip guide

is used to determine maturity of different cultivars and a two-tier system is used: (1) *US Mature*, which corresponds to minimum maturity, and (2) *Well-Mature* and/or tree-ripe. In those cases where skin ground color is masked due to full red color development before maturation, measurement of fruit firmness is recommended for accurate determination of maturity; in such cases, a maximum maturity index can be applied. Maximum maturity is the minimum flesh firmness, measured with an 8-mm tip penetrometer, at which fruit can be handled without any damage from bruising (Crisosto and Kader 2004).

Harvesting of peaches and nectarines is done manually into bags, baskets, or totes. Picked fruit is then dumped into bins on trailers, transported from orchards to packinghouse, and cooled as soon as possible after harvest.

At the packinghouse, the fruit is cleaned and sorted. Attention to details in sorting is important with peaches, where a range of colors, sizes, and shapes of fruit are encountered. Sizing segregates the fruit by either weight or size.

POSTHARVEST STORAGE AND PHYSIOLOGY

Postharvest Storage

Optimum storage conditions for peaches and nectarines are –1°C to 0°C and 90–95% RH with airflow of approximately 50 ft^3/min. Fruit tissue softening is accelerated at elevated temperatures where respiration rate can be as high as 10 times at 20°C compared to 0°C. At elevated temperatures, depending on fruit maturity, ethylene production rate increases significantly from less than 5.0 μL/kg/h at 0°C to as high as 160 μL/kg/h at 20°C (Crisosto and Kader 2004). Polygalacturonase enzyme is responsible for the softening of fruit tissue as a result of depolymerization of pectic polysaccharide chains during postharvest storage (Tijskens et al. 1998). Togrul and Arslan (2004) reported that the use of carboxymethylcellulose (CMC), from sugar beet pulp cellulose as a hydrophilic polymer, in an emulsion coating containing beeswax, triethanolamine, and oleic acid, was shown to extend the shelf life of peaches from 12 to 16 days at 25°C and 75% RH.

Zhang et al. (2010) reported that the firmness of peach fruit was closely related with the contents and nanostructural characteristics of carbonate-soluble pectin, which might be hydrolyzed by enzymes in fruit flesh. Lysiak et al. (2008) evaluated the storability of peaches after dipping in a 2% $CaCl_2$ solution at 20°C for 30 minutes and storing them at 4°C for 2 weeks in boxes covered with polyethylene bags. Overall, there were distinct improvements in storability resulting from the $CaCl_2$ and polyethylene barrier. The $CaCl_2$ treatment improved firmness, largely maintained the soluble solids content and increased sugar–acid ratio; use of polyethylene bags minimized fruit weight loss.

The effect of gamma irradiation (0.5–2.0 kGy) on the microbiological, physicochemical, and sensory properties of "Dangeumdo" peaches during 6-day storage at 20°C was investigated by Kim et al. (2009). The gamma irradiation was effective in achieving microbiological safety; it also improved the antioxidative activity but had somewhat negative effect on the color and texture of the peaches.

Caprioli et al. (2009) studied the effect of postharvest treatments (1-methylcyclopropene or 1-MCP, CO_2, and N_2) followed by storage at 10°C, and hydrocooling at 1°C followed by storage at 0°C on fruit quality, carotenoids, and ethylene and CO_2 production in peaches. Ethylene production was reduced by all the treatments, and hydrocooling in combination with low-temperature storage was the best treatment for maintaining fruit firmness.

Chilling Injury

Peaches (most mid- and late-season) and nectarines (some mid- and late-season cultivars) are susceptible to chilling injury during storage. Chilling injury develops faster and more intensely in fruit that is stored at 2.2–7.6°C (peaches) and 2.2–7.8°C (nectarines) than that stored at 0°C or below (Crisosto and Kader 2004). Brovelli et al. (1998) showed that, based on the development of flesh mealiness, the quality of nonmelting flesh peaches was not as severely affected as a result of chilling exposure as was the case with melting flesh peaches. This quality of nonmelting flesh peaches can be a major advantage for refrigerated storage and long-distance transportation. Modified atmosphere (MA) storage (12% CO_2 and 4% O_2) of peaches in unperforated polypropylene bags could be useful as it is associated with lower weight loss, less senescence and chilling injury, reduced incidence of decay, and delayed ripening of the fruit beyond normal shelf-life period (Fernandez-Trujilio et al. 1998).

High CO_2, controlled atmosphere (CA) storage is a proven technology to overcome chilling injury, while prestorage heat treatment appear like an emerging alternative although showing some undesirable side effects (Murray et al. 2007). Combined treatments were useful for improving juiciness and were the only alternative to reach 4 weeks with commercial quality Flavorcrest peach fruit. Although heat-treated fruit had generally redder flesh than others, this side effect was reduced by CA (Murray et al. 2007). Application of salicylic acid is helpful in alleviating the symptoms of chilling injury in peaches during cold storage (Wang et al. 2006). Ortiz et al. (2009) indicated that CA storage at 2°C, in addition to preserving other quality attributes, showed better retention of peach aroma as compared to fruit stored under air at 2°C.

Zhu et al. (2010) studied the effect of fumigation with nitric oxide gas, intermittent warming, or a combination of both in preventing chilling injury of "Feicheng" peaches. Chilling injury index, firmness, ethylene production, cell wall fractions, and cell wall metabolism-associated enzymes were evaluated. Their results showed that three treatments

significantly prevented mealiness in peaches. Although intermittent warming increased the activity of polygalacturonase, it was suggested that nitric oxide fumigation could offset the side effect of intermittent warming.

Methyl jasmonate application is also shown to be beneficial for maintaining quality by alleviating chilling injury symptoms of peach fruits under low-temperature stress (Meng et al. 2009; Ziosi et al. 2009).

PROCESSED PRODUCTS

About one-half of peaches and almost all of nectarines, produced are consumed fresh. Canned and frozen peaches are the two major processed peach products. Other products, like dried peaches, peach jam, jelly, and juice are processed on a much smaller scale (Reiger 2004). With increasingly new scientific claims of health benefits of phytochemicals, yellow-flesh peaches, which are rich in phytochemicals (Gil et al. 2002), have great potential for processing into a variety of new products.

Canned Peaches

About 40% of peaches produced in the United States are processed into canned products, mostly halves and slices. Clingstone peaches are commonly used for commercial canning, as they are able to retain flavor and consistency. In most cases, peaches are canned within 24 hours of delivery to the processing plant, which ensures that the peaches maintain nutritional value and flavor (Reiger 2004; CCPB 2010). The optimum maturity of peaches for canning purposes is when the color is orange–yellow and the fruit is still firm. A brief description of processing steps (Downing 1996) for canning peaches is given below:

- *Grading*: Since peaches received at the cannery usually include a wide range of sizes, it is necessary to grade fruits using a mechanical grader. In cases where fruit is to be stored before canning, this pregrading is done before the fruit has reached canning maturity (this minimizes bruising of the fruit).
- *Halving and pitting*: Peaches are usually canned as halves or slices. The halving and pitting of peaches is accomplished using automatic machines.
- *Peeling and washing*: Clingstone peaches are lye-peeled either by spray or immersion method. Conditions used for lye peeling are: 5–11% lye solution at a temperature of 215–220°F for 45–60 seconds. The treatment time, strength, and temperature of the lye solution depend on the maturity of the fruit. Following the hot lye treatment, fruit pieces are thoroughly sprayed with cold water for complete removal of the peel and the lye residue. Freestone peaches are peeled by (a) steaming, (b) scalding in water, (c) lye peeling, or (d) combination steam and lye.
- *Quality grading and slicing*: An inspection belt is provided for the grading and sorting of poorly sized, off-color, partially peeled, and otherwise imperfect fruit. It is recommended to grade and fill the halves directly from the inspection belt into cans as mechanical grading/filling often results in additional injury to the fruit. Fruit that is not canned as halves goes directly from the belt to the slicing machine.
- *Filling and syruping*: The peach halves should be filled as rapidly as possible after peeling and grading as extended exposure to the air results in discoloration. Slices should go over an inspection belt for removal of defective pieces. The slices are then discharged to handpack fillers. The standards of identity for canned peaches specify the densities of cut-out syrup that correspond to label names such as "heavy syrup" or "light syrup," etc. Syruping of canned peaches is accomplished by rotary and straight-line syrupers or by prevacuumizing syrupers.
- *Exhausting and closing*: The cans are given a steam exhaust for about 6 minutes at 190–195°F. Cans are closed immediately after exhausting; a gross headspace of 5/16 of an inch is recommended.
- *Processing and cooling*: It is recommended to process cans immediately after exhausting and closing of cans so that the heat of the exhaust is not lost before processing begins. Clingstone peaches are processed using continuous reel type cookers at 212°F for 20–35 minutes depending on the diameter of the cans and the type of product—halves or slices. Some processors also use commercial processes of 14–18 minutes at 240°F. After processing, the cans are water-cooled immediately to 95–105°F.

Firmness of canned peaches is an important quality attribute. In an attempt to improve the firmness of canned peaches, Wang (1994) treated peach slices by submerging them in pectinase solution containing 100 mg/L $CaCl_2$ under vacuum for 0.5–2 hours. This treatment was effective in improving the firmness of peach slices from 7 to 25 J/kg; also, calcium content increased from 280 to 430 mg/kg. Canning is shown to have negative effect on the retention of procyanidins in canned "Ross" clingstone peaches as well as in the syrup used in the canning (Table 30.4, Hong et al. 2004).

Styles of Canned Clingstone Peaches

The styles of canned clingstone peaches classified per US standards are: (a) "Halves or Halved" canned peaches-peeled and pitted, cut approximately in half along the suture from stem to apex; (b) "Quarters or Quartered" canned peaches–halved peaches cut into two approximately equal parts; (c) "Slices or Sliced" canned peaches–peeled and pitted peaches cut into sectors smaller than quarters; (d) "Dice or Diced" canned peaches–peeled and pitted peaches cut into

Table 30.4. Content of Procyanidin Oligomers in Frozen and Canned Peaches (mg/kg, Wet-Weight Basis)

Oligomer Fraction	Frozen Peach	Canned Peach			
		0 month	1 month	2 months	3 months
P1	19.59	17.50	17.18	15.77	15.85
P2	39.59	36.50	34.84	29.03	30.55
P3	38.81	34.77	31.33	19.23	19.06
P4	17.81	16.97	10.07	6.26	3.61
P5	12.43	11.85	7.61	2.83	–
P6	10.62	7.87	3.52	–	–
P7	3.94	2.76	–	–	–
P8	1.75	–	–	–	–

Source: Hong et al. (2004).

Table 30.5. Cut-out Brix Levels of Syrups Used in Canned Peaches

Designations	Brix Measurements
• "Extra heavy syrup" or "Extra heavily sweetened fruit juice(s) and water" or "Extra heavily sweetened fruit juice(s)"	22° or more but less than 35°
• "Heavy syrup"; or "Heavily sweetened fruit juice(s) and water" or "Heavily sweetened fruit juice(s)"	18° or more but less than 22°
• "Light syrup"; or "Lightly sweetened fruit juice(s) and water" or "Lightly sweetened fruit juice(s)"	14° or more but less than 18°
• "Slightly sweetened water"; or "Extra light syrup" or "Slightly sweetened fruit juice(s) and water" or "Slightly sweetened fruit juice(s)"	10° or more but less than 14°

Source: USDA-AMS (1985).

approximate cubes; (e) "Whole" canned peaches—peeled, unpitted, whole peaches with or without stems removed; and (f) "Mixed pieces of irregular sizes and shapes" are peeled, pitted, and cut units of canned peaches that are predominantly irregular in size and shape, which do not conform to a single style of halves, quarters, slices, or dice (USDA-AMS 1985).

Liquid Media and Brix Measurements

Cut-out requirements for liquid media in canned freestone peaches are not incorporated in the grades of the finished product since syrup or any other liquid medium is not a factor of quality for the purpose of these grades. The cut-out Brix measurements for the respective designations are shown in Table 30.5.

Frozen Peaches

About 6–8% of peaches produced are processed as frozen peaches. Processors usually need three different types of peaches: (1) for retail packages of slices, varieties with red around the pit cavity, such as 'Rio Oso Gem,' are desirable; (2) peaches frozen in bulk for later processing into preserves should have good flavor and should not have red color around the pit cavity for good color/appearance of the jam or marmalade. 'Fay Elberta' peaches picked on the immature side are ideal for preserves; and (3) for the institutional market, mainly pies, a highly flavored, firm-textured variety with resistance to browning is best suited. For freezing peaches, an ideal variety preferably should have the shape, bright color, and firmness of 'Rio Oso Gem,' the flavor of 'Elberta,' and the nonbrowning characteristic of 'Sunbeam' (Boyle et al. 1977). Fruit preparation steps of washing, peeling, and slicing are the same as discussed under Section 'Canned Peaches.'

Air-blast tunnel freezing is the most commonly used system by most processors. In this method, the prepared product ready to be frozen is placed on wire mesh trays and loaded on to racks. The tray racks are moved into freezing tunnel. Cold air is usually introduced into the tunnel at the opposite end from the one where product to be frozen enters. The temperature and velocity of the air is of critical importance in the freezing process. The temperature of the air is usually between 0°F and –30°F (–18°C and –34°C, respectively). Air velocity can range from 100 ft/min to 3500 ft/min. The length of time a product is subjected to cold air blast in the tunnel depends on the product size (Boyle et al. 1977).

Otero et al. (2000) compared classical methods of freezing and high-pressure shift freezing (HPSF) with respect to their effect on modification to the microstructure of peach and mango using a histochemical technique. With HPSF method, samples were cooled under pressure (200 MPa) to –20°C without ice formation, and then pressure was released to atmospheric level (0.1 MPa). The high level of super-cooling led to uniform and rapid ice nucleation. They concluded that problems associated with thermal gradients were minimized in HPSF method that prevents quality losses due to freeze-cracking or large ice crystal presence, thus, their method was helpful in maintaining the original tissue structure.

Hong et al. (2004) used normal-phase liquid chromatography–mass spectrometry (LC-MS) to determine the levels and fate of procyanidins in frozen and canned 'Ross' clingstone peaches as well as in the syrup used in the canning over a 3-month storage period. Retention of these health beneficial compounds was better in frozen peaches as compared to canned peaches (Table 30.4). Storage of canned peaches for 3 months demonstrated a time-related loss in high-molecular-weight oligomers (P5–P8) and that

by 3 months, oligomers larger than tetramers were not observed. After 3 months of postcanning storage, levels of monomers had decreased by 10%, dimers by 16%, trimers by 45%, and tetramers by 80%.

Varietal Types and Styles of Frozen Peaches

Varietal types of peaches that are processed as frozen include: (a) "Yellow freestone"—freestone peaches of the yellow-fleshed varieties, which may have orange or red pigments emanating from the pit cavity; (b) "White freestone"—freestone peaches that are predominately white-fleshed; (c) "Red freestone"—freestone peaches that have substantial red coloring in the flesh; and (d) "Yellow clingstone"—clingstone peaches of the yellow- or orange-fleshed varieties. Styles of frozen peaches include: (a) "Halved or halves"—the peaches are cut approximately in half along the suture from stem to apex, (b) "Quartered or quarters"—halved peaches cut into two approximately equal parts, (c) "Sliced or slices"—the peaches are cut into sectors smaller than quarters, (d) "Diced"—the peaches are cut into approximate cube-shaped units, and (e) "Mixed pieces of irregular sizes and shapes"—means peaches cut or broken into pieces of irregular sizes and shapes and which do not conform to a single style of halves, quarters, or slices (USDA-AMS 1961).

Dried Peaches

As per US standards, dried peaches are the halved and pitted fruit from which the greater portion of moisture has been removed. Before packing, the dried fruit is processed to cleanse the fruit and may be sulfured sufficiently to retain a characteristic color. Federal inspection certificates shall indicate the moisture content of the finished product, which shall be not more than 25% by weight. Dried peaches may be processed from freestone or clingstone peach types (USDA-AMS 1967).

Only 1–2% of peaches produced are processed as dried halves, quarters, or slices. Fruit preparation steps of washing, peeling, and cutting are the same as discussed under Section "Canned Peaches." To minimize discoloration, cut peaches are dipped in AA or other antibrowning solution for 5–10 minutes (see more detail on antibrowning agents under Section "Fresh-Cut Peaches and Nectarines"). Prepared fruit is spread in single layers on trays, usually 3-pounds/sq. ft. Peaches are dried to moisture content of about 25%. Germer et al. (2007) reported that fruit with low pulp (flesh) firmness presented problems during preparation steps for drying, thus resulting in low acceptance scores for appearance and color of dried product.

Generally, forced-draft tunnel dehydrators are used for drying peaches. For drying in a countercurrent tunnel, temperature should not exceed 155°F. Total drying time (24–30 hours) depends on the size of the product and the temperature used. Blanched peaches are dried more rapidly requiring about 18 hours to reach 25% moisture (Brekke and Nury 1964). In peach producing developing countries, sun-drying is still the most widely used method due to its low cost, however, quality is not as good as those dried in controlled and sanitary environment.

Hansmann et al. (1998) investigated the drying behavior of clingstone peach halves dehydrated without sulfites and suggested that enzymatic browning reactions can be controlled during dehydration by selecting dehydration conditions favoring low superficial product temperature and lower a_w. Also, peeled fruit dried faster than unpeeled one. Wang et al. (1996) dried yellow peach fruits cut into halves to a moisture content of 18% with microwaves of 2350 MHz at 0.3–0.45 m/s air velocity and hot air and far ultra-red waves. Microwave dried peaches had better color than those dried by the other two methods.

Many researchers have shown the benefits of osmotic drying before traditional dehydration. Lerici et al. (1988) reported that the osmotically dehydrated products had very good texture and good retention of aroma and color; the a_w was reduced sufficiently to improve shelf life but further processing (e.g., freezing, drying, and pasteurization) was necessary to ensure shelf-stable products. Erba et al. (1994) described "osmodehydro-freezing" as a combined process where osmotic drying is followed by air drying and freezing to prepare reduced-moisture fruit ingredients, free of preservatives, with a natural flavor, color, and texture, and with functional properties suitable for different food applications. Souti et al. (2003) studied suitability of osmotic drying as a method for predrying of peaches and showed that the use of osmotic pre-drying treatment produced dried peaches of better sensory quality than traditionally solar-dried peaches as judged by a sensory panel.

Peach Puree/Nectar

Peach puree is used extensively in baby food formulations. Typical processing steps for production of peach and nectarine puree and nectar are shown in Figure 30.2. Toralles et al. (2008) investigated the degradation of AA in 'Jade' peach puree (12°, 22°, and 32°Brix) under anaerobic conditions at 70–90°C. The kinetic analysis of the data showed that the degradation was significantly represented by zero- and first-order kinetic models and that the rate of AA degradation in peach puree was highly temperature-dependent. Lavelli et al. (2009) reported that carotenoid and phenolic contents were lower in the nectars obtained from peeled peaches (cv. 'Elegant Lady' and 'Red Haven') than in those obtained from unpeeled fruits. However, the color of peach nectars was improved by processing lye-peeled fruits at room temperature.

Attempts have been made to develop carbonated beverages using peach puree (Arora and Aggarwal 2009; Aggarwal and Arora 2010). Aggarwal and Arora (2010) studied the effects of processing and storage conditions on

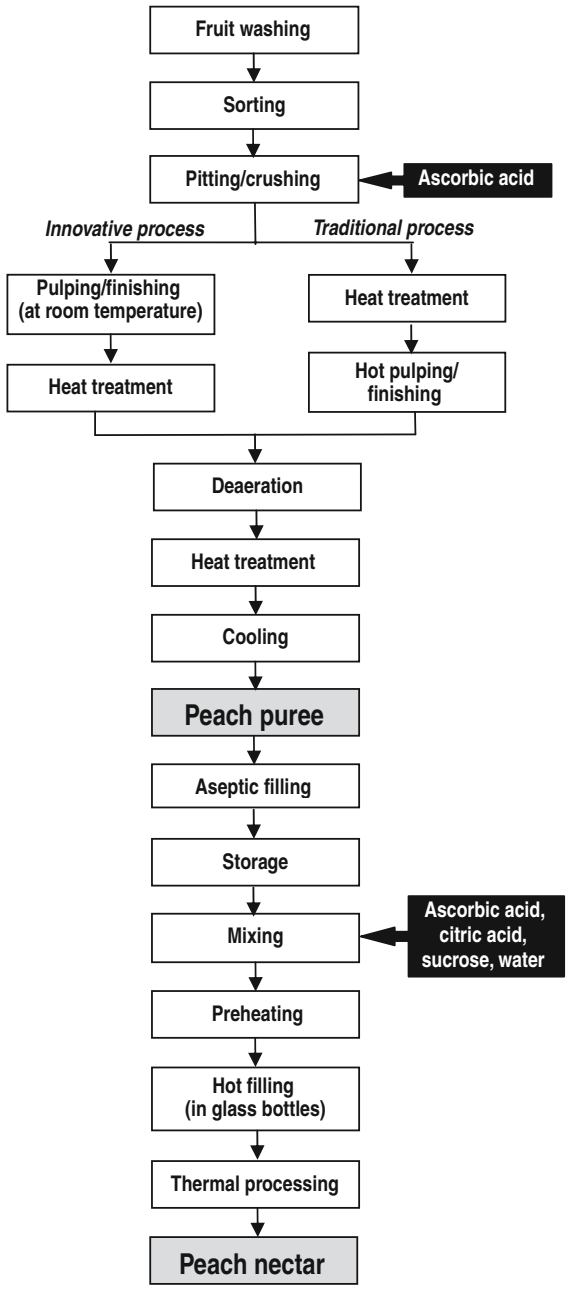

Figure 30.2. Flow diagram for production of peach and nectarine purees and nectars. (Adapted from Lavelli et al. 2008.)

physicochemical and sensory properties of a carbonated beverage with 20% of 13°Brix peach purees. Beverage samples prepared by the premix method retained significantly higher suspension levels and had a high overall sensory acceptability. Neither processing nor storage conditions had any significant impact on different quality attributes. The carbonated beverages stored at refrigeration temperatures retained better quality than those stored at room temperature.

Lavelli et al. (2008) studied the effects of an innovative process for the manufacture of peach and nectarine purees on selected quality attributes, for example, color, consistency, carotenoids and phenols content, and antioxidative activity. The innovative process (pulping/finishing step at room temperature) was compared to the traditional process (hot pulping/finishing). In comparison to the traditional process, the new process at scaled-up industrial level, improved the color of peach and nectarine products (shown by higher L* value and lower a* value; see Table 30.6) and maintained almost similar levels of carotenoids, hydroxycinnamates, flavan-3-ols, and flavonols. This study suggested utilization of fresh market surplus fruit and processing of selected fruit varieties rich in antioxidants but having higher browning potential (such as 'Stark Red Gold' nectarine).

Peach Juice

Peach juice is produced on a much smaller scale as compared to other processed peach products. After cleaning and washing, peaches are heated to about 45°C in large kettles. Stirring with propeller-type blender and addition of pectinase and hemicellulase enzymes aids in extraction of juice, higher yields, and soluble solids contents. Other steps like filtration, clarification, and pasteurization are similar to those for other juices. Pagan et al. (1997) extracted juice from Caterino variety of peaches by treating pulp with liquefying enzymes at temperatures between 30°C and 70°C. Yield and soluble solids contents of juice were higher with the enzymatic liquefaction method (up to 55°C) than by simple extraction. At temperatures over 55°C, the enzymes used were not effective. Dogan and Erkmen (2003) investigated the inactivation of *Escherichia coli* by ultra-high hydrostatic pressure (UHHP) ranging from 300 to 700 MPa in peach juice and reported that a 12-minute treatment at 600 MPa was sufficient to produce a commercially sterile peach juice.

Peach Jam and Jelly

About 2–3% of peaches are processed into jam, jelly, and juice combined (Reiger 2004). Jam, jelly, preserves, and marmalades are similar products (all are made from fruit, preserved by sugar and thickened or gelled to some extent). Jam is made from crushed or chopped fruit, holds its shape, but is less firm than jelly. Jelly is a mixture of fruit juice and sugar that is clear and firm enough to hold its shape. Granulated white sugar is most often used to make jelly or jam. Jams and jellies can be made with or without added pectin (Willenberg and Hughes 2004).

Type of sugar or sweetener and pectin added in jam can affect its textural qualities. Costell et al. (1993) reported that differences in formulations influenced rheological properties of peach jam. Raphaelides et al. (1996) investigated the effects of sugars as present in commercial mixtures on mechanical properties and texture of peach jam. A series of jam

Table 30.6. Hunter Color Values of Peach and Nectarine Purees and Nectars Obtained from Peeled and Unpeeled Fruits

	Puree		Nectar	
	Unpeeled	Lye-peeled	Unpeeled	Lye-peeled
*Hunter color L**				
Red Haven peach	46.96	53.62	41.41	42.38
Elegant Lady peach	38.90	50.18	36.35	44.12
Stark Red Gold nectarine	39.90	44.91	36.51	38.18
*Hunter color a**				
Red Haven peach	0.80	−5.97	−1.98	−7.35
Elegant Lady peach	13.62	−2.90	5.65	−5.31
Stark Red Gold nectarine	9.62	−2.56	2.61	−4.26
*Hunter color b**				
Red Haven peach	24.42	25.81	19.08	20.69
Elegant Lady peach	16.69	24.35	15.08	19.67
Stark Red Gold nectarine	19.52	23.77	17.58	19.27

Source: Lavelli et al. (2009).

samples was prepared using commercial glucose syrups of 38 and 44 dextrose equivalents (DE), isoglucose, maltose syrup, and their mixtures with sucrose. Jam texture was markedly affected by composition of the syrups. Sugar type was important, for example, monosaccharides and their mixtures with sucrose formed more rigid gels than disaccharides. These researchers concluded that, by carefully selecting blends of glucose syrups with or without sucrose, a range of jam consistencies could be derived. Grigelmo-Miguel and Martin-Belloso (2000) compared the quality of conventional peach jam with those made by total or partial substitution of pectin with added dietary fiber (DF) as a thickener. Peach jam with added DF had similar color but was more viscous than conventional jam. From a sensory point of view, high peach-DF jams were as acceptable as conventional jams.

Minimally Processed or Fresh-Cut Peaches and Nectarines

"Fresh-cut produce" is defined as any fresh fruit or vegetable or any combination thereof that has been physically altered from its original form, but remains in a fresh state (Laurila and Ahvenainen 2002; IFPA 2004). Currently, less than 1% of peaches and nectarines are processed as fresh-cut, however, both of these fruits have great potential to capture a sizeable share of fresh-cut market owing to the fact that more than half of peaches (Table 30.3) and almost all of nectarines produced are consumed fresh.

For processing of fresh-cut peach slices, the optimal ripeness is when flesh firmness reaches 13–27 N (3–6 lb-force). Depending on the cultivar, peach slices retain good eating quality for 2–8 days at 5°C and 90–95% RH. The optimal ripeness for preparing fresh-cut nectarines slices is the partially ripe (>27–49 N or 6–11 lb-force) or ripe (>13–27 N or 3–6 lb-force); depending on the cultivar and variety, these slices keep good eating quality at 0°C and 90–95% RH for 2–12 days (Crisosto and Kader 2004).

Gorny et al. (1998) investigated the effects of fruit ripeness and postcutting storage temperature on the deterioration rate of fresh-cut 'Flavorcrest' peaches and 'Zee Grand' nectarines. They reported that for preparing fresh-cut slices, the optimal ripeness was the ripe stages for peaches and partially ripe or ripe stages for nectarines. While retaining good eating quality, peach and nectarine slices had a shelf life of 6 and 8 days, respectively, at 0°C and 90–95% RH. Gorny et al. (1999) processed slices from 13 cultivars of peaches and 8 cultivars of nectarines using a 2% ascorbic acid +1% calcium lactate postcutting dip and reported acceptable sensory color and shelf life of 2–12 days at 0°C for slices from different cultivars, except those from 'Cardinal.' CA storage extended the shelf life by additional 1–2 days for slices from some cultivars.

Mild heat treatment prior to fruit cutting can also improve the quality of fresh-cut products. Koukounaras et al. (2008) investigated the effect of short-term heat treatment on quality of fresh-cut peaches using different parameters of heat treatment (intensity, duration, time of application). Their results showed a clear beneficial effect of 4-hour precutting heat treatment (50°C for 10 minutes) on postharvest quality of fresh-cut peaches.

Some important attributes to be considered for the sensory quality of a fresh-cut product, like peaches and nectarines, are: (1) color or appearance, (2) texture, (3) flavor, (4) taste, and (5) overall acceptance. However, from consumers' perspective, color or appearance of fresh-cut produce is the single most important factor among all the quality attributes mentioned earlier (Siddiq et al. 2004). If the color of a fresh-cut product is not acceptable or attractive, the consumer is

least likely to purchase it regardless of its excellent texture, flavor, taste, or other quality attributes.

Polyphenol oxidase and peroxidase are the two enzymes implicated in color deterioration of cut fruits and vegetables. In addition to visible color changes, these enzymes affect sensory properties and nutritive values (Vamos-Vigyazo 1981). Both enzymes have been widely studied in different fruits and vegetables with special emphasis on their inactivation (Nicolas et al. 1994; Weemaes et al. 1998; Siddiq and Cash 2000; Escribano et al. 2002). Traditionally, sulfites were used extensively in the food industry to control enzymatic browning. However, since the late 1980s, there has been an effort to avoid the use of sulfiting agents in foods due to safety, regulatory, and labeling issues (Lambrecht 1995). A number of alternatives to sulfites like ascorbic acid, citric acid, 4-hexylresorcinol, erythorbic acid, and sodium erythorbate (stereoisomers of ascorbates), benzoic acid, honey, and natural fruit juices (e.g., lemon juice) have been tried with varying success. Chitosan coating (Huaqiang et al. 2004), sodium hexametaphosphate (Pilizota and Sapers 2004), oxalic acid (Yoruk and Marshall 2003), and NatureSeal™, a commercially available product containing calcium ascorbate (Arvind et al. 2004), are the other alternatives tried more recently either alone or in conjunction with other inhibitors. In case of peach and nectarine, postcutting dips in ascorbate and calcium lactate, or use of modified atmosphere packaging (MAP) have shown to prolong the shelf life of fresh-cut slices (Gorny et al. 1998).

The passive MA storage was shown to be effective in preserving the quality of fresh-cut peaches that were pretreated with mild heat, which also showed significant firmness improvement. Lower levels of malic acid were observed in heat-treated samples, whereas succinic and citric acids were not affected (Steiner et al. 2006). Gonzalez et al. (2008) used a mathematical model to quantify the effects of temperature fluctuations on O_2 and CO_2 concentration in the packaging atmosphere of fresh-cut peaches. The O_2 consumption rate was a function of O_2 concentration; it was further shown that CO_2 production was linear and more sensitive than O_2 to a break in the cold chain.

BY-PRODUCTS

Peach kernels are rich in oil with important therapeutic properties and attractive nutritional profile because of the high concentration of oleic and linoleic acids (Mezzomo et al. 2010). Method of extraction of oil and other compounds can have a significant effect of their extractability and quality. Mezzomo et al. (2010) compared peach–almond extraction yields obtained by different methods: soxhlet extractions with different solvents; hydrodistillation; ethanolic maceration followed by fractionation with various solvents, and supercritical fluid extraction at 30–50°C at 100–300 bar, performed with pure CO_2 and with a co-solvent. The production of peach–almond oil through all techniques was substantially adequate and supercritical fluid extraction presented advantages, with respect to the quality of the extracts owing to the high oleic acid content.

INNOVATIVE PROCESSING

High Pressure Processing (HPP)

Blanching in hot water is a common method of inhibiting enzymes (especially, polyphenol oxidase and peroxidase) in fruits before drying, freezing, or canning. Kingsly et al. (2009) investigated high pressure processing (HPP) as an alternative to hot-water blanching; peach slices were pressure-processed (50–700 MPa) at 25°C, both with and without citric acid, for two holding times (5 and 10 minutes). Their results showed that HPP at more than 300 MPa, in combination with 1–1.2% citric acid, was an effective method for inactivation of polyphenol oxidase. Pressure-treated peach slices were then dried in a cabinet dryer at 70°C; HPP pretreatment enhanced drying rate thereby reducing drying time. These results indicated that HPP has a potential to be used as an alternative to hot-water blanching.

Color stability of fresh peach juice subjected to HPP was investigated during storage for 120 days by Zhou et al. (2008). Their results showed that browning by oxidation and polymerization of phenols could be avoided by storing pressure-treated peach juice at low temperatures.

Guerrero-Beltran et al. (2005) studied the shelf life of high hydrostatic pressure (HHP)-processed peach puree containing antibrowning agents; peach puree with or without 500 ppm of AA or cysteine (250 ppm) were exposed to HHP (517 MPa/5 min) followed by storage at 3°C, 21°C, and 35°C for 30 days. Polyphenol oxidase activity was decreased by 88–94.5% in different samples (Fig. 30.3). HHP-processed

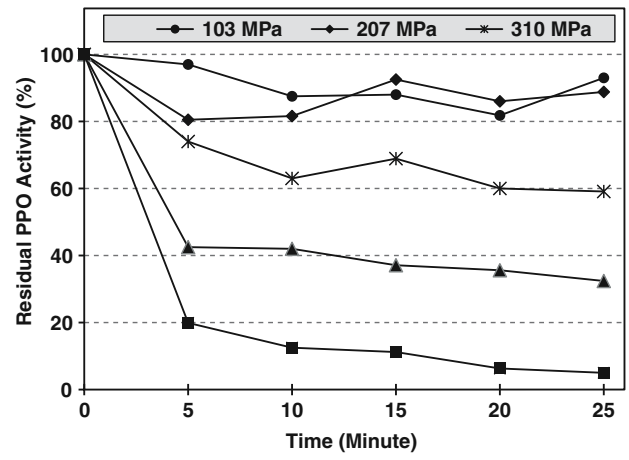

Figure 30.3. Residual polyphenoloxidase (PPO) in peach puree treated at selected high hydrostatic pressures and times. (Adapted from Guerrero-Beltrán and Barbosa-Cánovas 2004.)

purees retained their characteristics yellow (natural puree and puree with AA) and orange colors (puree containing cysteine) for 21–24 and 30 days, respectively. Only less than 10 CFU/g were counted in HHP-processed purees stored at 3°C.

Pulsed Electric Field (PEF)

Inactivation of *Botrytis cinerea* and *Penicillum expansum* inoculated into sour cherry juice, apricot, and peach nectars was determined by pulsed electric fields (PEF) based on the measurement of germination tube elongation and spore germination rate (Evrendilek et al. 2008; 2009). Results of both studies revealed that with increasing electric field strength and processing time, germination tube elongation, and spore germination rate were completely inhibited, making PEF treatment very effective in inactivating *B. cinerea* and *P. expansum*. This innovative processing method could be used to minimize or prevent product loss due to contamination by *B. cinerea* and *P. expansum*.

NUTRITION PROFILE AND COMPOSITION

Nutritional Profile and Health Benefits

Peaches and nectarines contain significant amounts of some major nutrients as shown in Table 30.7. These fruits are good sources of β-carotene. Peaches and nectarines, especially unpeeled, are a good source of fiber. Grigelmo-Miguel et al. (1999) investigated insoluble and soluble DF fractions in peach DF concentrates prepared from dried washed peach pomace obtained from juice extraction and showed that such concentrates which had low energy value could be an

Table 30.7. Composition of Peaches, Their Processed Products and Nectarines (Per 100 g Edible Portion)

	Unit	Raw Peaches	Canned Peaches[a]	Frozen Peaches[b]	Dried Peaches[c]	Raw Nectarines
Proximate:						
Water	g	88.87	84.72	74.73	31.80	87.59
Energy	kcal	39	54	94	239	44
Protein	g	0.91	0.45	0.63	3.61	1.06
Total lipid (fat)	g	0.25	0.03	0.13	0.76	0.32
Fatty acids, total saturated	g	0.019	0	0.014	0.082	0.025
Carbohydrate, by difference	g	9.54	14.55	23.98	61.33	10.55
Fiber, total dietary	g	1.5	1.3	1.8	8.2	1.7
Sugars, total	g	8.39	13.25	22.18	41.74	7.89
Vitamins:						
Vitamin A	IU	326	354	284	2163	332
Vitamin C, total ascorbic acid	mg	6.6	2.4	94.2	4.8	5.4
Thiamin	mg	0.024	0.009	0.013	0.002	0.034
Riboflavin	mg	0.031	0.025	0.035	0.212	0.027
Niacin	mg	0.806	0.593	0.653	4.375	1.125
Pantothenic acid	mg	0.153	0.05	0.132	0.564	0.185
Vitamin B6	mg	0.025	0.019	0.018	0.067	0.25
Folate, total	μg	4	3	3	0	5
Vitamin E (α-tocopherol)	mg	0.73	0.49	0.62	0.19	0.77
Vitamin K (phylloquinone)	μg	2.6	0	2.2	15.7	2.2
Minerals:						
Calcium	mg	6	3	3	28	6
Iron	mg	0.25	0.36	0.37	4.06	0.28
Magnesium	mg	9	5	5	42	9
Phosphorus	mg	20	11	11	119	26
Potassium	mg	190	97	130	996	201
Sodium	mg	0	5	6	7	0
Zinc	mg	0.17	0.09	0.05	0.57	0.17
Copper	mg	0.068	0.052	0.024	0.364	0.086
Manganese	mg	0.061	0.046	0.029	0.305	0.054

Source: USDA (2010).
[a]In light syrup (solids and liquids).
[b]Sweetened.
[c]Sulfured, uncooked.

Table 30.8. Total Phenolics, Total Ascorbic Acid, β-carotene, and Antioxidant Capacity in the Peel and Flesh Tissue of Peaches and Nectarines

	Total Phenolics (mg/kg)		Total Ascorbic Acid (mg/kg)		β-carotenes (μg/kg)		AEAC[a] (mg/kg)	
Fruit	*Peel*	*Flesh*	*Peel*	*Flesh*	*Peel*	*Flesh*	*Peel*	*Flesh*
Yellow-flesh peaches	485–1202	172–547	72–181	31–126	2650–3350	530–1680	313–1107	93–432
White-flesh peaches	670–1836	228–1042	112–202	48–65	110–430	40–80	530–1789	146–1006
Yellow-flesh nectarine	427–1403	138–415	78–130	53–61	1870–3070	580–1310	277–981	62–317
White-flesh nectarines	418–2020	91–901	93–200	42–122	50–570	20–100	230–1447	46–837

Source: Gil et al. (2002).
[a]Ascorbic acid equivalent antioxidant capacity.

adequate source of DF with an insoluble to soluble DF ratio of 66 to 34.

Peach bark has been used as a herbal remedy for a wide variety of ailments. It is said to be "one of the stronger blood moving herbs," and therefore has use in encouraging menstruation in females with delayed menses or congested blood. It also relieves bladder inflammation and urinary tract problems; functions as a mild laxative; has expectorant activity for the lungs, nose and throat; relieves chest pain and spasms. The ancient Chinese considered the peach a symbol of long life and immortality (Reiger 2004).

Bioactive Compounds and Antioxidant Capacity

Cantiín et al. (2009) analyzed antioxidant capacities and contents of total phenols, anthocyanins, flavonoids, and vitamin C in 218 genotypes from 15 peach and nectarine breeding progenies. Results exhibited significant differences among progenies with respect to antioxidant profiles, which varied depending on peach or nectarine and fruit flesh color (yellow or white). The importance of genetic background in selecting new peach and nectarine genotypes rich in bioactive compounds to benefit consumers' health should be considered in breeding programs.

Remorini et al. (2008) studied the peach rootstock influence and of harvesting time (early, middle, and late) on the quality characteristics and nutritional value (e.g., vitamin C, phenols, carotenoids, and total antioxidant capacity). Their results showed that phytochemical contents were best at late harvest. The removal of peel from peach resulted in a significant loss of total antioxidant capacity.

Palmer-Wright and Kader (1997) evaluated changes in quality, retinol equivalents (RE), and individual provitamin A carotenoids in fresh-cut 'Fay Elberta' peaches held for 7 days at 5°C in air or controlled atmospheres. They concluded that the limit of shelf life was reached before major losses of carotenoids were observed. Dried peaches, though high in calories, are an excellent source of fiber, most vitamins, and minerals. In addition, peaches are rich in B vitamins, vitamin C, folic acid, calcium, and many other nutrients essential for health. Peach and its processed products are very low in fat and have no cholesterol.

Gil et al. (2002) investigated the concentration of total phenolics, total ascorbic acid, β-carotene, and ascorbic acid equivalent antioxidant capacity (AEAC) in a number of cultivars of both yellow-flesh and white-flesh peaches and nectarine; and found a strong correlation (0.93–0.96) between total phenolics and antioxidant activities. Yellow-flesh fruit had significantly higher amounts of total phenolics than white-flesh fruits, and so did peel as compared to flesh regardless of the fruit flesh color (Table 30.8). Asami et al. (2003) reported that lye peeling of peaches resulted in 21% less loss of total phenolics compared to manual peeling.

Rossato et al. (2009) reported that peach could be of great interest as an important antioxidant source including chlorogenic acid, and it may provide health-promoting advantages to consumers by intake of this fruit or by utilization of its peels as antioxidant sources in industry. Muller et al. (2010) suggested that mango–peach smoothie was a good source of vitamin C.

Antioxidant activities, carotenoid, and polyphenol levels in seven cultivars of yellow-flesh peaches, five cultivars of yellow-flesh nectarines, and one cultivar of white-flesh nectarine at harvest and after 7 days of cold storage were evaluated by Di Vaio et al. (2008). Comparatively, yellow-flesh type contained higher amounts of total carotenoids per 100 g fresh-wt (182.45 μg for peaches and 117.37 μg for yellow-flesh nectarines). During cold storage, hydrophilic and lipophilic antioxidant activities increased for nectarines (by 22.9% in yellow-flesh and by 19.2% in white-flesh) and peaches, as did as polyphenolic compounds (by 13.37%).

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31
Plums and Prunes

Muhammad Siddiq and Muhammad Tauseef Sultan

Abstract: Plums (*Prunus domestica*) are produced in over 60 countries under diverse climatic conditions. This chapter covers production, postharvest storage, and processing aspects of plums. Commonly processed plum products are: dried prune, prune juice, prune juice concentrate, canned prunes, plum juice, plum puree/paste, jam and jelly. In addition to discussion on processing and quality aspects of plums and plum products, this chapter covers plum and prune composition, nutritional profile, and health benefits. Furthermore, given the antioxidant rich nature of plum fruit, there is a greater potential for preparing a variety of plum-based functional foods.

INTRODUCTION

The word plum is derived from the word "plume" (old English), a modification of *prunum* (Latin) or *proun-mom* (Greek) as described in Merriam-Webster Dictionary (Callahan 2008). Plum is a common name for trees of many species belonging to the genus *Prunus* of Rosaceae (rose) family and for their drupaceous (fleshy) fruits. Plums are generally cultivated in the temperate zones with numerous varieties and hybrids that are suitable for many soils and sites. Of the plum's more than 100 species, 30 are native to North America. They have been cultivated since prehistoric times, longer perhaps than any other fruit besides the apple (Anon 2007). World production of plums from 2004 to 2008 is shown in Figure 31.1; the 2008 world production was 10.2 million metric tons. China was the leading plum producer with 51% share of the total world production in 2008 (Table 31.1), followed by Serbia, and the United States. China also led in area under plums cultivation with 1.65 million hectares. Spain, Chile, and the United States were the leading exporters of plums whereas the United Kingdom, Russian Federation, and Germany were the top three plum importing countries (Table 31.2).

Plums can be divided into three groups, with the first two being the principal species of commercial plums (Anon 2004):

- *European-Asian (Prunus domestica)*: Familiar varieties of the European type are 'Stanley,' 'Reine Claude' ('Green Gage'), and the French and German prune ('Fellenburg') types. The European-type plums, purple to black in color, are best for eating fresh and for canning.
- *Japanese (Prunus salicina)*: Examples of Japanese plums are 'Methley,' 'Shiro,' 'Ozark Premier,' 'Burbank,' and 'Elephant Heart'. Color of fruit is yellow to crimson.
- *Damson (Prunus insititia)*: Plums in this group produce very tart fruits, which are used chiefly for cooking and preserving. Examples of Damson-type plums are 'Shropshire' and 'French Damson.'

Handbook of Fruits and Fruit Processing, Second Edition. Edited by Nirmal K. Sinha, Jiwan S. Sidhu, József Barta, James S. B. Wu and M. Pilar Cano.

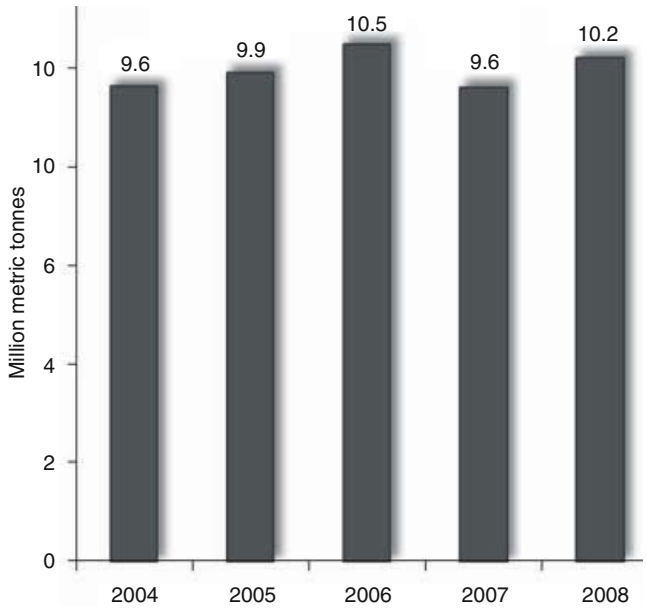

Figure 31.1. World total production of plums (2004–2008). (Adapted from FAO 2010).

A more detailed description of plum types, based on geographical and pomological grouping is shown in Table 31.3 (Gomez-Plaza and Ledbetter 2010). Most of the cultivated plums in the United States are derived from European and Japanese varieties, for example, *P. salicina,* introduced from Japan in 1870. A wild-type red plum (*P. americana*) is found along streams and in thickets from New York to the Rocky Mountains. Its small, sweet fruit has a purple bloom. This plum was utilized by Native Americans, who either ate it raw, cooked, or in dried form; when dried, it was a staple article of diet (Anon 2007).

Botanically, all prunes are plums but not all plums are prunes (Somogyi 1996); however, in North America, *prunes* refer to a variety that can be and is normally dried without removing pits. *Plums* include any variety primarily used for fresh consumption or in canning, freezing, and production of jams and jellies. Somogyi (1996) indicated that most plum varieties would ferment if dried as a whole fruit (with pits). However, if dried after the removal of pit, the product is called "dried plum" and not "prune." California accounts for over 99% of the prunes grown in the United States (see box on "US Prune Facts").

Since 1990, the per capita consumption of plums and plum products in the United States has seen a decline (Table 31.4).

Table 31.1. Leading Plum Producing Countries (2004–2008)

	Production (1000 Metric Tons)				
Country	2004	2005	2006	2007	2008
China	4835.3	5229.2	5326.3	4825.8	5223.0
Serbia	nr[a]	nr	556.2	680.6	606.8
United States	294.7	431.8	645.4	367.3	493.1
Romania	475.8	622.4	598.8	372.6	475.3
Chile	250.0	245.0	260.0	300.0	300.0
Turkey	210.0	220.0	214.4	240.9	248.2
Iran	147.0	147.0	147.0	147.0	190.6
Spain	145.6	251.8	178.7	191.1	184.6
Italy	179.3	185.4	180.5	178.3	184.0
India	140.0	140.0	160.0	160.0	160.0
France	229.5	214.3	234.0	248.9	146.9
Ukraine	173.3	165.9	127.1	109.6	135.5

Source: FAO (2010).
[a]Not reported.

Table 31.2. Plums in Global Trade: Leading Plum Exporting and Importing Countries (2008)

Rank	Exporters	Metric Tons	Importers	Metric Tons
1.	Spain	89,263	United Kingdom	73,205
2.	Chile	85,853	Russian Federation	68,214
3.	United States	62,361	Germany	61,938
4.	South Africa	49,283	Netherlands	47,300
5.	Italy	41,218	United States	29,701
6.	Netherlands	33,474	France	27,488
7.	Poland	22,704	Canada	26,845
8.	Serbia	22,690	China	20,314
9.	Hungary	17,011	Brazil	18,368
10.	Argentina	15,528	Italy	17,627

Source: FAO (2010).

US Prune Facts

- Over 99% of the prunes in the United States are grown in California.
- California grows almost 70% of the total world production of dried prunes.
- Approximately 1200 growers farm 86,000 bearing and 15,000 nonbearing acres of prunes in California.
- In 2000, the crop totaled 214,802 dried tons valued at approximately $166 million.
- Approximately 1% of the crop is sold fresh, primarily to the Asian market.
- The total cash costs for producing an acre of dried prunes varies from $2740 in the Sacramento Valley to $2840 in the San Joaquin Valley.

Source: Anon (2006).

Table 31.3. Grouping of Cultivated Plum Species Based on Geographical Distribution

Geographic Grouping	*Prunus* Species	Pomological Grouping	Representative Varieties
European–Asian	*P. domestica* L.	Green gages	Imperial Gage, Jefferson, Reine Claude
		Prunes	Agen, Hungarian, Italian, Sugar
		Yellow eggs	Yellow eggs, Golden Drop, Monroe
		Imperatrices	Arch Duke, Englebert, Monarch
		Lombards	Bradshaw, Compote, Pond, Victoria
	P. domestica var. *insititia* Bailey	Damsons	Crittenden, Grand Duke, Shropshire
		Bullaces	Black Bullace, Royal Bullace, White Bullace
		Mirabelles	Drap d'Or, Late Mirabelle
		Saint Julian	St. Julians
	P. cerasifera Ehrh.	Myrobalans	Lindsayae, Marianna, Nigra
		Common wild plums:	
American	*P. americana* Marsh.		Cherokee, DeSoto, Golden Queen
	P. nigra Ait.		Aitkin, Crimson, Oxford
		Wild Goose (Chickasaw) plums:	
	Prunus hortulana Bailey		Cumberland, Golden Beauty, Wayland
	Prunus angustifolia Marsh.		Caddo Chief, Ogeeche
	Prunus munsoniana Wight and Hedr.		Jewell, Osage, Pottawattamie, Texas Belle
		Beach plums:	
	P. maritime Marsh.		Bassett's American
		Pacific Coast plums:	
	P. subcordata Benth.		Sisson
		Japanese plums:	
Oriental	*P. salicina* Lindl.		Blackamber, Friar, Satsuma
		Apricot plums:	
	P. simonii Carr.		Climax, Wickson (hybrids with *P. salicina*)

Source: Gomez-Plaza and Ledbetter (2010).

The use of prunes and prune products as food ingredients have kept steady, most likely due to: (1) improved production and processing technologies, and (2) discoveries of health benefits of phytochemicals in fruits (like antioxidant benefits of phenolic compounds), which are present in significant quantities in plums and prunes. According to Somogyi (1996), marketers believe that the term "dried plum" has a more positive image to the consumers than "prunes." And that, based on Dried Fruit Association's opinion, manufacturers can use the term "dried plums" in labeling prune ingredients.

PRODUCTION AND HARVESTING

Trees of some plum cultivars are capable of self-pollination even if grown as single-isolated plant(s); other plum varieties require cross-pollination for fruit set and development. Some popular plum varieties are 'AU Amber,' 'AU Homeside,' 'AU Producer,' 'AU Roadside,' 'AU Rubrum,' 'Black Ruby,' 'Byron Gold,' 'Crimson,' 'Frontier, Methley,' 'Morris,' 'Ozark Premier,' 'Robusto,' 'Ruby Sweet,' 'Segundo,' and 'Wade.' Plum trees usually begin to bear fruit 3–5 years from planting and have a useful life of 15–20 years. Depending on the type of cultivars, average yields can range from 3 to 5 bushels per tree. However, other factors like fertilizer use, irrigation, pruning and training, and plant protection practices play a big role in yield per tree (Keulemans 1990; Vitanova 1990;

Table 31.4. US Per Capita Consumption of Fresh and Processed Plums, 1990–2008 (in Pounds)

Year	Total, All Forms	Fresh	Processed				
			Total	Canned	Juice	Frozen	Dried
1990	3.78	1.54	2.24	0.08	0.52	0.00	1.64
1995	2.74	0.93	1.82	0.05	0.47	0.00	1.30
2000	2.74	1.19	1.55	0.04	0.31	0.01	1.20
2005	2.46	1.11	1.35	0.02	0.42	0.00	0.91
2008	2.28	0.92	1.35	0.02	0.51	0.01	0.83

Source: Adapted from USDA-ERS (2010).

DeJong et al. 1992). Agricultural practices such as application of calcium sprays after bloom is reported to improve fruit quality (Wojcik 2001). Southwick et al. (2000) reported the use of gibberellin at preharvest stage to delay maturity and improve fruit firmness. Common pests and diseases of plum trees include plum curculio, European red mite, brown rot, leaf spot, and black knot (Anon 2004).

Visual sign of maturity and harvest date of plums can be estimated by skin color changes, which are cultivar-specific. A color chip guide is used to determine harvest maturity. In California, a two-tier maturity system is currently used to determine maturity; (1) "US Mature" (minimum maturity), and (2) "California Well Mature." Measurement of fruit firmness is recommended for those plum cultivars where skin ground color is masked by full red or dark color development before maturation. Flesh firmness, measured with a penetrometer, can be used to determine a maximum maturity index, that is the stage at which fruit can be harvested without suffering bruising damage during postharvest handling. For objective measurements of maturity, soluble solids contents and sugar-to-acid ratio provide more reliable markers (Crisosto and Kader 2000). Slaughter et al. (2003) reported a nondestructive optical method that can be employed successfully using near infrared (NIR) spectroscopy to determine total and soluble solids contents in fresh prune. Another nondestructive method, which uses ultrasound technology, was also found useful in evaluating plum quality attributes (Mizrach 2004).

A study by Khan and Singh (2010) investigated the role of preharvest application of putrescine in regulating fruit ripening and quality of early, mid, and late season Japanese plum fruits. Whole trees were sprayed with an aqueous solution containing putrescine (0, 0.1, 1.0, and 2.0 mM) 1 week before commercial harvest for each plum cultivar separately. Results showed that preharvest application of 2.0 mM putrescine delayed fruit ripening and reduced respiration rate, ethylene production, and fruit softening. Valero et al. (2007) investigated the nondestructive Sinclair iQ^{TM} firmness tester to monitor ripening and predict bruising susceptibility in stone fruits, including plums. These researchers pointed out the importance of relating nondestructive measurements directly to important commercial physiological stages rather than relying on current standard penetrometer values. Paz et al. (2008) indicated that the fruit industry requires rapid, economical, and nondestructive methods for classifying fruit by internal quality, which can be built into the processing line. NIR spectroscopy could be used as a nondestructive analytical method to access total soluble solids (°Brix) and firmness (N).

Ripening typically results in increased fruit weight and soluble solids, decreased fruit firmness, darker color of fruits, increased concentration of total sugars, decreased concentration of total acids, and increased concentration of anthocyanins. There was no influence of ripening on the content of phenols (Usenik et al. 2008). Usenik et al. (2009) investigated the accumulation of anthocyanins and the ensuing evolution of plum fruit color during ripening. Fruit ripening resulted in an increase of total anthocyanins and changes in the ratios of individual anthocyanins. This study showed that correlation between individual anthocyanins and color parameters in ripe plums were cultivar-dependent.

Plums and fresh prunes are generally machine-harvested; however, in some areas they are handpicked into bags and then dumped into bins on trailers that move between tree rows. Each method of harvest has some advantages as well as some disadvantages over the other.

POSTHARVEST PHYSIOLOGY AND STORAGE

At the packinghouse, after washing, sorting is done to eliminate fruit with visual defects and sometimes to divert fruit of high surface color to a high-quality pack (sizing segregates fruit by either weight or dimension). Ideal storage conditions for plums are a temperature of 0°C and 90–95% relative humidity; under such conditions, storage life is 2–4 weeks (Crisosto and Kader 2000). Martinez-Romero et al. (2003) reported that forced-air cooling after harvesting and before transportation to packinghouse, handling in packinghouse, and during storage helped maintain fruit quality and prolong shelf life. Their research indicated that forced-air cooling led to a reduction in respiration rate of mechanically damaged plums that otherwise deteriorate rapidly.

Guerra et al. (2009) conducted a study to determine storage capacity and changes in quality and consumer acceptance of plums harvested at different dates, and to assess the instrumental parameters that showed good correlation with sensory quality and consumer acceptance. The results showed that both harvest date and storage time had significant impact on quality and sensory characteristics. Furthermore, a high degree of linear regression was observed between color parameter, a*, and total soluble solids and acidity ratio, which suggested that nondestructive measurement of instrumental color a* value could be used as an estimate of consumer acceptance.

Generally, during postharvest storage, concentration of sugars increases and organic acids decrease. Figure 31.2 shows changes in concentrations of sugars and organic acids during 0°C storage of 'Amber Jewel' plums harvested on two different dates (D1 and D2) 1 week apart (Singh et al. 2009). The increase in total sugar levels between two harvesting dates 7 days apart (129 and 136 days after full bloom) was not significant, but the concentrations of individual sugars changed. It was also reported that fruit harvested on both dates showed a similar increase in concentration of total sugars during storage at 0°C.

During postharvest storage of fruits, ethylene triggers many, though not all, aspects of fruit ripening. Abdi et al. (1998) reported that within a fruit species, such as plum, high-ethylene producers would soften and ripen at a faster

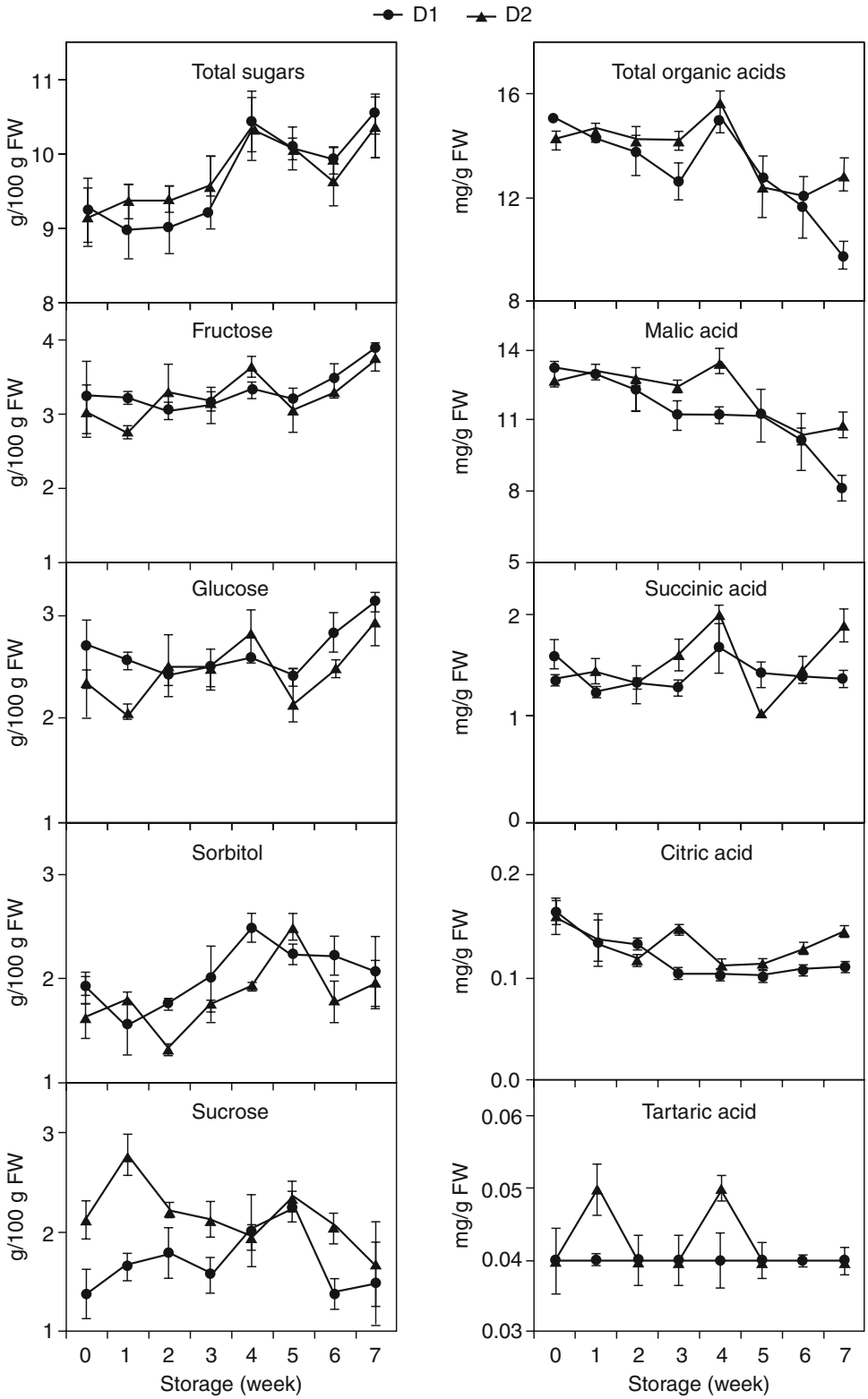

Figure 31.2. Changes in concentrations of sugars and organic acids during 0°C storage of "Amber Jewel" plums harvested on two different dates (D1 and D2) 1 week apart. (From Singh et al. 2009).

rate than low ethylene producer cultivars. The ethylene action inhibitor 1-methylcyclopropene (1-MCP) has been shown to delay ripening and improve postharvest quality of climacteric fruits (Abdi et al. 1998; Dong et al. 2002).

Menniti et al. (2006) reported that an application of 1-MCP before air storage of plums could be the best way to reduce the ripening process for short or medium storage periods (40 and 60 days) while controlled atmosphere (CA) storage plus 1-MCP treatment could be used for long-term (80 days) quality retention. Ozkaya and Dundar (2009) studied the effect of 1-MCP on different quality parameters and respiration rate of 'Black Diamond' plums during storage that were harvested at commercial maturity. Treatment with 1-MCP was effective in reducing weight loss and maintaining firmness during 30-day storage at 0°C and 5 days of shelf life. The other quality parameters (titratable acidity, color, total soluble solids, and individual sugars) were not affected significantly by 1-MCP. Traditional use of 1-MCP has been in the gaseous form but a recent study (Manganaris et al. 2008a) also reported using this treatment in the form of an immersion method for plum fruit to extend their shelf life.

Edible coatings have been used for a variety of fruits to extend their shelf life. Eum et al. (2009) treated 'Sapphire' plums with a coating based on carbohydrate (Versasheen) with sorbitol as plasticizer and stored at 20°C and 85% RH. The effect of coating on the gas transmission rates was estimated to assess coating efficiency. The coating treatment reduced the transmission rate of CO_2, O_2, and H_2O. The loss of firmness was delayed as a result of coating treatment thereby improving keeping quality of plums. Navarro-Tarazaga et al. (2008) studied the effects of the composition of hydroxypropyl methylcellulose-beeswax edible coatings on the postharvest quality of coated 'Angeleno' plums; the coating treatments reduced plum softening and bleeding but were not effective in reducing fruit weight loss.

A number of other methods of improving postharvest quality of plums have been reported in the literature. Treatment of plums with nitric oxide effectively reducing oxidative damage during postharvest storage at 25°C storage for 13 days (Yao et al. 2010). Luo et al. (2010) explored the potential of hot-air treatment to delay ripening of 'Qingnai' plums as a potential technology to expand the marketing of green plums was determined. Heat-treated fruits changed from green to yellow at a slower rate than control fruits. The hot-air treatment extended the postharvest life of 'Qingnai' plums by up to 6 days, from 12 to 18 days. Perez-Vicente et al. (2002) investigated the role of exogenously applied putrescine, a polyamine, during postharvest storage of mechanically damaged plums; exogenous putrescine inhibited and delayed ethylene and CO_2 production rates.

Chilling injury and internal browning are the two physiological disorders reported in plums. Most plum and fresh prune cultivars exhibit flesh translucency associated with flesh browning as chilling injury, or "gel breakdown" a term used in South Africa for chilling injury (Taylor et al. 1995; Crisosto et al. 1999;). Internal browning is a physiological disorder that originates before the harvest and is associated with high temperatures during fruit maturation and delayed harvest. Polyphenol oxidase can initiate flesh discoloration in injured or bruised fruits (Siddiq et al. 1993; 1996). This enzyme not only affects sensory color but can also be detrimental to nutritional quality. Guerra and Casquero (2009) showed that prompt cooling is important for the physiochemical and sensory quality of plums and that delayed cooling can increase internal breakdown symptoms in fruit that can lead to chilling injury. Plums are also susceptible to flesh reddening, a disorder associated with chilling injury (Manganaris et al. 2008b). Delayed storage can increase severity of flesh reddening, which is accompanied by an increase in anthocyanins content. It was also suggested that continuous exposure to ethylene resulted in particularly marked increases in reddening (Manganaris et al. 2008b).

PROCESSED PRODUCTS

Plums have a great potential as a fresh market and/or processing crop, which can be harvested between cherry and apples in many areas, especially in the Unites States. About one-half of the plums are consumed fresh while the rest are processed. The major processed plum products are dried prunes, prune juice, and whole canned plums. The amount of plums processed as canned has decreased consistently and significantly during the last two decades; from 39,100 pounds in 1990–1991 to 6,400 pounds in 2008–2009 (Fig. 31.3).

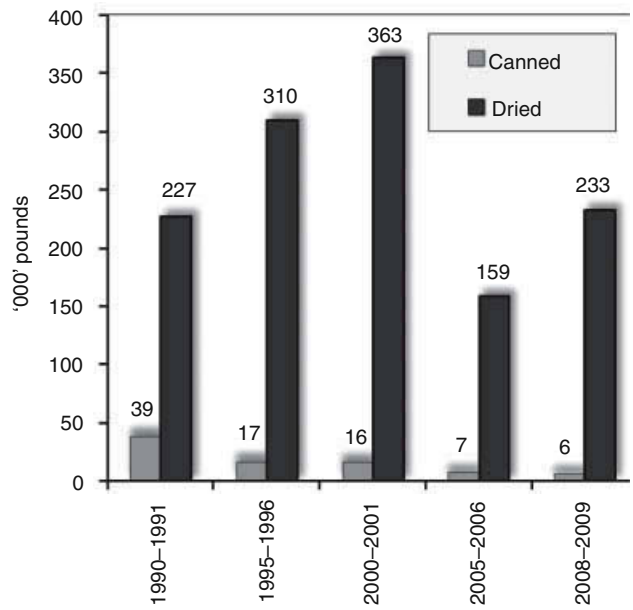

Figure 31.3. US processing of canned and dried plums for selected years since 1990–1991. (Adapted from USDA-ERS 2010).

Processing of dried plums had about 60% increase between 1990–1991 and 2008–2009 (to 363,200 pounds); however, the amount of plums dried in 2008–2009 has dropped back to slightly above 2005–2006 levels (USDA-ERS 2010).

Other processed forms, such as paste, sauce, and plum juice have not been developed and marketed on a scale similar to these products from other fruits such as apples, cherries, citrus, pears, apricots, etc. (Chang et al. 1994; Espie 1992). However, with new scientific claims of many health benefits of the phytochemicals (plums being rich in many), plums have a great potential for a variety of new processed products than are currently available in the market.

Dried Plums/Prunes

Dried plums or prunes represent over one-half of the processed plum products consumed on a per capita basis in the United States (Table 31.4). Fruit is harvested at full maturity when soluble solids contents reach at least 22% (22°Brix). Other maturity indices include fruit firmness, flesh, and skin color. Modern dehydrators have replaced the old methods of drying prunes in the sun in the United States (Somogyi 1996). However, in many of the plum-producing developing countries, sun drying still continues to be one of the cheapest sources of drying plums.

Typical processing steps involved in the production of prunes are listed as follows (Somogyi 1996):

- Plum quality analysis at harvest (Brix, titratable acidity, color, % initial moisture).
- Air classification to remove leaves, stems, and extraneous matter followed by a wash with approximately 20 ppm chlorinated water.
- Washed plums loaded onto drying trays and trays transferred to dryers.
- Drying at 140–165°F for 24–36 hours (to a moisture of about 16 ± 3% from initial moisture of ∼80%).
- Dried prunes stored at ambient temperature for about 1–2 weeks for moisture equilibration.
- Packaged in high density polyethylene-line corrugated box.
- Stored at dry, cool, condition (preferably refrigerated, 40–55°F).

Prunes are dried to about 18% moisture, which has sufficiently low water activity to avoid problems of microbial spoilage allowing long-term storage (Newman et al. 1996). Generally, forced-draft tunnel dehydrators are used for drying plums, with a total drying process time of 24–36 hours, depending on the size and soluble solids contents of the prunes. The operating temperature for the tunnel is 145–165°F (dry bulb temperature) with wet bulb 15°F lower than the dry bulb at the cool end. Yield of dried prunes is about 33%. For the prunes that are marketed as "Dried Prunes with Pits," dried fruit from above step are rehydrated to 24–30% moisture, pasteurized, inspected and bulk- or retail-packaged for food service or consumer use, respectively. Potassium sorbate is the most commonly used preservative for prunes when moisture contents of the finished prunes are higher than 25%. Some products made from dried prunes, on a smaller scale, are prune juice, juice concentrate, whole pitted prunes, canned prunes (pitted), and various forms of dry and low-moisture products (diced prunes, prune bits, prune paste, low-moisture prune granules, low-moisture prune powder, prune fiber, prune fillings and toppings).

Most of recent research related to prune processing has been focused on ways to improve efficiency of the drying methods with due consideration given to the retention of best quality characteristics (both chemical and nutritional) in the finished product. In order to increase the drying rate, Jazini and Hatamipour (2010) employed a new physical pretreatment of plums that consisted of piercing fruit with a thin needle. The effect of physical pretreatment on drying time was compared with chemical pretreatment (dipping of plums in hot 1% NaOH solution). Their results showed that pierced plums dried faster than chemically pretreated plums. Koocheki and Zarpazhooh (2010) investigated water loss (WL), solid gain (SG), weight reduction (WR), and shrinkage during osmotic drying of plums, using response surface methodology. In most cases, increases in sucrose concentration, temperature and immersion time increased WL, SG, WR, and shrinkage. Immersion time and temperature were the most significant factors that affected WL during osmotic dehydration of plums followed by the concentration of sucrose solution. The partial replacement of sucrose and monosaccharides by fructooligosaccharides reduced the calorific value of carbohydrates in osmotically dried material by 12–37% depending on process conditions (Klewicki and Uczciwek 2008).

Doymaz (2004) studied the effect of a dipping treatment on air-drying of plums, and observed that dipping of plums in 5% potassium carbonate and 2% ethyl oleate for 1 minute was effective in removing the natural wax coating and hence reduced the drying time by about 30% as compared to untreated fruit. Cinquanta et al. (2002) reported that physical (abrasion) and chemical (alkaline ethyl oleate dip) pretreatments before drying significantly reduced losses of total phenols. Gabas et al. (2002) studied the rheological properties of prune as a function of drying conditions. Their data showed that prunes exhibited a more pronounced elasticity at low moisture content and drying temperature. Higher moisture content and temperature resulted in more viscous and less rigid prunes. Sabarez et al. (2000) used solid phase microextraction (SPME) in conjunction with GC–MS to monitor changes in some major volatile flavor compounds under simulated commercial drying conditions (80°C air temp. 35% RH, 5 m/s air velocity) for 'd'Agen' plums. They observed that aroma profile was significantly modified during drying and substantial loss of the original volatile flavors. Piga et al. (2003) reported that drying had a detrimental effect on anthocyanins and ascorbic acid in plum cultivars they studied.

Table 31.5. Functional Attributes of Dried Plums

Functional Attribute	Reduction/Replacement Of
Humectancy	Mono- and diglycerides
Natural color	Caramel color, molasses
Flavor enhancement	Salt, artificial flavors
Natural sweetness	Refined sugars
Natural preservative	Calcium propionate
Fat replacement	Emulsifiers, modified starches, fats

Source: American Society of Bakery Engineers (Sanders 1993).

Stier (2008) reported a number of properties of dried plums with potential benefit in processed food products (high fiber content, natural source of sorbitol, high levels of malic acid, low glycemic index, and flavor enhancer). These nutritional and functional properties make dried plums, plum powders, or juice concentrates suitable for use in meat and poultry products, bakery products, sauces, marinades, etc. Sanders (1993) noted a variety of functional attributes of dried plums (Table 31.5); that include natural preservative and a fat substitute, which could be of special benefits owing to more emphasis on low-fat foods and products processed without added preservatives by the consumers.

Dried plum products are suitable for use in many bakery products as shown in Table 31.6, which in addition to added nutritional benefits, can also improve desirable sensory attributes.

Prune Juice

Prune juice is essentially a water extract of dried prunes with a Brix of 18.5°. It is a brownish to reddish brown liquid having taste and flavor of prunes. The process involves direct heating of the dried prunes in appropriate volumes of water (typically 4–5 times the fruit weight) to extract fruit solids without burning and affecting flavor and color. Traditionally, the process can take several hours (1 h boil, 10 h simmering) and under atmospheric cooking. A short duration (10–15 minutes) pressure-cooking may speed-up juice extraction. After extraction, other unit operations of filtration (to remove pits and undissolved solids), pasteurization (88°C for 1 minute) and packaging can be similar to processing of other juices. The juice thus made can also be concentrated in a vacuum evaporator. For canning and bottling, the product should be hot filled (88°C) and sealed before processing in boiling water for 20–35 minutes depending on the size of a can. As per FDA regulations, prune may contain citrus (lime and lemon juices) and enriched with vitamin C. The Federal regulations require that the following label declaration appear on the container below the words Prune Juice: "A water extract of dried prunes." Luh (1980) reported that prune juice differed from other juices, which are squeezed from fresh fruits.

Table 31.6. Dried Plum-Based Bakery Ingredients

Product Form	Suggested Uses
Diced dried plums and extruded bits	Breads, muffins, cookies, cakes, fillings
Dried plum paste	Fillings, breads, bagels, cookies
Dried plum juice concentrate	Breads, pastries, cakes, muffins, cookies, fillings
Dried plum powder/ granules/flakes	Dry mixes, bagels, reduced-fat/ fat-free mixes
Dried plum puree	Reduced-fat/fat-free bakery cakes, cookies, muffins, fillings

Source: American Society of Bakery Engineers (Sanders 1993).

Prune Juice Concentrate

Prune juice, processed as earlier, can be concentrated to 60°–72°Brix depending on the intended end use. Concentrate with lower soluble solids is frozen and used for reconstitution into single strength juice. The high Brix (≥65% soluble solids) is shelf-stable/self-preserving without any need for freezing or added preservatives; the latter quality is of great benefit for shipping long distances, for export markets.

For better process efficiency, prune juice before concentration is depectinized by the addition of commercial pectic enzymes (Somogyi 1996). Juice is concentrated in a high vacuum evaporator; many types of such evaporators are available commercially. Process is carried at temperature of 48°C or lower. Water in the juice is evaporated and the juice sugars and other solids are concentrated to the desired level.

Prune juice concentrate offers many benefits and applications in different food systems (Anon 2010); it (1) extends the shelf life of bread products, serves as an antistaling agent; (2) sweetens and colors natural-baked goods; (3) is a natural substitute for preservatives; (4) can be a good sugar substitute, and natural color/flavor enhancer; (5) can be used as filling for hard candies and chocolate; (6) maintains moisture in chewy cakes and cookies; and (7) can be used as binding agent in cereal bars.

Canned Prunes

Dried prunes make an excellent product when canned. Processing consists of washing dried prunes, blanching for 4 minutes in hot water (to start softening of prunes), filling in cans, and adding syrup. Cans are exhausted for 12–15 minutes at 170°F before sealing. Thermal processing is carried out at 212°F for 12 minutes. Canned prunes can be more prone to form hydrogen springer than other canned fruits, which can be minimized with high vacuum as a result of extended exhaustion before can closure (Downing 1996).

Canned prunes, which are moist, have no added preservatives, and a long shelf life, can be used for ready-to-eat snacking. Studies on canned prunes in syrup showed that use of syrup previously employed in the osmotic dehydration process did not impair quality of the canned product (Silveira et al. 1984). Bolin et al. (1971) reported that when apple juice was used as stewing medium for canned prunes, a desirable flavor was produced. Flavor did not improve by the addition of citric acid and ascorbic acid; both had rather an adverse effect instead.

Plum Juice

Most of the research on plum juice production was undertaken in the 1970s and 1980s. Plum juice has not been processed to a scale similar to prune juice, probably due to its high acidity. Siddiq et al. (1994) developed a method using pectinase enzymes to press juice from 'Stanley' plums that increased juice yields significantly. Chantanawarangoon et al. (2004) evaluated antioxidant capacity, total phenolics, and total anthocyanins in juices prepared from 10 plum cultivars and suggested that plum juice with high antioxidant capacity, total phenolics, and total anthocyanins could be new healthy beverages for consumers and potential sources of nutraceutical supplements as well.

Plum Puree/Paste

Plum paste is another product with limited commercial production, however, with recent research on health benefits of polyphenols and dietary fiber, it offers a great potential for increasing production and uses in many food formulations.

Wang et al. (1995) developed a procedure to produce pastes from 'Stanley' plums and studied the effects of processing conditions on chemical, physical, and sensory properties of the pastes. Plums were processed by heat concentration into two pastes of 25° and 30°Brix. Soluble solids of these two pastes were increased to 40° and 45°Brix, respectively, by addition of sugar. Heat concentration resulted in a significant decrease in titratable acidity, total anthocyanins, and total pectin. Pastes showed pseudoplastic behavior within the shear rate range of 20–100 rpm. Sugar addition had a darkening effect on color, but no noticeable effect on rheological properties of the pastes. Sensory evaluation indicated that preference could be adequately predicted by flavor and color under suitable °Brix/acid ratio. Raina et al. (1999) also reported that concentration of plum paste had significant effects on the rheological properties and acidity of the resultant paste. It was not feasible to concentrate the paste beyond 35°Brix. Sweetened paste had higher acceptability scores than unsweetened paste.

Yildiz-Turp and Serdaroglu (2010) studied the effects of using different amounts of plum puree (5%, 10%, or 15%), as an extender, on some properties of low-fat beef patties. Moisture content of patties decreased as the concentration of plum puree was increased; however, the highest cooking yield and moisture retention were found in samples with 5% plum puree. Overall, the results showed that 5% or 10% plum puree can be used as an extender in low-fat beef patties with increased juiciness and higher texture scores.

Jam and Jelly

Plum jam and jelly have not gained enough consumer acceptances to result in commercial production. However, there is potential for the production of jams and jelly in combination with other fruits, which are lower in phenolic compounds and antioxidant activity. Kim and Padilla-Zakour (2004) investigated the changes in total phenolics, antioxidant capacity, and anthocyanins from fresh fruits (cherries, plums, and raspberry) to processed shelf-stable jams, with the objective of finding if high sugar and acid levels may provide protection to phenolic compounds. Their results showed that jam processing had no consistent effect on phenolics, although antioxidant capacities generally decreased. Nonetheless, plums can be used as a source of phenolics in jams prepared from other fruits that may be low in these phytochemicals.

Fresh-Cut Plums

"Fresh-cut produce" is defined as any fresh fruit or vegetable or any combination thereof that has been physically altered from its original form, but remains in a fresh state. Regardless of commodity, it has been washed, trimmed, peeled, and cut into 100% usable product that is subsequently bagged/packaged to offer consumers with high nutrition, convenience and value while still maintaining freshness (IFPA, 2004). In recent years, a market for fresh prunes has developed; however, less than 1% of prunes produced in California are marketed through this channel due to volatile market conditions (Anon 2006). Fresh-cut plum can keep good quality for 2–5 days, depending on the cultivar and ripeness stage (firmness) when stored at 0°C in packages that minimize loss of water (Crisosto and Kader 2000). Cisneros-Zevallos and Heredia (2004) studied the role of ethylene and methyl jasmonate on the changes in health-promoting antioxidant compounds in different fresh-cut produce that included plums. They found that these two plant hormones combined with wounding (cutting) could be used to enhance the health promoting antioxidant content of fresh-cut produce.

Other Products

Yang et al. (2010) optimized a process for preparation of green plum vinegar: green plums were pitted, washed, mashed into a slurry, and pectinase enzyme added for pectin hydrolysis. Dry yeast was used for the fermentation of plum juice at 28°C for 72 hours. The vinegar thus produced had an aroma typical of green plums and vinegar.

NUTRIENT PROFILE, BIOACTIVE COMPOUNDS, AND HEALTH BENEFITS

Nutrient Profile

Plum and prune products, in addition to being low in fat content, contain significant amounts of some major nutrients as shown in Table 31.7. The values shown here are for the fruit grown and processed in the United States; therefore, some differences can be anticipated in composition of plum and prune products in other parts of the world owing to different climatic and soil conditions, agricultural practices, postharvest handling, and processing techniques, etc. Additionally, varietal differences can also contribute to variations in the composition of raw and finished products.

Ki and Jong (2000) reported that drying was the mildest processing method for maintaining original levels of dietary fiber in vegetable and fruit products as demonstrated by 7.35% and 3.45% increase in total dietary fiber in prunes and raisins, respectively. Somogyi (1996) gave examples of variations in fiber contents (from 2.04 to 16.1 g/100 g prunes with 23.3–32.4% moisture), reported by various sources, and indicated that these variations could not be attributed solely to the natural variations in the composition of fruits. He concluded that the lack of standardized tests, especially for the extraction of soluble fibers, might be responsible for such discrepancies. Plum and prune products, though not a very good source of vitamins based on US RDA requirements, do contain fair amount of different vitamins. Dismore et al. (2003) investigated the presence of vitamin K in the US diet containing nuts and fruits and found that with the exception of some berries, green fruits, and prunes, most nuts, and fruits are not good sources of this vitamin.

Table 31.7. Composition of Plums, Prunes, and Their Processed Products (Per 100 g Edible Portion)

Nutrient	Unit	Plums	Canned[a]	Dried (Prunes)	Prune Juice[b]
Proximate:					
Water	g	87.23	83	69.73	81.24
Energy	kcal	46	63	107	71
Protein	g	0.7	0.37	0.96	0.61
Total lipid (fat)	g	0.28	0.1	0.16	0.03
Carbohydrate, by diff.	g	11.42	16.28	28.08	17.45
Fiber, total dietary	g	1.4	0.9	3.1	1
Sugars, total	g	9.92	15.35	24.98	16.45
Vitamins:					
Vitamin A, IU	IU	345	231	342	3
Vitamin C, total ascorbic acid	mg	9.5	0.4	2.9	4.1
Thiamin	mg	0.028	0.016	0.024	0.016
Riboflavin	mg	0.026	0.039	0.1	0.07
Niacin	mg	0.417	0.297	0.723	0.785
Pantothenic acid	mg	0.135	0.072	0.107	0.107
Vitamin B6	mg	0.029	0.027	0.218	0.218
Folate, total	μg	5	3	0	0
Choline, total	mg	1.9	1.3	4.4	2.7
Vitamin E (α-tocopherol)	mg	0.26	0.18	0.19	0.12
Vitamin K (phylloquinone)	μg	6.4	4.3	26.1	3.4
ß-Carotene	μg	190	127	173	2
Lutein + zeaxanthin	μg	73	49	65	40
Minerals:					
Calcium	mg	6	9	19	12
Iron	mg	0.17	0.86	0.41	1.18
Magnesium	mg	7	5	18	14
Phosphorus	mg	16	13	30	25
Potassium	mg	157	93	321	276
Sodium	mg	0	20	1	4
Zinc	mg	0.1	0.08	0.19	0.21
Copper	mg	0.057	0.038	0.123	0.068
Manganese	mg	0.052	0.032	0.131	0.151

Source: USDA (2010).
[a]In light syrup (solids and liquids).
[b]Canned.

Bioactive Compounds and Antioxidant Capacity

Plums are reported to be high in natural phenolic phytochemicals, such as flavonoids and phenolic acids, which function as effective natural antioxidants in human diet and have been reported to reduce the risk of cancer and other chronic diseases (Block et al. 1992; Ames et al. 1995; Machlin 1995). Cultivar differences are known to affect the total phenolics and chlorogenic acid contents, as shown in Table 31.8 for some varieties of plums grown in Michigan (Siddiq et al. 1994). Slimestad et al. (2009) analyzed six plum cultivars, grown in Norway, for phenolic composition. Neochlorogenic acid was found to be the most predominant phenolic acid in all cultivars, whereas, cyanidin-3-rutinoside accounted for more than 60% of the total anthocyanin content. Minor amounts of flavonols (rutin and quercetin 3-glucoside) were also detected. The total antioxidant capacity among different plum cultivars ranged from 290 to 814 μmol of Trolox equivalent (TE) per 100 g on fresh-weight basis. Bouayed et al. (2009) identified and quantified major polyphenol compounds in plums using reversed-phase HPLC, and tested these compounds to evaluate their protective effect on peripheral blood granulocytes from oxidative stress. Their results showed that individual polyphenols contributed directly to the total protective effect of plums.

According to Shahidi and Naczk (1995), presence of phenolic compounds in foods has an important effect on the oxidative stability and microbial safety of these products. In addition, many phenolics in foods possess important biological activity related to their inhibitory effects on mutagenesis and carcinogenesis. Therefore, in recent years, a rapid progress has been made on different aspects of polyphenols in food. Kim et al. (2003) demonstrated that antioxidant capacity of plums, expressed as vitamin C equivalent antioxidant capacity (VCEAC), was substantially higher (up to three times) when compared with apples. In another study, Wang et al. (1996) reported 4.4-times higher total antioxidant capacities in plums than apples, the latter being the most commonly consumed fruit in our diet. Prunes are shown to have the highest antioxidant capacity, expressed as oxygen radical absorbance capacity (ORAC, Table 31.9) that measures a food's ability to subdue oxygen-free radicals by comparing its absorption of peroxyl or hydroxyl radicals to that of Trolox, a water-soluble vitamin E analog (Keeton et al. 2002). Plums are shown to have a very good free radical scavenging activity against O_2-derived free radicals, such as hydroxyl and peroxyl radicals (Murcia et al. 2001).

Rop et al. (2009) compared traditional commercial plum cultivars with the less known and regionally grown ones in Carpathian Mountains range of Europe. The results of this study showed that regional cultivars had outstanding nutritional properties, including the total content of phenolic substances, which were highly correlated with the total antioxidant capacity of the fruit.

Table 31.8. Total Phenolics and Chlorogenic Acid Contents in Different Plum Cultivars

Cultivars	Total Phenolics[a] (μg/g)	Chlorogenic Acid (μg/g)
Beauty	922	103
Pipestone	736	77
La crescent	590	88
Abundance	437	38
Pobeda	353	63
Au Roadside	339	35
Underwood	300	43
Wade	299	33
Shiro	295	46
Stanley	282	75

Source: Siddiq et al. (1994).
[a]As chlorogenic acid.

Table 31.9. ORAC Values of Fruits with Antioxidant Potential

Fruits	ORAC[a] Value/100 g
Dried plums	5770
Raisins	2830
Blueberries	2400
Blackberries	2036
Strawberries	1540
Raspberries	1220
Plums	949
Oranges	750
Red grapes	739
Cherries	670
Kiwi fruit	602
Grapefruit, pink	483

Source: Keeton et al. (2002).
[a]ORAC, oxygen radical absorbance capacity.

Flavor Compounds

The main flavor compounds identified in different plum species are ketones, aldehydes, alcohols, esters, lactones, and hydrocarbons (Gomez-Plaza and Ledbetter 2010); these researchers reported that plums vary widely in their flavor and aroma characteristics and intensity and that many cultivars have been developed for use for specific purposes (fresh market or processing). According to Cinquanta et al. (2002), higher levels of sorbitol content is of great importance in prune-type plums due to its resistance to excessive caramelization (resulting in product darkening) during drying process. Both cultivated and native/wild plums are preserved in a wide variety of forms (chutney, compote, glacé, jam, pickling, etc.) and retention of flavor these products is of

critical importance for best culinary experience (Gomez-Plaza and Ledbetter 2010).

Health Benefits

Fresh plums and prunes are an excellent healthy food due to their low fat and good source of dietary fiber. Prunes are a moist and convenient snack, and an easy way to get more natural fiber into the diet. Health experts have been advising people of all ages to consume more dietary fiber, based on the research findings, which suggest that fiber may prevent cancer, diabetes, heart disease, and obesity. Prune fiber mostly consists of soluble fraction (about 80%), mainly pectin, hemicellulose, cellulose, and some lignin. Prunes could be classified as a unique health food that is not only high in dietary fiber but also exhibits the highest antioxidant activity.

Halloran et al. (2010) reported that dried plums contain proanabolic factors that can dramatically increase bone volume and restore bone that has already been lost due to aging. Dried plums can provide effective prophylactic and therapeutic agents for the treatment of osteoporosis. A study by Arjmandi et al. (2010) also showed benefits of dried plum in bone mineral density augmentation. Gallaher and Gallaher (2009) suggested that consuming dried plums or prunes, which are high in pectin with substantial antioxidative activity, may help slow the development of atherosclerosis.

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32
Tropical Fruit I: Banana, Mango, and Pineapple

Lillian Occeña Po and Edgar C. Po

Abstract: Tropical fruits have unique flavors and are excellent sources of vitamins, minerals, and phytonutrients. Banana contributes significant potassium to our diet, ripe mango is a rich source of vitamin A, and pineapple is one of the lowest caloric fruits and a source of vitamin C. The changing demographics and global trade have increased demand for tropical fruits. This chapter reviews and discusses important production, quality and processing aspects of three leading tropical fruits, banana (*Musa* sp.), mango (*Mangifera indica* L.), and pineapple (*Ananas comosus* L.). Produced primarily in tropical and subtropical climates, the economic production and marketing of these fruits requires specific handling, processing,

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and preservation techniques. The coverage includes production and cultural practices including pest and disease, harvest, postharvest handling, and storage; processing into important products such as juice, nectar, concentrates, dehydrated fruits, chips, etc.; physicochemical and nutritional characteristics; and consumption and utilization trends.

INTRODUCTION

Globalization of trade and changing US demographics have helped increase the demand for tropical fruits in the United States. The continuing influence of ethnic cuisines in the food service and food processing industries has provided a venue for incorporation of tropical fruits in various ethnic dishes, as well as processed foods and beverages. Tropical fruits are versatile fruits, and diversification of products is an effective way to increase consumption of fruits. Tropical fruits are excellent sources of vitamins, minerals, and phytonutrients. Bananas contribute significant potassium and soluble fiber to the diet. Mango is a rich source of vitamin A, and pineapple is one of the lowest caloric fruits and sources of vitamin C. This chapter provides an overview of production, consumption, physicochemical, nutritional, and processing aspects of three major commercial tropical fruits: banana, mango, and pineapple.

BANANA

Historical Brief

Bananas (*Musa* sp.; from Arabic for "finger") originated from Southeast Asia, but Portuguese and Spanish explorers brought bananas to the New World. International trading of bananas started as a result of developments in railroads and refrigerated maritime transport toward the end of the nineteenth century. The early processed banana products exported to the United States were dried bananas, and came from Brazil, Honduras, and Mexico (Von Loesecke 1949). There are now several fresh banana varieties and novel processed banana products found in mainstream international markets coming from other Latin American countries, as well as the Asian and African regions.

World Production and Consumption

Production

About 20% of bananas are exported from the developing to the developed countries, an example of unidirectional, south–north trade. The world production of bananas in 2008 was 90,705,922 and 34,343,343 metric tons (Mt) for table and cooking bananas, respectively, grown over total areas of 4,817,551 and 5,390,731 hectares (ha), respectively (Table 32.1). Table bananas are produced primarily in Asia (56.8%), Latin America (28%), and Africa (13.4%), with the remainder spread to countries of Oceania and Europe. On the other hand, plantain (cooking banana) production is concentrated in Africa (71.3%), followed by Latin America (25.4%), and Asia (3.4%).

The average over a 5-year period ending in 2008, indicate India as accounting for a quarter of total world banana production, followed by China, the Philippines, Brazil, and Ecuador, each contributing between 6% and 9% of worldwide production. On the other hand, plantain production is led by Uganda accounting for 27% of worldwide production, with Colombia, Nigeria, Rwanda, and Ghana adding between 8% and 9% each. However, only 1% of total plantain production enters the export market, in contrast to 19% for table bananas (FAOSTAT 2010).

Consumption

Bananas are perhaps the most consumed fruit in the world. One reason is that it is relatively inexpensive, and it is also easily digestible by the very young and old alike. Bananas are not grown in the United States, yet it is the number 1 fresh fruit consumed in the United States, with average annual per capita consumption over 4.5 kg. The countries of Sao Tome and Principe in Africa hold the distinction of having the highest average (2003–2007) annual per capita table banana consumption of 151 kg. Another African country, Uganda, had a similar average consumption, but for plantains which often serve as a staple food in Africa. Highest per capita consumption for Europe is in Sweden, at 16 kg. The European Union considers banana a fair-trade commodity from certified Pacific, Asian, and African countries.

Growth and Cultural Practices

Cultivation

The banana plant thrives in tropical climates (temperatures around 26.70°C, annual rainfall of 2007–2489 mm, and moist soil with good drainage) as drainage problems may lead to its root mat floating, causing among other things, susceptibility to toppling over. Minimal hurricane winds can uproot plants bearing heavy fruit bunches, and bring damage to an entire plantation. Bananas are generally grown within 30° North and South latitude. Growth ceases when temperatures drop below 13°C, causing chilling injury to the banana fruit.

Bananas are herbaceous giant perennial plants grown from corms, rhizomes, or suckers. They can normally be found in the field as a cluster of plants (stool) with the most mature one known as the leader, surrounded by a couple of growing suckers (Fig. 32.1). However, under plantation conditions, only one or two daughter suckers accompany the mother plant. Modified leaves compactly cluster around each other as the plant height increases, each of which ultimately unfurls to the familiar banana "leaves." At the center of these modified

Table 32.1. Leading Countries and World Aggregate in Banana and Plantain Production (2004–2008)

		Production (MT)		Area Harvested (ha)	
Commodity	Country	Average	2008	Average	2008
Banana	India	20,607,940	23,204,800	611,420	646,900
	Philippines	6,979,147	8,687,624	427,285	438,593
	China	7,214,780	8,042,702	296,696	311,106
	Brazil	6,891,660	7,116,808	503,162	513,656
	Ecuador	6,216,242	6,701,146	213,977	215,521
	Indonesia	5,257,019	5,741,352	286,235	105,797
	Tanzania	3,000,788	3,500,000	415,628	480,000
	Mexico	2,186,233	2,159,280	76,833	78,471
	Thailand	2,060,000	2,000,000	157,800	153,000
	Costa Rica	2,098,557	1,881,783	42,865	44,313
	Others	21,221,396	21,670,427	1,776,560	1,830,194
	World	*83,733,762*	*90,705,922*	*4,808,461*	*4,817,551*
Plantain	Uganda	9,277,400	9,371,000	1,676,000	1,680,000
	Colombia	3,174,920	3,379,742	394,319	414,129
	Ghana	2,786,572	2,930,000	294,838	302,000
	Rwanda	2,643,234	2,750,000	370,186	380,000
	Nigeria	2,703,000	2,727,000	456,000	462,000
	Peru	1,761,677	1,834,511	144,348	147,817
	Côte d'Ivoire	1,539,171	1,555,454	387,709	385,000
	Cameroon	1,374,112	1,400,000	253,094	255,000
	Congo	1,200,795	1,206,690	267,419	268,587
	Myanmar	627,420	630,000	60,605	60,000
	Others	6,882,982	6,558,946	1,074,447	1,036,198
	World	*33,971,282*	*34,343,343*	*5,378,965*	*5,390,731*

Source: FAOSTAT (2010).

leaves will emerge a modified growing point in the shape of a "heart" that houses the plant's inflorescence. The inflorescence is covered by a flap structure arranged in layers. Floral cluster in-between two flaps consisting of a row of 15–30 individual flowers will ultimately develop into a "hand" of banana bunch, with each "finger" of the "hand" representing the individual flowers. As each "hand" increases in size, it forces the flap to open up wider. The next lower flap will follow the same series of steps. When a banana bunch is fully grown, it will be composed of 7–10 "hands" spiraling around the fruit axis. The leader will eventually die off and the next mature sucker will take its place.

Sword suckers with a pseudostem diameter of 0.15 m still attached to a healthy mother plant is recommended as planting material. The amount of planting material needed is dependent on several factors, but for a Cavendish variety with a target production of 45,000 MT a year, a population of 1730 production unit per hectare will have to be maintained. Establishment of a banana plantation takes into consideration optimum exposure of the plants to sunlight, as well as ease of movement to facilitate field operations. An example of a field layout could be two rows of bananas spaced at approximately 2 m and between each two rows is a tractor or passageway of approximately 4 m. At each row, sword suckers are spaced at approximately 2 m. The depth of the planting holes should be enough to accommodate the entire root ball of the plant. If diseased spots are observed on the planting material, the observed section can be trimmed and the banana sucker dipped in 54°C hot water for 20 minutes. Nutrient requirement to supplement native soil fertility is determined through leaf and soil samplings. The lifespan of a single banana plant could range from 1 year to $1^1/_2$ years. The banana plant reaches maximum height when banana inflorescence appears. As soon as the fruits are formed, the bunch is wrapped with a perforated polyethylene sleeve to protect it from pest and diseases (Fig. 32.1). Prior to bagging, a fixed number of hands are determined and the excess removed. Remnants of the male flowers at the tip of the individual fingers are removed to reduce inoculum level that the fruit bunch may have harbored. A ribbon tied at the bottom of the polyethylene sleeve serves as a guide for harvesting (which can be 10–15 weeks after). When the desired number of weeks has passed, the plantation is scouted for the right ribbon code. The mother plant is cut in an inverted V shape, facilitating the dropping of the bunch with the least possibility of damage. If diseases and pest are not a major concern, the debris can be left to decompose, otherwise, appropriate sanitary practices need to be implemented.

Figure 32.1. A group of banana plants (stool) [I] showing corm (A), rhizome (B), suckers (C), and tightly packed unopened leaves comprising the pseudostem (D); [II] a banana plantation; [III] wrapped banana fruits for pest, disease and physical handling damage protection; [IV] a bunch of banana fruits (E), banana inflorescence (F); and [V] banana "hands" and "fingers."

Tissue-cultured plantlets are now used to start new plantations. Micropropagated banana plants provide pest and disease free propagation materials for starting new plantings, but require more investment, including a nursery.

Varieties

Bananas are members of the genus *Musa* (family Musaceae) and include dessert bananas (fresh eating quality, soft and sweet: *Musa acuminata*) and plantains (starchy, less sweet, cooking or processing bananas: *Musa balbisiana*). Among important banana cultivars for fresh consumption are "Dwarf" and "Giant" Cavendish, and Gros Michel. The subgroup of "Giant" Cavendish, "*Grand Nain*" (has thick skin and can withstand bruising) is the most common cultivar imported into the United States where consumers prefer bananas with unblemished skins. Subtropical Baby Bananas ("*Lady Finger*," "*Oritos*," "*Manzanos,*" *or* "*Apple*") have thin skin with a yellow–pinkish cast and are very sweet. Other sweeter and thin-skinned cultivars ("*Senorita*," "*Lacatan*," *and* "*Sucrier*") are small and easily brown.

Pests and Diseases

A number of insect pests and diseases treat bananas as its host. These include aphids, ants, thrips, weevils, black leaf streak, Panama disease, fruit rots, nematodes, and bunchy top, among others. Their impact on bananas can range from physical deformities that affect the photosynthetic efficiency of the plant, and when in sufficient number, death. Insects and nematodes can serve as vectors of diseases, as well. Control measures include any of the following: (a) use of buffers surrounding banana plantations where nonbanana and any other alternative hosts of suspected pests and diseases are removed; (b) baiting with condemned banana materials such as portions of the pseudostem to bait weevils; (c) use of clean planting materials such as those derived from tissue cultured bananas; (d) regular scouting to monitor breach of pest and disease threshold population to warrant chemical control; and (e) outright fallow for 6 months or more to reduce pest and disease inoculum pressure.

Harvest, Postharvest Practices, and Storage

Banana is a climacteric fruit and can be harvested before it is ripe. However, after harvest, there will be a climacteric rise in the base level of the ethylene leading to rapid ripening. To delay the ripening process, bananas can be placed in low-temperature storage or placed in containers lined with ethylene scrubbers. Increase in size as well as accumulation of starch accompanies the maturity process. Palmer (1971)

discussed in detail respiratory and compositional changes during ripening of banana. The increase in size stops when the fruits reach total physiological maturity. Bananas are harvested from the plants when light green in color and about 75% mature. Entire bunches (Fig. 32.1) are cut by hand from pseudostems. For local consumption, the "hands" are left on the stalks and sold to vendors who cut hands/fingers according to customer specifications. In large-scale operations, the banana bunches are carried to a nearby tramline or cableway for transport to the packinghouse. Banana bunches hanging on tramways are pulled by tractors to minimize handling and bruising of the fruits. Bananas should be protected from light after harvesting to delay softening and onset of ripening. Bananas for export are treated by floating in water or dilute sodium hypochlorite solution to remove latex, which causes black peel staining. "Hands" are cut into units of 4–10 fingers, graded for both length and width, and carefully placed in polylined 18 kg boxes for export.

Fruits are shipped when they are green, and ripened by exposure to ethylene (∼1000 ppm for ∼24 hours) in sealed "banana ripening rooms." Storage temperature should not be lower than 13°C, since bananas are susceptible to chilling injury. Gibberellins, reduced temperatures, and modified atmospheres have all been reported to delay the onset of banana ripening (Kapoor and Turner 1976; Taylor 2001). A 7-point color index scale describes the various stages in the ripening of banana: 1 = all green; 2 = with trace of yellow; 3 = more green than yellow; 4 = more yellow than green; 5 = green tips and necks; 6 = all yellow; and 7 = yellow with brown flecks (Nakasone and Paull 1998). A computer vision system using Hunter color L*, a*, b* bands and brown area percentage has been used to predict the seven ripening stages of banana (Mendoza and Aguilera 2004).

Physicochemical, Nutritional, and Phytonutrient Quality

The edible portion of banana contains about 5% starch and 12% sugars. It is one of the few low-acid fruits, with pH of about 5.0. Ripened banana has a pleasant flavor and creamy yellow color.

Nutritional Content

Table 32.2 provides the nutritional composition of banana fruit and processed banana products. One fresh banana supplies about 15% vitamin C, 20% vitamin B_6, 11% potassium, and 16% dietary fiber to help meet the Recommended Daily Intakes (RDI). Bananas contain a relatively higher starch content and digestible carbohydrates than any other fruit. The nutritional composition of bananas differ with varieties. For instance, the Hawaiian Dwarf Brazilian (HDB, *Musa* sp. AAB) bananas, a sugar banana which is genetically more like plantains (*Musa* sp. AAB), was reported to have almost three times the vitamin C (12.7 mg/100 g fresh weight) of Williams (Cavendish type, *Musa* sp. AAA) variety (4.5 mg/100 g). HDB's β-carotene (96.9 mg) and α-carotene (104.9 mg/100 g) contents were also higher compared to William's average of 55.7 mg/100 g β-carotene and 84.0 mg α-carotene/100 g, respectively. Vitamin A content of HDB bananas averaged 12.4 mg RAE/100 g (ranging from 7.7 to 17.1 mg RAE/100 g), while that of Williams ranged from 6.1

Table 32.2. Composition of Banana Fruit and Banana Products

Nutrients (per 100 g)	Fruit[a] (*Musa acuminata Colla*)	Powder[b]	Puree[c]	Chips[d]	IQF[e]
Calories (kcal)	74.9	346	95	147	
Total fat (g)	0.33	1.81	0.80	9.5	
Sodium (mg)	1.0	3.00	8.30	2.0	
Potassium (mg)	358.0	1491	298.0	152	
Total carbohydrate (g)	22.84	88.28	21.3	16.5	
Total dietary fiber (g)	2.6	9.9	2.00	2.2	
Total sugar (g)	12.23	47.30	18.60	10.0	
Calcium (mg)	5.0	22	4.40	1%	
Iron (mg)	0.26	1.15	0.32	2%	
Vitamin C (mg)	8.7	7.0	5.66	3%	
Vitamin A (IU)	64	248	93.0	0%	
Vitamin A (mcg RAE)	3			–	
Protein (g)	1.09	3.89	0.65	0.7	

[a,b]USDA National Nutrient Database: http://www.nal.usda.gov/fnic/foodcomp/search/.
[c]Aseptic Banana Puree, iTi tropicals: http://www.bananapuree.com/specs2.php.
[d]Data of typical commercial product, 1 serving (10 oz, 28.3 g); based on 2000 cal diet.
[e]Data of commercial product: Individually Quick Frozen (IQF). Courtesy of Graceland Fruits Inc., Frankfort, MI, USA.

to 9.3 mg RAE/100 g. The differences in vitamin A values are likely due to variability in maturity of bananas (Wall 2006).

Phenolic Compounds and Antioxidant Capacity

A strong water-soluble antioxidant, dopamine, was identified in the commercial banana *Musa cavendishii*. The peel and pulp of ripened banana was shown to contain 80–560 mg and 2.5–10 mg dopamine per 100 g, respectively (Kanazawa and Sakakibara 2000). However, dopamine, through its condensation product salsolinol, is implicated in the appearance of black spots in overripe bananas (Palmer 1971; Riggin et al. 1976). Table 32.3 shows the antioxidant capacity and total phenolic content of banana fruit. The carotenoid lutein content in ripe bananas was found to be higher than the provitamin A pigments α and β carotenes. Lutein has antioxidant activity, which has been associated with a decreased risk of macular degeneration. Average lutein concentrations were 154.9 and 108.3 mg/100 g for Dwarf Brazilian and Williams fruit, respectively (Wall 2006). As banana is consumed extensively, it is an excellent contributor of natural antioxidants to our diet.

Banana Processing

"Cooking" bananas (ex. plantains, *Saba* variety) have a higher starch content, therefore preferred for processing over the "dessert" or table bananas. They are also less susceptible to enzymatic browning due to polyphenol oxidase (PPO), and to discoloration as a result of the reaction between metal ions and the vascular bundles ("peel rag") loosely attached to the banana skin (Occeña-Po 2006).

Banana Puree

Banana puree, the highest volume processed banana product (Sole 2005), is available either as canned or frozen puree (Fig. 32.2), and can be incorporated in the preparation of many industrial and retail products. Figure 32.2 summarizes the processing steps involved in the manufacture of aseptic banana puree and banana essence. Both cold and evaporator-recovered essence can be added back to the banana puree to enhance flavor profile. Banana puree is mixed with other fruit purees to provide various fruit flavor characteristics, for example, in baby food formulations.

An acidification (use of ascorbic acid or citric acid) step is often followed in making banana puree to prevent browning. Johnson and Harter (1981) used an extrusion process to produce banana puree: heating up to 121°C and cooling to 2–3°C, filling, and blast freezing (−20°C). Other researchers (Palou et al. 1999; Premakumar and Khurdiya 2002) investigated the use of high hydrostatic pressure, microwave (3 minutes) and water bath (212°F; 8 minutes) blanching of bananas to retard enzymatic browning. Banana puree can also be prepared without freezing or sterilization, using citric acid to lower the pH to 4.1–4.2, and potassium sorbate (200–250 ppm) as a preservative (Downing 1996).

Banana ketchup is a popular condiment and substitute for tomato catsup in the Philippines. It is prepared from fresh banana pulp or puree mixed with vinegar, salt, sugar, onion powder, and spices. The product is exported to the United States and United Kingdom, and mostly sold in Asian stores or markets.

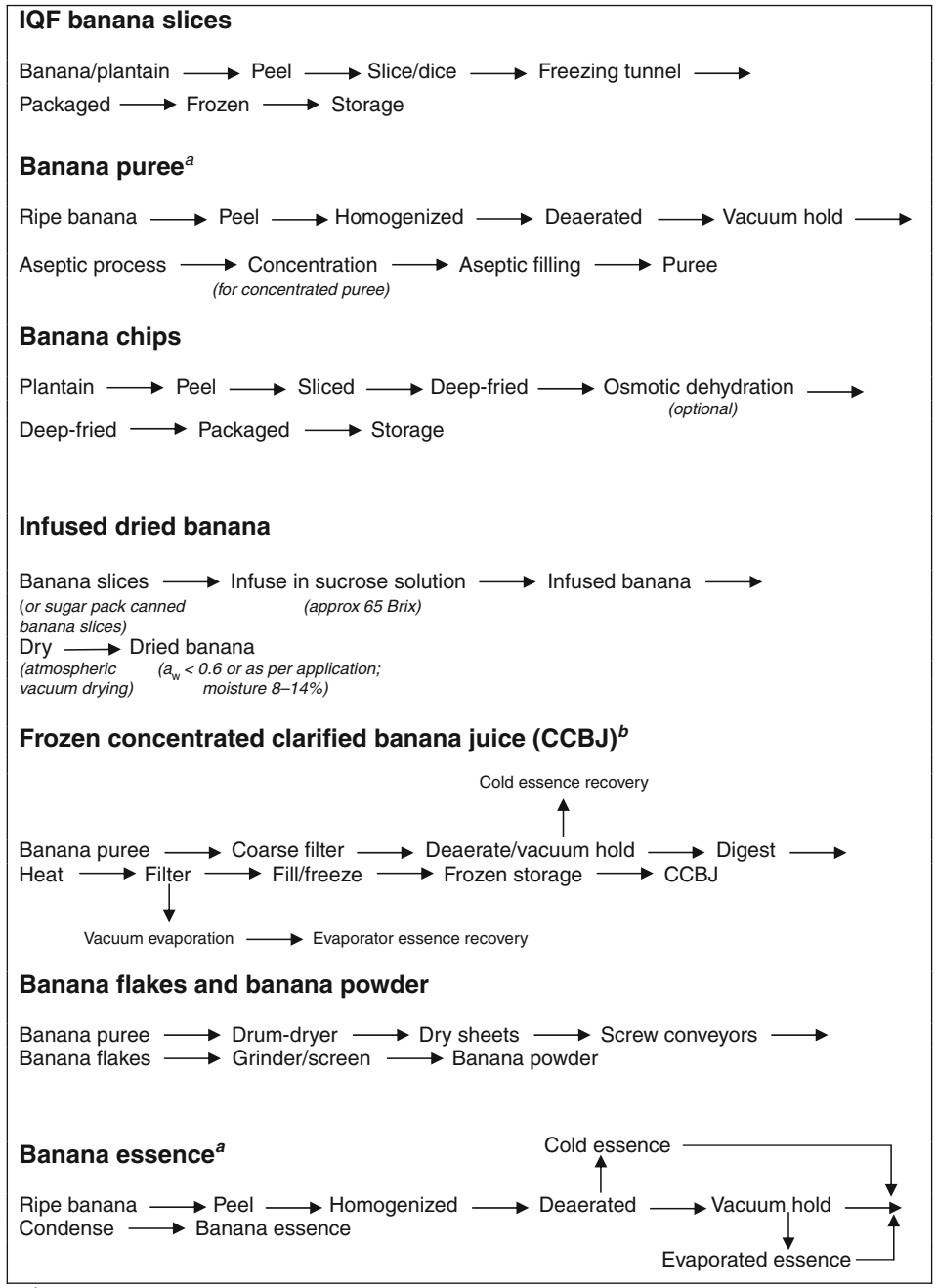
Banana Chips

In the Philippines, green or unripe *Saba* variety (*Musa spientum var. Saba*) of cooking banana is the starting raw material for banana chips. Figure 32.2 summarizes the main processing steps for chips. Properly selected unripe but mature, green bananas are trimmed and sliced to the required shapes and sizes (wholes, quarters, slivers or long cut, fine brokens, or a combination of brokens and quarters). Chips are sweetened by dipping in sugar syrup solution or in honey. Banana chip flavors include sweetened, unsweetened, honey dipped, or toasted. Following osmotic dehydration (soaking in sugar solution), banana pieces are deep fried (∼375°F for 1 minute) in coconut oil, sometimes with added banana flavor. Resulting banana chips can be air-dried at room temperature (∼27°C), or cabinet dried (∼60°C) to allow for moisture equilibration. The cooled chips are packed in air tight, high-density polyethylene bags. For natural banana chips, the osmotic dehydration step is skipped. Light-colored banana chips for export in bulk are repacked in moisture-resistant laminated

Table 32.3. Total Phenolics and Antioxidant Capacity of Banana, Mango, and Pineapple

Fruit	Moisture (%)	TP[a] (mg GAE/g)	TAC[b] (μM TE/g)	Serving Size (g)	TAC/Serving (μM TE)
Banana	73.5	2.31 ± 0.60	8.79	118.0	1037
Mango	81.7	2.66	10.02	165.0	1653
Pineapple	86.8	1.74 ± 0.52	7.93	155.0	1229

Source: Wu et al. (2004).
[a]TP, total phenolics determined as gallic acid equivalent (GAE).
[b]TAC, total antioxidant capacity (lipophilic and hydrophilic oxygen radical absorbance capacity) as Trolox Equivalent (TE).



[a,b]US Patent 4,874,617.

Figure 32.2. Flow diagram for processing of banana products. (Adapted from Lima and Lima 1970; Johnson and Harter 1981; Sole 1987.)

plastic pouches (Sole 2005). Banana chips can be eaten as a snack food, used as a confectionery or incorporated in muesli or trail mixes and ready-to-eat breakfast cereals.

To improve the quality and color of banana chips, various studies have looked at: (a) browning inhibitors, microwave, sulfiting agents, water- or steam-blanching prior to deep-fat frying, and freeze drying (Krokida et al. 2000; Krokida et al. 2001; Waliszewski et al. 2000; Woodroof 1975); (b) combination of air and vacuum-microwave drying (Mui et al. 2002); and (c) effects of packaging during storage on the color of banana chips (Ammawath et al. 2002). Thuwapanichayanan et al. (2008) produced crisp banana chips using a combination of foaming of banana puree, and drying temperature of 80°C at superficial air velocity of 0.5 m/s. An initial foam mat

(5 mm thick) with density of 0.5 g/cm^3 is dried to a moisture content of 0.03 kg/kg (db). The porous cells or cavities filled with air and a structural phase or cell walls that are formed by a brittle matrix, results to a dry crisp product. Besides egg albumin, foaming agents include modified soybean protein and soy protein isolate.

Banana Powder

The foam mat drying method was also utilized by Sankat and Castaigne (2004) to produce banana powder. Fresh banana puree (density = 0.93 g/mL) was foamed (density = 0.50 g/mL) with the addition of soy protein (10 g/100 g) as a foam inducer. After 12 minutes of whipping, the resulting banana foam mats were dried in a forced air, cross-flow cabinet dryer (45–90°C) to a dehydrated, hard, porous and brittle solid which can be ground to banana powder. Drying time was directly related to the thickness of the foam mats, while increasing the air temperature reduced the drying time.

Other Processed Banana Products

Table 32.4 provides a descriptive listing of commercially available processed banana products, including product specifications, shelf life, packaging, and applications.

MANGO

Historical Brief

Cultivated mango (*Mangifera indica* L.) originated in southeastern Asia, but Portuguese and Spanish traders brought this fruit to East Africa and Western Mexico. Mangoes were introduced in Brazil and the West Indies during the 1700s, and were brought to England during the colonization of India, and to Florida during the 1800s.

Production

The export market has been led by India (Table 32.5), and the mango cultivars: "*Haden*," "*Tommy Atkins,*" "*Keitt*," "*Kent*," "*Palmer*," and "*Irwin*." With the exception of Mexico, Brazil, and Nigeria, world production of mangoes in 2008 was dominated by Asian countries. However, the United States imports most of its mangoes from Mexico. A total of approximately 34,343,083 Mt of mangoes were produced in 2008, up 9% over the average production of the previous 5 years. Around 4,690,120 ha of land were dedicated to world production of mangoes in 2008. However, these figures may not actually account for all mangoes produced, especially those grown in family backyards and in small farms. Further, the production figures reflected in the Food and Agriculture Organization statistics database (FAOSTAT 2010) combines mango with data on mangosteen and guava productions.

Consumption

Fresh mangoes used to be found only in ethnic stores in the United States and Europe, but are now readily available in the produce section of mainstream supermarkets. Imported mangoes are mostly processed into puree and juice. The 2008 US annual per capita consumption of mango was 379 g. The popularity of cooking shows on the US television featuring ethnic dishes and fusion cuisines has led to inclusion of mango in home preparations in the form of *salsas,* fruit sauces, smoothies, and desserts.

Growth and Cultural Practices

Cultivation

Mangoes grow best in seasonally wet/dry climates of the lowland tropics or frost-free subtropical areas characteristic of the leading mango-producing countries. Mangoes have a taproot system, which is able to penetrate deep into the soil. The site for mango cultivation therefore should include areas with a deep soil profile without obstruction for vertical root growth. Mangoes can grow in many soil types provided they are adequately drained and mildly acidic, although they are grown on limestone gravel in Florida. Although commercial growers maintain mango trees in cultivated orchards, it is not uncommon to find them in backyards of family homes. The world's heaviest mango weighing at 3.5 Kg (0.30 m length and 0.50 m diameter) according to the Guinness Book of World Records is Keitt variety mango grown by a couple in the Philippines. Prior record holder of the heaviest mango title was also a Keitt mango from Hawaii.

The planting distance for mango plantation is dependent on the cultivar chosen for production. The diameter of the plant canopy at maturity will have an impact on the planting distance between seedlings. More mango trees can be planted over the ultimate target population. However, the extra trees need to be removed at the appropriate time to prevent overcrowding and negative impact on yield. For example, with a planting distance of 11–12 m apart, initial planting may call for planting at 5–6 m. Nurse crops planted in between mango seedlings help protect the growing mangoes from too much sunlight, as well as protect the ground from erosion, and perhaps even supply part of its nutritional requirement when leguminous crops are used. Low branches that develop need to be eliminated so as not to be susceptible to splashing during heavy rain and possible transfer by soil-borne inoculum to the foliages of the mango tree. Any pruning to limit the number of branches or removal of possible disease portions have to be done when the tree is not producing new vegetative part (flushing). Irrigation strategy for growing mango trees if rainfall is not adequate involves watering every second week during the first year, and decreasing the intensity to every 3 weeks on the second year. Presence of a 2-month window before flower emergence of a dry period is conducive to

Table 32.4. Commercially Processed Banana Products

Product	Characteristics	Packing	Shelf Life	Applications
Sliced and whole peeled[a,b]	Ripened, peeled and frozen; used when piece identity is essential	33 lb carton	Frozen (0°F)	Used like fresh bananas; Beverages; Dairy products; Bakery products
Sliced[a]	• Packed in high fructose corn syrup—color stable, sweetened • Packed in light syrup; processed in acidified light sugar syrup	Resealable package No. 10 cans	Shelf-stable No refrigeration required until opened	Bakery products; Dairy products; Food service and institutional products; Used when fresh banana appearance/identity is desired
Puree[c,d,e] Acidified Puree[c,d,e]	Brix: 21°–25°; 22–26°[e] TSS: 23–28%[e] pH: 4.6–5.2[e] Acidity: 0.35–0.7% (as citric acid)[e] Viscosity: 3–9 cm/sec at 68°F pH: 4.2–4.5[e] (citric/ascorbic acid)	58 lb aseptic metallized bag-in-box; 506 lb aseptic metallized bag-in-drum; 2.034 lb aseptic metallized bag-in-bin; 275 gal tote; 6 gal bag-in-box; and 1 L tetra pack[e]	12 months (59–86°F) in sealed containers Room temperature –74°F	Baby food; Fruit preparations; Beverages; Dairy products; Bakery products; Frozen desserts and soft food diets; Catsup; Sauce
Concentrated juice[f]	Brix: 72° $\pm$ 1°; pH: 4.0–4.3; TA: 0.95–1.45%	300 kg drums; 25 kg plastic pails	Frozen (0°F)	Ingredient
IQF[b]	3/8″	33 lb carton	Frozen (0°F)	Fruit preparations; Frozen desserts; Bakery products
Flakes[c]	Moisture $\leq$2.5%	40 lb bag-in-box; 44.1 lb bag-in-box; Heat-sealed polyethylene bag	18 months (69.8°F)	Dry fruit preparations; Substitute for fresh mashed bananas (1:3 reconstitution); Fruit preparations; Beverages; Bakery products; Dairy products; Cereals[d]
Powder[c, g]	Moisture $\leq$3.0%	30.5 lb bag-in-box	18 months (69.8°F)	Dry fruit preparations; Beverages; Bakery products; Substitute for fresh mashed bananas (1:3 reconstitution); Fruit preparations; Dairy products; Baby food

(*continued*)

Table 32.4. Commercially Processed Banana Products (*Continued*)

Product	Characteristics	Packing	Shelf Life	Applications
Chips[h]		Wholes (1625 cartons × 15 lbs net); Premium (1625 cartons × 14 lbs net); Long cut/slivers (2.5 kg × 2 bags); Quarters (2.5 kg × 2 bags); Brokens (1625 cartons × 18 lbs net); Brokens/quarters (1625 cartons × 17 lbs net)		Muesli; Trail mixes; Breakfast cereals
Diced dried pieces[a]	$a_w \leq 0.55$; Varied sizes and shapes		Shelf-stable	Cereals; Bakery products; Dairy products; Snacks
Puree extract[a]	Natural banana aroma and bouquet of ripe bananas; Heat stable; Alcohol based		Shelf-stable	Beverages; Dairy products; Bakery products
Essence[c]	Dosage—1% by weight and adjust up or down as desired	20.8 lbs plastic jugs; 45 lbs per carton; 484 lbs plastic drum; 507 lbs	12 months (44.6°F) absence of air and light	Applications in water-based system to impart banana flavor ex. Refrigerated beverages; Dairy products; Combination with puree to enhance aroma of product
Tostones[a]	Ripened, sliced, fried in soybean oil, cooled		Frozen	Breakfast (mashed and egg scrambles); Appetizers; Lunch; Dessert

[a]Chiquita Banana Products, http://www.chiquitabrands.com/.
[b]iTi Tropicals http://www.itropicals.com/ProductList.pdf; IQF also available in organic form.
[c]Trobana® Banana Products, Confoco www.confoco.com/confoco/ingles/productos.htm.
[d]Also available as nonacidified form.
[e]iTi Tropicals http://www.bananapuree.com/specs2.php.
[f]Florida Products Adapted from Sole (2005).
[g]Also available in organic form.
[h]http://www.bgfruits.com/.

Table 32.5. Leading Countries and World Aggregate in Mango Production[a] (2004–2008)

	Production (MT)		Area Harvested (ha)	
	Average	2008	Average	2008
India	12,601,600	13,649,400	2,035,840	2,138,500
China	3,975,106	3,976,716	436,515	452,663
Indonesia	1,660,858	2,013,123	261,374	185,196
Mexico	1,812,957	1,855,359	183,024	177,308
Thailand	1,780,000	1,800,000	282,000	285,000
Pakistan	1,591,343	1,753,686	149,883	166,223
Brazil	1,142,674	1,272,180	72,872	75,911
Philippines	963,367	884,011	176,448	186,770
Bangladesh	614,918	802,750	108,300	84,500
Nigeria	732,100	734,000	125,900	126,500
Others	5,433,790.80	5,601,858.00	748,775.60	811,549.00
World	32,308,714	34,343,083	4,580,932	4,690,120

Source: FAOSTAT (2010).
[a]Data as presented by FAOSTAT includes mangosteen and guava.

flowering. Presence of adequate moisture is important to ensure good yield from fertilized, nonaborted flowers.

Nutrient fertilization for growing mango seedlings can be administered twice at the beginning of the wet season, and immediately before the onset of the dry season. Fertilizers can be applied at approximately 0.20–0.45 m from the plant during the first 3 years, but later at 1–2 m distance. A detailed guide on fertilization, as well as other aspects of mango production can be found in Litz (2009).

Varieties

Mangoes are large fleshy drupe fruits in which the hard stone (endocarp) containing a single seed is covered with an edible juicy pulp. There are two classes of mango: (a) the "Indian" cultivars (ex. *Alphonso, Malda, Totapuri, Kent, Tommy Atkins*), described as rounded and plump, having a bright red blush to the skin; and (b) the "Indochinese" cultivars (ex. *Carabao, Cambodian, Kaewsaard*) characterized by kidney-shaped, elongated and flattened fruit with light green or yellow skin. The Indian cultivars are monoembryonic, so they are mostly grafted on seedling rootstocks and bear fruit much ahead than seedling trees do, which is the case for polyembryonic Indochinese mangoes (Rieger 2005b). Knight (1997) provided a review of the important mango cultivars in the world.

Pest and Diseases

Typical diseases plaguing mangoes and the infected part include Anthracnose (leaves and fruits), *Colletotrichum gloeosporioides* (flowers, fruits), Stem-end rot (fruits), Sooty mold (leaves and fruits), Powdery mildew (*Oidium mangiferae*; flowers, leaves, young fruit), and Tip burn (leaves; associated with potassium deficiency, water stress). On the other hand, insect pests include Mediterranean fruit fly (*Ceratitis capitata*), Oriental fruit fly (*Bactrocera dorsalis*), Mango weevil (*Cryptorhynchus mangiferae*), Scales, including *Ceroplastes rubens* and *Pseudaulacaspis cockerelli*, Red-banded thrips (*Selenothrips rubrocinctus*), Mango blossom midge (*Dasineura mangiferae*), Southern green stink bug (*Nezara viridula*), Mango shoot caterpillar (*Penicellaria jocosatrix*), Black twig borer (*Xylosandrus compactus*), and mites.

Harvest, Postharvest Practices, and Storage

Mango is a climacteric fruit, which is best harvested in a mature but unripe stage, about $2^1/_2$–$4^1/_2$ months from blooming, and usually transported in the firm, green preclimacteric stage. The fruits are essentially handpicked and pickers use poles to reach fruits high up in the tree, although it is not uncommon for big orchards to use ladders and hydraulic lifts. Following harvesting, mangoes are dipped in hot water (50–53°C; 15 minutes) as a postharvest control of destructive pest mango anthracnose, as well to remove the latex sap that causes darkening.

Ripening of mango depends on variety, maturity at harvest, storage temperature, and humidity. During ripening, about 1-week storage at 20–24°C (relative humidity of about 85–90%) enables development of the mango flavor. Ethylene is often used to effect ripening and produce a uniform yellow color. The shelf life of mango would vary depending on the initial quality of the fruit and storage temperatures (2–3 weeks storage life at 5–10°C is not uncommon). However, mangoes are susceptible to chilling injury when stored at

temperatures near freezing, developing discoloration of skins, or brown/dark spots of the pulp.

Physicochemical, Nutritional, and Phytonutrient Quality

Physicochemical

Chemical composition of ripe mangoes varies with the cultivar: moisture content ranges from 72% to 86%; soluble solids from 14° to 23°Brix; pH 3.8 to 5.6 and acidity (as citric acid) from 0.11% to 0.48%. Major organic acids include citric, tartaric, oxalic, malic, and glycolic. Ripe mangoes have a relatively higher sucrose content (7.36%) compared to reducing sugars (3–10%), with total sugars ranging from 9% to 21% (Hulme 1971; Nanjundaswamy 1997).

The major flavor volatiles found in mango are monoterpene hydrocarbons. In canned mango puree, the volatiles identified included butyrolactone, gamma-octalactone, furfural and 5-methyl furfural methoxy furanone (Hunter et al. 1974). A commercial water-soluble mango flavor, Treattarome 9830®, is a distillate derived from ripe mango that contains high levels of fruity esters, lactones, spicy terpenes, and sugary/caramel-like furanones.

Nutritional Content

Nutritive value of mangoes varies with cultivar, cultural and climatic conditions, ripeness, postharvest storage, and processing. Table 32.6 shows that mangoes have a relatively high content of vitamin A. The characteristic color of the mango skin and edible flesh is mostly due to the presence of carotenoids. Mango fruits contain both provitamin A carotenoids (α-carotene, β-carotene, and γ-carotene) and oxygenated carotenoids (xanthophylls, β-cryptoxanthin, lutein, zeaxanthin, violaxanthin, antheraxanthin, auroxanthin, and neoxanthin) (John et al. 1970; Cano and de Ancos 1994). α-carotene is the major carotenoid in unripe and fully ripe mangoes.

Godoy and Rodriguez-Amaya (1989) reported that changes in the carotenoid composition of processed mangoes are closely related to the mango cultivar. Except for the increase in luteoxanthin, the carotenoid composition was maintained during processing of mango (Tommy Atkins) slices. However, in Golden mango cultivars processed as puree, a considerable loss of α-carotene (84%) occurred after 24 months of storage. According to Cano and de Ancos (1994), the predominant carotenoids and carotenol fatty acid esters in extracts from fresh, frozen, and canned mango fruit slices were composed of xanthophylls, carotenol mono (fatty acid esters), hydrocarbon carotenoids, and carotenol bidfatty acid esters. Changes in individual carotenoids occurred during the processing of mango slices and puree (Godoy and Rodriguez-Amaya 1987). In commercially processed mango juice, β-carotene was the major carotenoid, with the conversion of violaxanthin, which is present in fresh mango, to auroxanthin, which is absent in mango fruit (Mercadante and Rodriguez-Amaya 1998). Chavasit et al. (2002) reported little loss of carotenoid pigment during freezing of mango slices, although there was some decline with storage. Mango leather is a promising source of vitamin A, with provitamin A content of 600–650 retinol equivalents. The loss of β-carotene during processing of candied mango was 17–18%, which increased to 30–40% during storage (Chavasit et al. 2002).

Mango contains vitamin C. Ascorbic acid retention in mangoes frozen by liquid nitrogen was 90% compared to 72% by

Table 32.6. Nutritional Composition of Mango Fruit and Mango Products

Nutrients (per 100 g)	Fruit[a]	Pulp[b]	Infused-Dried Fruit[c]	Slices[d]	Nectar[e]
Calories (kcal)	65.0	74	331	70	51
Total fat (g)	0.27	0.60	0.78	0	0.06
Sodium (mg)	2.0		24	15	5
Potassium (mg)	156.0		182	–	24
Total carbohydrate (g)	17.0	16.90	83.1	19	13.12
Total fiber (g)	1.8	0.30	6.1	<1	0.3
Total sugar (g)	14.80		75.6	17	12.45
Protein (g)	0.51	0.60	0.67	0	0.11
Calcium (mg)	10.0	16.00	28.0	0	17
Iron (mg)	0.13	1.60	0.83	0	0.36
Vitamin C (mg)	27.7	20.00	262.0	100%	15.2
Vitamin A (IU)	765.0		1554	15%	692
Vitamin A (RAE)	38	2.743 mg			35

[a,e] http://www.ars.usda.gov/ba/bhnrc/ndl.
[b] http://www.fao.org/inpho/content/compend/text/Ch20sec2_8.htm#.
[c] Data of commercial product: Infused with sugar prior to drying, contains added ascorbic acid and high oleic sunflower oil. Courtesy of Graceland Fruits Inc., Frankfort, MI, USA.
[d] http://www.delmonte.com/Products/FruitItem.asp?id=46; SunFresh® Mango (serving size = $^1/_2$ cup = 124 g).

slow tray freezing (Pruthi 1999). In mango, vitamin B complex content is relatively low, except for niacin (Wu et al. 1993).

Phenolic Content

Phenolic content (31–75 mg tannic acid equivalent/100 g flesh) of ripe mango is influenced by variety and size (Hulme 1971; Narain et al. 1998). Table 32.3 provides the total phenolic content and total antioxidant capacity of mango fruit.

Heat treatment and storage at 5°C resulted in inhibited carotenoid development and moisture loss, while antioxidant capacity was largely unaffected. Carotenoid concentration (32 mg/L) was positively correlated with carotenoid antioxidant capacity (17 Trolox equivalents (TE) μM/mL R2 = 0.72). Fortification with vitamin C acted to prevent carotenoid concentration losses between 20% and 30%, while fortification with vitamin E preserved carotenoid antioxidant capacity during 45 days storage (Moore 2003). However, the concentrations of xanthophylls, violaxanthin, and antheraxanthin were compromised either by heat treatment or cold temperature storage.

The presence of phenolic compounds in mango puree concentrate, particularly flavonol glycosides, may have partly originated from the peel since mango puree is prepared both from peeled and from unpeeled fruits (Schieber et al. 2000). The latex deposited in fruit ducts and removed with the fruit during harvest has been shown to be a source of monoterpenes (Saby et al. 1999).

Mango Processing

Fully ripened mangoes are preferred for industrial processing because the flavor, color, and texture are well developed. However, with the popularity of ethnic foods and food products, there is a niche market for beverages, sauces, relishes, marinades and tenderizer, chutneys and pickled mango products, which utilize immature or green mangoes as starting raw material. Some mango cultivars that are too fibrous or soft for fresh consumption are utilized for juice making. This section describes major processed mango products.

Mango Puree

Mango puree is processed either canned or frozen. Canning mango puree is perceived as better than freezing or chemically preserving it, but freezing slows down chemical changes during low-temperature storage. Freezing of mango puree needs a previous enzymatic heat inactivation to avoid the development of undesirable changes in flavor and color of the final product. Various mango cultivars that differ in their sensory attributes can be blended into mango puree using either whole or peeled mangoes. A minimum-soluble solids of 13°Brix and pH value of 3.4 to 4.0 are required for fruit selection. To prevent discoloration, 0.1% ascorbic acid is used as an antioxidant. Mangoes are subjected to a "steaming" tunnel, cooled, peeled, and passed through a combined pulper/destoner unit. The resulting puree is homogenized, sterilized, placed in an aseptic buffer tank, cold sterilized, filled into bags-in-drums, and undergo a quick freezing process (Pruthi 1999). Mango pulp can also be frozen using air-blast freezers or plate freezers (–37°C to –40°C) and stored at –18°C to –20°C, ready for consumption or for export. Frozen mango puree undergoes vacuum-packing to remove air (Wu et al. 2005). The physicochemical and microbiological characteristics of the final mango pulp consists of the following: (a) a minimum (min.) of 16% total soluble solids; (b) min. of 0.5% acidity (% citric acid); (c) pH < 4.00; (d) °Brix/acid ratio of 32; (e) min. 200 ppm ascorbic acid; (f) total plate count and yeast count each of less than 50 Colony Forming Units (CFU)/g; and (g) a mold count less than 10 CFU/g (de la Cruz-Medina and Garcia 2002a).

Mango Concentrate

Mango concentrate results from the thermal treatment of the pulp to remove at least 50% of the initial water content. The concentrate is stable without the addition of chemicals as long as it is kept frozen. It serves as base for further industrial processing and formulations as mango juice, nectars, and ice cream and drink mixes. Enzymatic liquefaction has been employed to improve the quality of higher °Brix concentrates (Wu et al. 2005).

Mango Juice, Nectar, and Squash

Figure 32.3 outlines the processing steps for mango juice production. Studies have been conducted showing the use of enzymes to facilitate juice extraction, cloud stabilization and viscosity, and to increase the free flow and yield extraction of juice (Occeña-Po 2006). Mango juice can be aseptically packaged in a bag-in-box and stored at ambient temperature, although storage at low temperature results in better preservation (Wu et al. 2005).

Mango nectar results from the blending of the juice with a certain amount of solids from the pulp containing the same amount of °Brix as the original fruit. Nectars are prepared by diluting fruit pulp to 30°Brix (de la Cruz-Medina and Garcia 2002a). Mango juice can be further processed into mango nectar by any of the following methods: (a) "spin-cooker"; (b) flash pasteurization; or (c) pasteurization and aseptic packing in plastic-lined cartons (Wu et al. 1993; Wu et al. 2005). When a preservative (350 ppm SO_2 or 0.1% sodium benzoate) is added, the product is referred to as mango squash.

Mango Slices and/or Scoops

Figure 32.3 summarizes the process for canning mango slices/scoops. Varieties most suited for canning include Creole, Mora, Philippine Carabao, Irwin, and Haden (de la

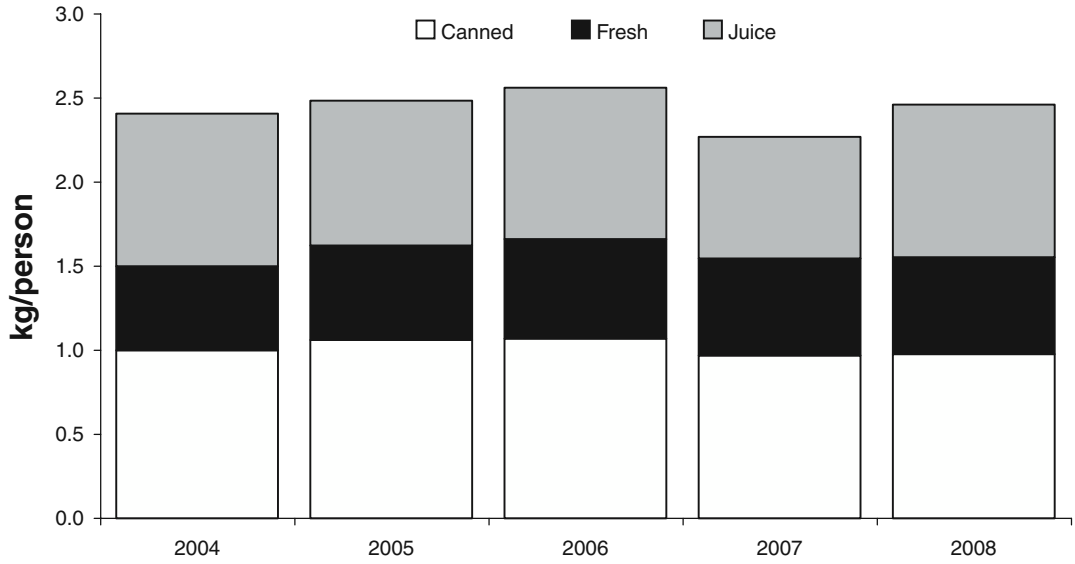


Figure 32.3. US per capita consumption of pineapple juice, canned and fresh pineapples (2004–2008).

Cruz-Medina and Garcia 2002a). Conventional canning of mango slices in syrup results in a commercial product with a dark orange appearance different from that of the fresh fruit. Other canned mango styles include halves, diced, and pieces, depending on the size of cut. Packing medium can consist of water, with or without sweetening ingredient, or natural reconstituted, concentrated fruit juice or juices, or fruit puree or nectar, with or without a sweetening agent, and may contain pectin, calcium-based firming agents, and β-carotene. The Codex Alimentarius provides international quality standards for canned mangoes (de la Cruz-Medina and Garcia 2002a).

Mango slices can also be frozen packed in polythene, in bulk or institutional packaging, and stored at –18°C for 12–18 months. Calcium pretreatment (2%) helps in maintaining firm texture. The freezing process leads to a product with similar color characteristics and appearance as the fresh mango slices. The advantages of quick freezing by immersion in liquid nitrogen are reduced losses in weight and in textural properties of the mango slices (Pruthi 1999).

Mango Leather, Mango Bar, and Dehydrated Mango

The industrial preparation of mango leather (*Aam Papad*) is summarized in Figure 32.3. Potassium metabisulfite is added to homogenized mango pulp at a rate of 2 g/kg of pulp. After drying of one layer, another layer is spread over it and dried and the process repeated until the desired thickness is attained. The leather slabs are cut into pieces and wrapped in butter paper or plastic sheets (de la Cruz-Medina and Garcia 2002a). Highly acceptable mango bars have been prepared using 25°Brix pulp with 0.5% sodium alginate and drying at 140°F (Singh et al. 2004). Drying rate for mango leather was reported to have been lowered by the addition of soy protein concentrate (Gujral and Khanna 2002). According to de la Cruz-Medina and Garcia (2002a), the best drying of mango strips involves pretreatment by dipping mango slices (1:1) for 18 hours in a 40°Brix sugar solution with 3000 ppm SO_2, 0.2% ascorbic acid, and 1% citric acid, followed by drying using an electric cabinet dryer (60°C).

Sulfiting is a common practice in developing countries to retain the yellow–orange color of dehydrated mango products, but has been under critical consideration with respect to allergen labeling of foods. The process for preparing infused-dried mango fruit (Fig. 32.3) retains the natural color without the need for sulfites (Sinha 1998).

Mango Powder

Figure 32.3 summarizes the steps involved in processing mango powder. Green mango slices seasoned with turmeric are dried and powdered (*amchoor*) to impart acidity to vegetables, soups, and curries, or as a marinade for barbecued meats in Indian cuisine. Drum drying of mango puree has been utilized for producing dried mango flakes and powder, but undesirable cooked flavors and aromas in the dehydrated product can result due to the severity of heat. Drum-dried products are also extremely hygroscopic (de la Cruz-Medina and Garcia 2002a). Jaya and Das (2004) vacuum-dried mango pulp and used maltodextrin (MD) to eliminate the stickiness of the mango powder and get a less hygroscopic powder; Glycerol monostearate (GMS) and tricalcium phosphate (TCP) were used as foam stabilizer and anticaking agents, respectively. Evaluation of mango powder properties (i.e., hygroscopicity, degree of caking, dispersibility, flowability, etc.) demonstrated an optimum feed mix composition of 0.43–0.57 kg

MD per kg of mango solid, and an optimum requirement for TCP and GMS of 0.015 kg/kg of mango solid.

Fresh-Cut and Minimally Processed Mangoes

Fresh-cut mangoes could be preserved by treating the slices with a combination of hexylresorcinol, isoascorbic acid, and potassium sorbate to address browning issues. Storage in plastic containers prevents drying. Treating whole fruits with methyl jasmonate prevented the development of chilling injury during cold storage and had no effect on ripening, softening processes, or water loss (de la Cruz-Medina and Garcia 2002a).

A modified atmosphere packaging (MAP) system for fresh-cut mango dices using a gas mixture treatment (4% O_2, 10% CO_2, and 86% N_2) achieved the longest shelf life compared to other treatments including vacuum packing. Microbial growth, texture, and color were also significantly ($P < 0.005$) different between the gas and other treatments. Sensory analysis showed slight difference between the fresh and MAP mango (Martinez-Ferrer et al. 2004).

Other Mango Products

Table 32.7 summarizes the characteristics and applications of various commercial mango products. Other industrial processing possibilities for mangoes include fruit sauces, mango wine, glazings, and ice-cream mixes.

According to Larrauri et al. (1996), major wastes of mango processing amount to 35–60% of the total fruit weight.

Table 32.7. Commercially Processed Mango Products

Product	Characteristics	Packaging	Shelf Life	Applications
Slices[a]	Peeled; Sectioned; Ready-to-eat	Resealable 24 oz glass mason jar; 64 oz glass	Refrigeration	Snacks; Dessert
IQF dices[b]	3/8″; 5/8″; 3/4″; 1″	33 lb carton	Storage below 0°F	Fruit preparations; Bakery Products; Frozen desserts
Aseptic puree[b]	Brix: 14°–19°;	55 gal drums;	Shelf-stable	Fruit preparations; Beverages;
Aseptic puree[b]	Brix: 14°–16°;	6 gallon carton	Shelf-stable	Dairy products; Bakery
(Organic)	Brix: 15°–17°	55 gal drums;	Storage below 0°F	products; Frozen desserts
Frozen puree[b]		6 gallon carton 430 lb drum		
Aseptic concentrate[b]	Brix: 28° min	55 gal drums; 6 gallon carton	Shelf-stable	Beverages; Dairy Products
Frozen concentrate[b]	Brix: 28° min	463 lb drum	Storage below 0°F	
Clarified concentrate[b]	Brix: 70°	55 gal drums	Storage below 0°F	
Flakes[c]	Moisture ≤3.0%	22.1 lb bag-in-box; 24.5 lb per box; Polyethylene bag	18 months (70°F)	Dry fruit preparations; Substitute for fresh mango puree (6:1 reconstitution); beverages; Bakery products; frozen desserts, and Soft Food Diets
Powder[c]	Moisture ≤3.0%	39.6 lb bag-in-box 41.8 lb Polyethylene bag	18 months (70°F)	Dry fruit preparations; Beverages; Bakery Products; Substitute for mango puree (6:1 reconstitution); Fruit Preparations; Dairy products; Soft Food Diets; Frozen Desserts
Infused-dried diced[d]	Moisture 12% ± 3%;	25 lbs	Store in a cool (preferably 40–50°F), dry location. Shelf life: 1 yr	Cereals; Trail Mixes; Bakery Products; Snacks
	Oil <1%	10 lbs		
Essence[b]		40 lb pail		Applications in water-based system to impart mango flavor

[a]Del Monte http://www.delmonte.com/Products/FruitItem.asp?id=46.
[b]iTi Tropicals http://www.ititropicals.com/ProductList.pdf.
[c]Trobana® Products, Confoco http://www.confoco.com/confoco/ingles/mango.htm.
[d]GracelandFruit http://www.gracelandfruit.com/dried_fruit.php.

Peels originating from mango fruit processing are a promising source of phenolic compounds that might be recovered and used as natural antioxidants or functional food ingredients. Flavonol O- and xanthone C-glycosides were extracted from mango (*Mangifera indica* L. cv. "Tommy Atkins") peels. Seven quercetin O-glycosides, one kaempferol O-glycoside, and four xanthone C-glycosides were found. Mangiferin and isomangiferin and their respective galloyl derivatives were identified. A flavonol hexoside with m/z 477 identified as a rhamnetin glycoside has also been reported in mango peels.

Mango seed kernel fat is a promising source of edible oil whose fatty acid and triglyceride profile is similar to that of cocoa butter; it may also be used as a source of natural antioxidants characterized as phenolic compounds (gallic and ellagic acids, and gallates) and phospholipids. Gallotannins and condensed tannin-related polyphenols were also reported in mango kernels. Mango peels were also reported to be a source of dietary fiber containing high amounts of extractable polyphenolics with high *in vitro* antioxidant activity (Larrauri et al. 1996). The recovery of good quality mango peel pectin with a 75% degree of esterification has recently been developed.

PINEAPPLE

Historical Brief

It is believed that the pineapple originated in southern Brazil and Paraguay, and was spread by the Indians to other parts of South and Central America. The pineapple was brought to Europe by Columbus in 1493, and distributed to the Pacific Islands, India, the Philippines, and Africa by the Spanish and Portuguese explorers.

Hawaii used to produce most of the world's pineapples with the establishment of the first commercial plantation on Oahu in 1885. The pineapple was first canned in Malaysia and canned fruits were exported from Singapore around 1900 (Rieger 2005c).

World Production and Supply

Production

Table 32.8 summarizes the top ten leading pineapple producers over the last 5 years (2004–2008). World production in 2008 was 19,166,560 Mt over 848,140 ha, about 76% of which was contributed by the top ten producers. Pineapple production in Thailand is composed of thousands of small farms. In contrast, pineapple production and marketing in countries including the Philippines, Costa Rica, Honduras, and Ecuador have been exclusively by multinational corporations on large plantation systems with mechanized operations. A report on the market for organic and fair-trade mangoes and pineapple indicated that major suppliers to the American and European markets come from Latin America (Costa Rica) and Africa (Ghana) (Pay 2009).

Table 32.8. Leading Countries and World Aggregate in Pineapple Production (2004–2008)

	Production (MT)		Area Harvested (ha)	
	Average	2008	Average	2008
Brazil	2,447,488	2,491,974	64,365	62,142
Thailand	2,416,656	2,278,566	95,180	93,116
Philippines	1,921,548	2,209,336	51,899	58,251
Costa Rica	1,616,021	1,624,568	28,732	33,488
China	1,344,355	1,402,060	64,937	70,613
India	1,296,000	1,305,800	83,360	81,900
Indonesia	1,314,680	1,272,761	16,504	20,802
Nigeria	894,800	900,000	116,900	117,500
Mexico	642,316	685,805	15,615	16,377
Viet Nam	458,980	470,000	35,840	36,200
Others	4,478,149	4,525,690	248,735	257,751
World	18,830,993	19,166,560	822,067	848,140

Source: FAO (2010).

The top three suppliers of fresh and frozen pineapple to the United States are Costa Rica, Honduras, and Ecuador, while the Philippines is the largest supplier of processed canned pineapple products and juice. The US consumption of processed pineapple products in the form of juice and canned pineapple products exceeds that of fresh pineapples. Demand for most canned fruit products have been declining as consumers have shown increased preference for fresh and other processed-fruit products like juice and dried products (Fig. 32.3).

Growth and Cultural Practices

Cultivation

Pineapples can take up to 18–20 months to fruit. They grow best in climates with high rainfall and in well-drained sandy loams with pH 4.5–6.5, and temperatures of 24–32°C. These conditions are characteristic of the major pineapple producing countries of Latin America, Africa, and Asia (Table 32.8).

Land preparation prior to planting involves plowing to a depth of 0.6 m and subsoiling when necessary to break hard pans. Preplant application of fertilizers follows disking of soil clumps, as well as application of nematicides if nematodes are a problem. Planting materials used are primarily crowns from previous cropping and if supply is short, slips and suckers may be used as well. The amount of planting materials required for a hectare is between 59,000 and 74,000. Annual water requirements of pineapple can be upward to 60 cm. Postplanting nutrient application can be through boom sprayers mounted on trucks. A niche market

in Southeast Asia, specifically in South Korea, caters to organically grown pineapples. Contrary to heavy application of commercial fertilizers in conventionally grown pineapples, organic pineapples are grown using vermi-compost as the main source of fertilizer input (M. Porras 2010, personal communication).

Varieties

The pineapple fruit is a multiple fruit covered with a waxy, leathery rind made up of hexagonal "eyes" arranged spirally, denoting the position of individual flowers. The predominant cultivar is "*Smooth Cayenne*," chosen for worldwide dissemination and trading for its desirable characteristics. Table 32.9 summarizes the characteristics of pineapple cultivars suited for canning. The Del Monte Gold® Extra Sweet (MD-2 variety), reportedly the world's sweetest pineapple, claims to be twice as sweet as the regular cultivars. However, this is best consumed as fresh pineapple but not ideal for processing because it fails to achieve the desired Brix/acid ratio for canning. MD-2 hybrid pineapple cultivars cultivated under organically certified production practices and sold under the fair-trade certified label, are now available to meet the emerging market for organically grown fruits for environmental and health conscious consumers, as well as to ensure fair-trade pricing for farmers.

Pests and Diseases

Pineapples are subject to a host of pest and diseases that need to be managed to attain optimum yield. Thrips (*Thrips tabaci, Frankliniella occidentalis*), mealybugs (*Dysmicoccus brevipes*), and (*D. neobrevipes*) are insects of concern not only for the physical damage to the fruit but also as disease vectors. Pineapple heart and root rots can be caused by different organisms (*Phytophthora cinnamomi, Phytophthora parasitica, Pythium* spp., *Thielaviopsis paradoxa,* and *Ceratocystis paradoxa* to name a few). The presence of mealybugs and a closterovirus can lead to pineapple wilt. Management of these pests and diseases involves understanding the pests and disease cycle. Though mealybugs are the ones capable of carrying viral agents, the presence of ants attracted by the mealybug secretions complicates the use of natural predators in reducing the target insect population. Therefore, implementing a disease prevention strategy focusing on the elimination of ants makes sense. Additional steps that can be

Table 32.9. Important Commercial Groups and Varieties of Pineapple for Canning

Group	Varieties	Country	Flesh Color	Sugar (Brix)	Acid (%TA)	Descriptor
Cayenne	Smooth Cayenne, Hilo, Kew, Champaka, Sarawak	Thailand, Philippines, Indonesia, Australia	Pale yellow	12–16	0.5–0.9	Most important group; more than 70% of pineapple grown in the world; average wt. 2.5 kg; for fresh fruit consumption and canning
Queen	Moris, Mauritius, MacGregor, Ripley Queen, Alexandra	India, South Africa, Australia, South East Asia	Deep yellow	14–18		Average wt. 0.8–1.5 kg; fresh fruit
Spanish	Singapore Spanish, Ruby, Red Spanish, Masmerah, Gandul, Hybrid 36, Selangor Green, Nangka, Betik	Malaysia	Deep golden yellow	10–12	0.3–0.6	Average wt. 1–2 kg Poorer cannery recovery Fibrous flesh
Pernambuco and Mordilona	Perolera	Brazil, Ecuador, Peru, Colombia	White	Mild flavor	Low acid	Less economic importance, restricted to South America; Perolera has high vitamin C content and used in hybridization programs for improving Smooth Cayenne cultivars

Source: Shukor et al. (1998).

taken to protect pineapples are the use of chemical dips for crowns used prior to planting.

Harvest, Postharvest Practices, and Storage

Pineapple is categorized as a nonclimacteric fruit, that is, there is no significant increase in the amount of ethylene production as well as CO_2 production at ripening. Maximizing therefore the amount of time the fruit stays attached with the mother plant ensures the fruit attain optimum quality demanded by the market. The most common method of determining maturity of the pineapple fruit is by the change in color from green to yellow, the flat eyes, and the large, well-formed crown. However, a minimum of 12°Brix measured by a refractometer signals harvest maturity. Pineapples for canning are allowed to reach a more advanced stage (about $^1/_2$–$^3/_4$ yellow) prior to harvest. Application of a plant growth regulator ethephon forces synchronization of pineapple ripening through its metabolization to ethylene by the plant eliminating multiple pickings.

Harvesting is carried out mechanically in plantations, with two conveyors, one on top of the other, breaking off the pineapples and carrying the fruits to the lower conveyor where they are de-crowned (Fig. 32.4). Fresh pineapples are washed and waxed prior to packing in boxes. Fruits for export are almost completely green when harvested for transoceanic shipment. Pineapples that are too ripe and yellow are hand-harvested for the domestic market. Pineapples can be stored for up to 4 weeks at recommended storage between 7°C and 12°C, at 90–95% RH (Paul and Chen 2003).

Physicochemical, Nutritional, and Phytonutrient Quality

Physicochemical Quality

Ripe mature pineapple flesh on the average contains about 85% moisture, 0.70% citric acid, and 14°Brix, with a pH of 3.4. It also contains 6.47–7% sucrose, 1.7% glucose, and 2.15% fructose. Other organic acids present include malic, oxalic, and phosphoric acid. Camara et al. (2005) reported a citric acid/L-malic acid ratio close to 2 as an index of authenticity of pineapple products. MD-2 hybrid pineapple cultivar grown organically has been found to demonstrate a higher Brix (as high as 17°Brix), making it ideal

Figure 32.4. Images showing different aspects of pineapple production: (**A**) pineapple crown; (**B**) fields being planted with pineapple crowns placed on the sideline; (**C**) a pineapple plantation with nonfruiting plants; (**D**) harvest and decrowning; (**E**) fully grown pineapple ready for harvest; and (**F**) harvested pineapples loaded into trucks headed to processing center.

for fresh consumption, but not for processing as it does not meet ideal Brix/acid ratio (J. Maglasang 2010, personal communication).

Data on the constituents of fresh pineapple juice include the following: TSS (11.2–16.2 g/100 g); acidity (reported as citric acid, 0.46–1.21 g/100 mL); fructose (1.72–4.75 g/100 mL); glucose (1.21–4.52 g/100 mL); sucrose (2.45–9.73 g/100 mL); citric acid (0.439–1.151 g/100 mL); malic acid (0.073–0.391 g/100 mL); and isocitric acid (80–265 mg/L), K (830–1410 mg/L). These values can be utilized in the detection of adulterated pineapple juice.

Nutritional Content

Table 32.10 summarizes the nutritional composition of fresh pineapple fruit and some processed pineapple products. Pineapple is a significant source of potassium, magnesium, and vitamin C, and also contains substantial vitamin A. Organically grown MD-2 pineapple cultivar demonstrated a higher sugar, magnesium, and iron content per serving size compared to the conventionally grown MD-2 (G. Lianda 2010, personal communication).

The major constituents of carotenoids of fresh pineapples have been found to be violaxanthins (50%), luteoxanthins (13%), β-carotene (9%), and neoxanthins (8%). Less abundant carotenoids included zeta-carotene, hydroxy α-carotene, cryptoxanthins, lutein, auroxanthins, and neochrome

A powder produced from pineapple fruit shell contained a high, total dietary fiber content (70.6%) similar to dietary fibers from apple and citrus fruits, with the insoluble dietary fiber fraction about 99%. Xylose (36% of total sugar) and glucose (43% of total sugar) were the major neutral sugars in the soluble and insoluble dietary fibers, respectively. Total uronic acids and Klason lignin contents were 5.1% and 11.2%, respectively.

Phenolic Content and Antioxidant Compounds

Phenolics in pineapple have been identified as *p*-coumaric acid and ferulic acid, about 32–73 and 20–76 μg/g fresh weight, respectively (Dull 1971). The alkaloid 6-hydroxy-1-methyl-1,2,3,4-tetrahydro-*â*-carboline was reported by Herraiz and Galisteo (2003) in pineapple (0.62 μg/g ± 1.02) and its juice (1.69 μg/g ± 1.40). Wu et al. (2004) reported total phenolics and total antioxidant capacity of 1.74 mg Gallic Acid Equivalents (GAE)/g and 7.93 μM TE/g, respectively (Table 32.3). Huang et al. (2004) reported total phenolic content in pineapple core to be 74.42 ± 3.31 μg of GAE/g fresh weight, and antioxidant activity of 73.05 ± 3.95 μM of ascorbic acid/g fresh weight. Pineapple fiber showed a higher Antioxidant activity (AA) (86.7%) than orange peel fiber (34.6%), with myricetin identified as the major polyphenol. Montero-Caldero et al. (2010) found that vitamin C content and total antioxidant capacity were lower in fresh-cut pineapple packed in high oxygen modified atmosphere than in low oxygen modified atmosphere pack and air-packages.

The phenolic composition of pineapple juice (mg/100 mL single-strength juice, normalized to 12.8°Brix) analyzed by HPLC showed nine major peaks: (a) tyrosine, 3.6(1.4); (b) serotonin, 1.8(0.8); (c) dimethylhydroxylfuranone, 1.4(0.7); (d) dimethylhydroxylfuranone β-glucoside, 6.2(3.0); (e) tryptophan, 2.2(0.9); (f) S-sinapyl-L-cysteine, 1.1(0.6); (g) *N*-g-L-glutamyl-S-sinapyl-L-cysteine, 2.3(1.1); (h) S-sinapyl glutathione, 5.4(1.4); and (i) *p*-coumaric acid-like phenolic compound (calculated as *p*-coumaric acid), 0.5(0.4). According to Wen and Wrolstad (2002), these components could be useful for the evaluation of the authenticity and quality of pineapple juice.

Flavor Components in Pineapple

The characteristic pineapple flavor is due to two thioesters, methyl 3-(methylthio) propanoate and ethyl 3-(methylthio) propanoate (Brat et al. 2004). Elss et al. (2005) also reported methyl 2-methylbutanoate, methyl butanoate, methyl hexanoate, ethyl hexanoate, 2,5-dimethyl-4-methoxy-3(2H)-furanone(mesifurane), and 2,5-dimethyl-4-hydroxy-3(2H)-furanone (furaneol) as major constituents.

The main contributors to pineapple aroma for the Super Sweet cultivar (F-2000) were reported to be 4-hydroxy-2,5 dimethyl-3(2H)-furanone, ethyl 2-methylpropanoate, ethyl 2-methylbutanoate, with odor activity values above 1000. The largest contributors to Gold cultivar pineapple aroma were methyl 2-methylbutanoate, mesifurane (2,5 dimethyl-4-methyoxy-3(2H)-furanone), and ethyl 2-methylbutanoate.

Analysis of juices made from fresh-cut fruit revealed the prevalence of esters, with methyl 2-methylbutanoate, methyl 3-(methylthio)-propanoate, methyl butanoate, methyl hexanoate, ethyl hexanoate, and ethyl 3-(methylthio)-propanoate, as well as 2,5-dimethyl-4-methoxy-3(2H)-furanone (mesifurane) and 2,5-dimethyl-4-hydroxy-3(2H)-furanone (furaneol) as major constituents. In most cases, the characteristic methyl esters and hydroxy or acetoxy esters were lacking completely or appeared only in minor amounts in these products. Methyl butanoate, methyl 2-methylbutanoate, and methyl hexanoate were the most abundant volatiles in modified atmosphere packed fresh-cut pineapples. Most odor-active volatiles were methyl and ethyl 2-methylbutanoate, 2,5-dimethyl-4-methoxy-3(2H)-furanone, and ethyl hexanoate. Methyl 2-methylbutanoate, ethyl 2-methylbutanoate, 2,5-dimethyl-4-methoxy-3(2H)-furanone, and ethyl hexanoate were the most active volatiles in pineapple aroma throughout storage and could be used as quality indicators of fresh-cut pineapple throughout storage (Calderon et al. 2010).

The following compounds have been identified as components of pineapple essence: acetoxyacetone, dimethyl malonate, tetrahydro-α,α,trimethyl-5-vinyl furfuryl alcohol, methyl *cis*-(4)-octenoate, γ-butyrolactone, methyl

Table 32.10. Nutritional Value of Raw Pineapple and Some Pineapple Products

Nutrients (per 100 g)	Raw[a] (All Var.)	Raw[b] Extra Sweet	Raw[c] Super Sweet	Raw[d] Super Sweet (Organic)	Juice,[e] Canned with Ascorbic Acid	Juice,[f] Frozen Concentrate	Pineapple Canned Juice Pack,[g] Solids and Liquids	Pineapple Frozen, Chunks,[h] Sweetened	Infused-Dried[i] Pineapple
Calories (kcal)	48.0	51	62.83	61.97	56.0	179	60.0	86	341
Total carbohydrate (g)	12.63	13.50	14.82%	14.72%	13.78	44.30	15.70	22.20	85.4
Total sugar (g)	9.26	10.32	1.57	3.21	13.58	43.60	14.45	21.10	66.1
Total fiber (g)	1.4	1.4	–	–	0.20	0.7	0.80	1.1	5.1
Protein (g)	0.54	0.53	0.55	0.39	0.32	1.30	0.42	0.40	0.39
Total fat (g)	0.12	0.11	0.15	0.17	0.08	0.10	0.08	0.10	1.31
Vitamin C (mg)	36.2	56.4	–	–	24.0	42.0	9.5	8.0	350.0
Vitamin A (IU)	56.0	57.0	–	–	5.0	50	38.0	30	70.0
Vitamin A (mcg RAE)	3	3							
Potassium (mg)	115.0	108	70.8	52.5	134.0	472	122.0	100	228.0
Calcium (mg)	13.0	13	12.3	14.4	17.0	39	14.0	9	16.0
Magnesium (mg)	12.0	12.0	14.6	20.0	12.0	35.0	14.0	10.0	
Sodium (mg)	1.0	1.0	6.9	5.8	1.0	3	1.0	2	32.0
Iron (mg)	0.28	0.28	0.3	0.7	0.26	0.90	0.28	0.40	0.90
Phosphorus		8	5.2	7.0					

[a,b,e,f,g,h]http://www.nal.usda.gov/fnic/foodcomp/search/.

[c]Data of conventionally grown commercial product; Courtesy of Nature's Fresh Pineapple, Inc, Aglayan, Malaybalay City, Bukidnon, Philippines.

[d]Data of ongoing project; Courtesy of Nature's Organic Fresh Pineapple, Inc, Aglayan, Malaybalay City, Bukidnon, Philippines.

[i]Data of commercial products; Infused with sugar prior to drying, contains added ascorbic acid and high oleic sunflower oil; Courtesy of Graceland Fruit, Inc, Frankfort, MI, USA.

β-hydroxybutyrate, methyl and ethyl β-hydroxyhexano-ate, methyl and ethyl β-acetoxyhexanoate, γ-octalactone, and δ-octalactone (Creveling et al. 1968).

Pineapple Processing

Translucency of the pineapple fruit has been utilized as a maturity index and a quality attribute desirable for processing. Semi-translucent slices are considered to have better flavor. Fully translucent pulp has an overripe flavor, while not translucent are too sour. As the pulp becomes more translucent, air cavities decrease in size and in porosity. Porosity should be minimal and the °Brix to acidity ratio should be near 20. Acidity should be kept close to 0.75% (de la Cruz-Medina and Garcia 2002b). For large operations, mechanically harvested pineapples are washed and separated by a roller sorter to two different sizes and packing lines. The pineapples are peeled, cored, and trimmed by a machine with a circular blade that spins at high speed, referred to as "*Ginaca*©." The coreless pineapple cylinder is sent to separate processing lines for canned slices, chunks, and tidbits. The average yield in processing ranges from 45% to 55% (de la Cruz-Medina and Garcia 2002b). For every 100 lbs of pineapple fruit, only about 27% are processed as primary pineapple products: 59% pineapple chunks, slices, and tidbits; and 41% crushed pineapple and/or juice material. About 35% of the fruits are utilized as juice material, 91% of which is made into pineapple juice, and 9% is pomace. About 38% of the pineapple fruits become by-products (32% pomace and 68% mill juice). The following sections describe briefly the processing of major commercial pineapple products. Figure 32.5 summarizes the steps involved in the processing of some other popular pineapple products. Occeña-Po (2006) also provides a descriptive listing of high-sugar pineapple products which are increasingly gaining popularity as food toppings (particularly the low- or sugar-free types) or utilized as fruit sauces.

Selected Canned Pineapple Products

Pineapple Slices The USDA/FDA Standards for grades and identity, quality and container fill weight provide guidelines for canned pineapple products. Pineapple fruits are sized and trimmed mechanically to fit corresponding can sizes. Slicers equipped with single- or multiple-blades cut slice packs out of trimmed pineapple cylinders. Slices or rings of 1/2" are designated for No. $2^1/_2$ cans, and $25''/64''$ slices for No. 2 cans. Pineapple slices are visually graded to meet specifications, and manually or automatically packed in cans. Slices are graded as *fancy* (geometrically perfect, excellent, uniform color, whole), *choice cut* (not as perfect with less color) or *standard*. The cans go to an exhaust or vacuuming chamber, or directly to the syruping step. The syrup concentration depends on the quality of the pineapple product: the Hawaiian No. 1 grade is packed with 24°Brix cutout syrup, and the No. 2 and 3 grades with 20°Brix syrup. Atmospheric closure is used for hot filling (88°C). With a pre-vacuuming syruper, either a mechanical vacuum or steam-flow closure is utilized. Processing is carried out by either a continuous rotary pressure sterilizer (102–104°C) or by an ordinary retort operating at atmospheric pressure (100°C for 12–18 minutes for No. $2^1/_2$ cans). Cans from a rotating cooker go to a rotating cooler (Hepton and Hodgson 2003; Pruthi 1999).

Pineapple Chunks and Tidbits

Pineapple slices may be further cut into tidbits, cubes, and chips, while thicker slices are cut into chunks or pieces. For pineapple tidbits, fresh pineapple is cut in symmetrical segments (1.27 cm × 1.37 cm) or cubes (Woodroof and Luh 1975).

Pineapple Juice

The extraction of juice is often combined with the production of canned fruit packs to utilize any pineapple pieces discarded from other product lines, including slices that have been cut too thick or too thin, and broken pieces. These are all crushed to extract juice. Other solid components utilized for juice consist of: (a) pineapple cores; (b) *eradicator meat* (thin layer of flesh between the shell and fruit cylinder removed using the *Ginaca*); and (c) trimmings. Whole fruits not required for solid packs, or fruits too small for canning are peeled and pressed for juice, or simply crushed and pressed. The juice is homogenized to stabilize the slightly cloudy appearance, and heated to coagulate solids. The thin slurry passes through a continuous centrifuge, removing suspended solids, including fibers and coarse pieces ((Hepton and Hodgson 2003, Woodroof and Luh 1975). Processed "*beverage juice*" (juice from fruit, cores, and skin waste) is distinguished from "*skin juice*" utilized as base for sweeteners. However, the use of other solid pineapple materials for juice production is not allowed in the United States (Shukor et al. 1998; Hepton and Hodgson 2003). It is also not unusual to blend batches of juices to attain proper acidity and sensory qualities; juices from other fruits blended with pineapple juice can result into novel juice mixes (de la Cruz-Medina and Garcia 2002b).

Crushed Pineapple

Crushed pineapple is obtained from finely cut or shredded pieces of pineapple from other processing lines, from small, irregularly shaped slices unsuited for regular canned pineapples, and *eradicator meat*. The crushed pineapple is pumped into steam-jacketed kettles and heated to 77–91°C, automatically packed into cans, sealed, and heat processed for 10 minutes. An alternative processing is to cold-fill, exhaust to 82°C, sealed and processed in boiling water for 30–40 minutes (Pruthi 1999; Woodroof and Luh 1975).

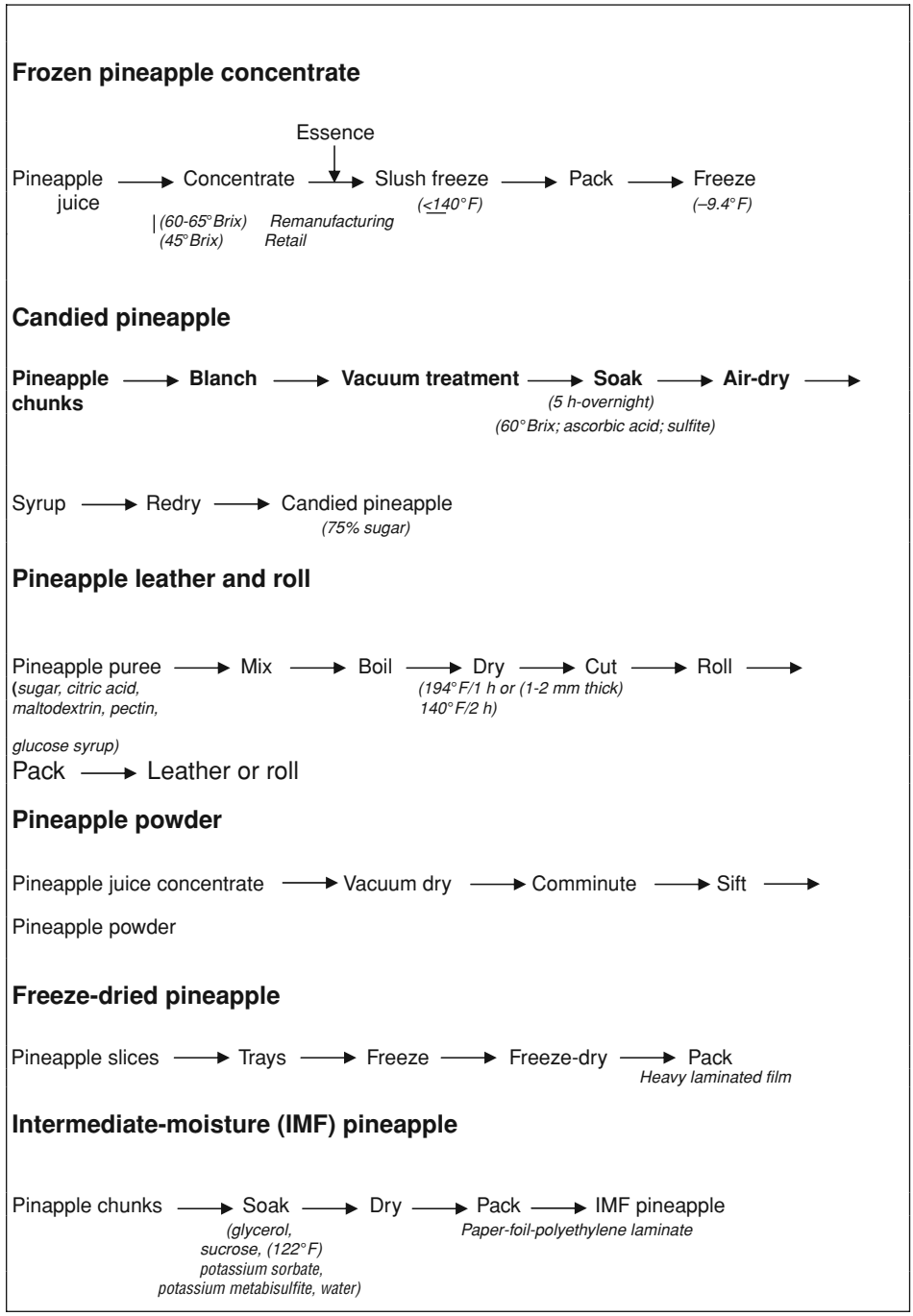


Figure 32.5. Flow diagram for processing of pineapple products. (Adapted from Hodgson and Hodgson 1993; Nagy et al. 1993; Nakasone and Paull 1998.)

Minimally Processed Pineapple

"Fresh-Cut" Pineapples The demand for convenience food products has created a niche for minimally processed pineapple. However, the relatively short-life is a limiting factor. "Fresh-cut" pineapples are packaged as peeled whole, slices, or chunks in sealed plastic tubs or cups, and chilled to optimum temperature levels until purchased by the consumer. The balance between sweetness and acidity is relevant in selecting the pineapple cultivar to use. Fresh-cut processing causes wounding, increases metabolic activities,

and decompartamentalizes enzymes and substrates, causing possible browning and decay of the fresh fruit. Gonzalez-Aguilar et al. (2004) reported that treatment of pineapple slices with anti-browning agents isoascorbic acid (IAA; 0.1 mol/L), ascorbic acid (AA; 0.05 mol/L), or acetyl cysteine (AC; 0.05 mol/L), prolonged the shelf life of fresh-cut pineapples for up to 14 days at 50°F, with no observed off-flavors. Martinez-Ferrer and Harper (2005) reported that the use of methyl jasmonate (MJ) emulsion (10^{-4} M) decreased microbial growth in diced pineapple by 3 logs after 12 days storage at 44.6°F, without affecting firmness or color. Modified atmosphere packaging (MAP) (gas mixture of 4% O_2, 10% CO_2, and 86% N_2) of fresh-cut-diced pineapple previously blanched and dipped in ascorbic acid, was reported to be not significantly different from fresh pineapple in its sensory properties (Martinez-Ferrer et al. 2002). In a study by Montero-Caldero et al. (2010) on various modified atmospheres (LO, low oxygen: 12% O_2, 1% CO_2; AIR: 20.9% O_2; and HO, high oxygen: 38% O_2), the storage life of Gold cultivar fresh-cut pineapple was limited to 14 days at 5°C due to losses of volatile compounds and fermentation processes. The physicochemical attributes (color parameters, SSC, TA, and pH) of the MAP-treated fresh-cut pineapple did not significantly change over time. The vitamin C content and total antioxidant capacity were better preserved under LO and AIR atmospheres. The AIR packaging allowed the preservation of volatile compounds and nonvolatile components and permitted longer withholding of volatile emission and antioxidant attributes. The use of HO reduced juice leakage from pineapple pieces, but favored losses in volatile compound content and antioxidant characteristics, and accelerated acetaldehyde production. High concentrations of CO_2 promoted volatile losses, juice leakage, and anaerobic respiration (Montero-Caldero et al. 2010).

High Pressure Processing (HPP)

High hydrostatic pressure is a novel technology for minimal processing of pineapple products. Bacterial survival and total yeast and fungi counts decreased with increase in processing pressure in fresh-cut pineapple chunks packed in heat-sealed polyethylene pouches and treated under various ultra-high pressure, temperature, and time combinations (Hepton and Hodgson 2003). Water and solute of pressure-pretreated pineapple were reported to demonstrate a significantly higher diffusion rate during osmotic dehydration (Ramaswamy et al. 2005).

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33
Tropical Fruit II: Production, Processing and Quality of Guava, Lychee, and Papaya

Jiwan S. Sidhu

Abstract: Recent research has indicated that consumption of fruits and vegetables protects us not only from constipation but also from a host of age-related diseases. Because of their unique flavor characteristics, tropical fruits and their products are gaining popularity all over the world. Topics related to three of the tropical fruits (guava, lychee, and papaya), such as their physiology and ripening characteristics, chemical composition, nutritive value, postharvest handling, storage and marketing, processing into value-added products, fresh-cut fruits, by-products of processing industry, are discussed in this chapter.

INTRODUCTION

Consumption of fruits and vegetables is reported to reduce risks of many types of cancers (Steinmatz and Potter 1991; Slattery et al. 2004; Kawasaki et al. 2008). A number of studies have suggested the roles of potassium, folic acid,

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and antioxidants present in fruits and vegetables in reducing the incidence and mortality from cardiovascular diseases (Ness and Powles 1997; Tribble 1999; Djousse et al. 2004; Cesari et al. 2004). Increased consumption of fruits and vegetables has been shown to provide protection against age-related diseases such as cataract and macular degeneration (Ames et al. 1993). Certain antioxidants such as vitamins C, E, and β-carotene are suggested to provide these health benefits (Garcia-Alonso et al. 2004; Einbond et al. 2004; Tylavasky et al. 2004). In addition, phytochemicals present in fruits and vegetables are important for good health (Vinson et al. 2001; Hollman 2001). As free-oxygen radicals may be involved in several of these pathological conditions, vitamins, antioxidants, and phytochemicals present in fruits and vegetables may provide protection against the age-related diseases (Knekt et al. 2002; Hertog et al. 1992; Prior and Cao 2000). Our knowledge of benefits of consuming various fruits, especially about availability of vitamins, antioxidants, and phytochemicals present in fruits is still evolving. This chapter discusses production, processing, and quality aspects of three important tropical fruits, namely guava, lychee, and papaya.

SECTION 1: GUAVA

INTRODUCTION

Guava (*Psidium guajava* L.) is an important member of the Myrtaceae family. The genus *Psidium* includes five species, namely *P. guianense*, *P. cattleianum*, *P. chinensis*, *P. friedrichsthalianum*, and *P. guajava*. Most of the cultivated guava belongs to the guajava species. It is reported to have originated in Central America but is now grown throughout tropics and subtropics (Sidgley and Gardner 1989). By virtue of its commercial and nutritional values, guava is considered a common man's fruit and can be rightly termed as the "apple of the tropics."

Guava is of commercial importance in about 58 countries, but the leading countries are India, Brazil, Egypt, South Africa, Colombia, the United States, Puerto Rico, Jamaica, Taiwan, Sudan, Kenya, Israel, the Philippines, Pakistan, Malaysia, Australia, and West Indies (Eipeson and Bhowmik 1992). Guava fruit production from some of the leading producers is shown in Table 33.1. Among the tropical fruits, guava is becoming popular in the United States and consequently, a large quantity of guava products are imported (Table 33.2).

The guava plant can be a shrub or tree, commonly multi-trunked with wide-spreading branches that reach heights of up to 10 m. Plants are propagated mostly from seeds, but for uniform quality and production, guava should be propagated through root cutting, grafting, budding, or layering. Seeds normally take 2–3 weeks to germinate under favorable conditions. When seedlings are 5–7 cm tall, these are transferred into another nursery giving larger spacing and allowed to grow for about a year before planting into orchards. Spacing between plants is about 6–8 m depending on the cultivar. Guava trees start bearing fruits from the fourth year onward. Interestingly, guava tree tends to flower and ripen fruits indiscriminately throughout the year. Guava fruit is a berry, and the fruit consists of a fleshy pericarp and seed cavity.

Table 33.1. Leading Guava-Producing Countries of the World

Country	Production (MT)
India	165,000
Mexico	127,000
Pakistan	105,000
Thailand	100,000
Indonesia	56,000
Malaysia	30,000
Colombia	29,000
Egypt	28,000
Brazil	27,000

Source: FAO (2003).

The fruit takes about 17–20 weeks from fruit set to reach full growth, but the fruit is harvested about 2–3 weeks before attaining full maturity, as it continues to undergo changes associated with ripening (Paull and Goo 1983). The guava tree can be grown with less irrigation water in a wide range of soil types; well-drained light soils are, however, most suited for guava cultivation. Guava being a hardy plant requires less water and is not affected by extremes of hot or cold temperatures, but cannot tolerate frost. The optimum temperature for the growth of guava tree ranges from 23°C to 28°C. The

Table 33.2. The US Guava Imports During 2003

Country	Paste and Puree	Prepared or Preserved	Jams
Brazil	1612	714	340
Colombia	325	274	0
Costa Rica	14	112	271
Dominican Republic	781	1165	33
Ecuador	335	632	0
Fiji	5	0	0
France	26	4	0
India	586	153	0
Malaysia	0	534	0
Mexico	348	761	3
Netherlands	21	0	0
Philippines	25	0	0
South Africa	33	343	0
Thailand	0	121	2
Others	9	10	7

Source: FAO (2003).

guava fruit has higher nutritional value as a source of vitamin C even in the form of many processed products and has, thus, become an important fruit crop in the domestic economies as well as in the international trade of many tropical countries.

In addition to fruit, the guava leaves have been investigated for health benefits. Hsieh et al. (2007) reported the guava leaf extract to exhibit potent antiglycative and anticoagulant properties, thus being of great value in preventing glycation-associated cardiovascular diseases in diabetes. Pretreatment, method of drying, method of extraction, and the leaf maturity have been shown to significantly influence the role of bioactive compounds and the antioxidant power of guava leaf extract (Nantitanon et al. 2010). According to Chen and Yen (2007), guava leaf extracts displayed a significant scavenging ability on the peroxyl radicals. They found a linear relationship between the antioxidant potency, free-radical scavenging ability, and the content of phenolics in the guava leaf extract.

CULTIVARS

Based on the shape of guava fruit, the cultivars are classified in two broad categories, the pyriferum (the pear-shaped guava) and the pomiferum (the round-shaped guava), and these are often called pear guava and apple guava, respectively. The fruits from wild trees range in size from 3 to 8 cm in diameter, but from cultivated trees, the fruits attain a size of up to 13 cm in diameter, and fruit weight of approximately 700 g. Guava fruit has many small hard seeds numbering from 153 to 664 per fruit located in the central core of flesh (Palaniswamy and Shanmugavelu 1974). Seedless varieties have been developed, but the fruit shape and quality is inferior.

Numerous stone cells (scleroids) are present in the fleshy part of the fruit. These stone cells impart a gritty texture to flesh and processed juice. The flavor of guava can be described as sweet, musky, strong, and highly aromatic (Wilson 1980).

Based on the color of flesh of ripe fruit, the guava fruit is classified as pink-fleshed sour type or white-fleshed sweet type. A number of cultivars in both types are being grown commercially for fresh fruit as well as for processing purposes. Pink cultivars such as Beaumont and Ka Hua Kula in Hawaii, the United States, Malberbe and Saxon in South Africa are being cultivated. Pink guava is shown to be a richer source of lycopene, ascorbic acid, provitamin A, sulfur aroma compounds, and anthocyanins (Kong and Ismail 2010; Clery and Hammond 2008). Among the white cultivars, Paipa in Taiwan; Elisabeth in West Indies; Safeda (most popular), Chittidar, Karela, Lucknow, Sind, Dholka, Nasik, and Habshi in India are preferably grown for processing. Some of the other cultivars recommended for cultivation in Florida, the United States, are Miami Red, Miami White, Supreme, Red Indian, and Ruby (Malo and Campbell 1968).

PHYSIOLOGY AND RIPENING

Guava fruit usually takes about 110–150 days from the onset of flowering to reach maturity and longer time for maturity is required during rainy season than in winter. Guava is a climacteric fruit and exhibits a typical increase in respiration and ethylene production during the ripening period (Brown and Wills 1983). The peaks for ethylene production occur at the half-ripe stage (usually the fourth day of harvest) and coincide with the peak for rise in respiration rates (Broughton and Leong 1979). Treatment of guava fruits with ethylene gas or immersing in 1000 ppm ethephon has been shown to improve fruit ripening with uniform color, desirable flavor, firmness, and sensory quality (Mahajan et al. 2008). For extending the shelf life of guava fruit, treatment with 1-methylcyclopropene (300 ppm) proved to be the most effective and maintained acceptable quality for 4 weeks (Mahajan and Singh 2008). Chlorophyll fluorescence has been used as a nondestructive technique for studying the fruit ripening (quality attributes, such as skin color and fruit firmness) during postharvest storage of guava (Bron et al. 2005). Depending on the cultivar, guava fruits exhibit a change in skin color from green to yellow during ripening. The color becomes yellow due to the loss of chlorophyll. However, some cultivars stay green on maturation. On the other hand, flesh of the mature fruit changes color from white to creamy white, yellowish pink, deep pink, or salmon red depending on the presence of carotenoids, lycopene, and β-carotene (Wilson 1980; Wilberg and Rodriguez-Amaya 1995a, 1995b). During different phases of guava maturation, ascorbic acid decreases while pectin methylesterase (PME) specific activity increases with maturation (Carvalho et al. 2009). PME purified from the Brazilian guava, Paluma cultivars, has been shown to be a thermostable (up to 85°C) enzyme (Leite et al. 2006). The presence of residual PME activity in all steps of commercial processing of guava is important as the PME can adversely change the quality of the pulp during storage (Leite et al. 2009).

A number of physicochemical changes take place during the development of guava fruit. The fruit weight and volume increases moderately up to the first 50 days after flowering, but rapidly up to 100 days, and very slowly later on until maturity (Yusof and Mohamed 1987). Sugar content of guava increases during ripening. Among the sugars, fructose increases rapidly, but the glucose builds up slowly. The pectin content of guava increases during fruit development but declines in overripe fruits. The differences in the rate of softening between cultivars correlate well with the extent of loss of total pectin content (Chin et al. 1994). Besides pectin, hemicellulose and cellulose are also modified during the fruit ripening process, with a general decline in the level of alkali-soluble hemicelluloses. The activities of the softening enzymes polygalacturonase (PG), pectinesterase (PE), β-galactosidase, and cellulase increase with ripening (El-Buluk et al. 1995).

Guava being a climacteric fruit is highly perishable. The fruit should be harvested only when the green color on the skin starts to fade, as this indicates the onset of ripening. If guava is harvested too green, it will not develop good flavor during postharvest ripening. Fully yellow guavas ripened on the tree have the best flavor, but these are often damaged by insects and birds. Moreover, the fully ripened fruits are too soft and thus difficult to handle and transport. For most cultivars, the fruits are ready for harvest after 120–150 days of flowering and should be harvested only when they turn yellowish green or with a pink blush. Guava fruits are usually harvested manually, and have postharvest life of about 10 days at ambient conditions (Brown and Wills 1983).

CHEMICAL COMPOSITION

Guava fruit consists of peel (about 20%), flesh (50%), and seed core (30%). Guava fruit has a low caloric value (275 kJ/100 g) and protein (1%). It contains 74–83% moisture, 13–26% dry matter (DM), 0.8–1.5% fat, and 0.5–1.0% ash (Mukherjee and Datta 1967). During ripening, total soluble solids (TSS) and soluble sugars increase from 10.5% to 12.75% and from 4.81% to 7.32%, respectively. Ascorbic acid increases from 118.53 to 199.26 mg/100 g, while fruit acidity decreases from 0.72% to 0.55%, (Aggrawal et al. 2002). Mainly the citric, malic, glycolic, tartaric, and lactic acids contribute toward the acidity of guava fruit (Chang et al. 1971). Guava cultivars are reported to differ in their sugar contents; fructose is shown to vary from 5.6% to 7.7%; glucose, 1.9% to 18.1%; and sucrose, 6.2% to 7.8% (El-Buluk et al. 1996). Fructose, glucose, and sucrose have been reported to be the predominant sugars in guava from China. Among the three cultivars studied, Xinshiji guava cultivar was reported to have the highest total antioxidant activity (67.26 mmol/L) (Shengfeng et al. 2009).

Guava is a good source of phosphorus (23–37 mg/100 g), calcium (14–30 mg/100 g), and iron (0.6–1.4 mg/100 g). It is also a good source of vitamins such as ascorbic acid, niacin, pantothenic acid, thiamine, riboflavin, and vitamin A (Paull and Goo 1983). White-flesh guava is reported to be a better source of vitamin C (142.6 mg/100 g) than the pink-flesh guava (72.2 mg/100 g) and is also rich in phenolics and β-carotene (Luximon-Ramma et al. 2003). Phenolic compounds were shown to decrease with firmness, more rapidly initially in white-fleshed than in pink-fleshed guava, but their content was consistently higher than the latter (Bashir and Abu-Goukh 2003). The antioxidant capacity and phenolic content of Thai guava have been reported by Alothman et al. (2009a). In addition to improving the microbial safety of fresh-cut guava, UV irradiation processing led to an increase in antioxidants, polyphenols, and flavonoids (Alothman et al. 2009b).

Ascorbic acid (vitamin C) content of guava would vary depending on the cultivar, season, and flesh color. Within the guava fruit, the vitamin C content was highest close to the pericarp (137.26 mg/100 g) but only about 40% (85.78 mg/100 g) of this in the central core part (Shenghui et al. 2007).

Sachan and Ram (1970) reported 37–1000 mg vitamin C per 100 g in guava fruits. Pink-flesh guava was reported to have higher vitamin C than the white-fleshed varieties (Kumar and Hoda 1974). Similarly, fruits maturing in winter season (November–December) had more vitamin C (325 mg/100 g) than fruits maturing in the rainy season (July–August) (140 mg/100 g) (Sachan et al. 1969). Vitamin C reaches a maximum level in fully ripe fruit and then decreases (Agnihotri et al. 1962).

Total phenolics, flavonoid, proanthocyanidin, carotenoid, vitamin C contents, and antioxidant activities of guava, lychee, and papaya are presented in Table 33.3 (Luximon-Ramma et al. 2003; Setiawan et al. 2001).

Guava fruit is one of the richest sources of pectin ranging from 0.5% to 1.8%, and pectin is affected by variety, stage of maturity, and crop season. The quality of pectin is judged by its ability to form a gel and is measured in terms of jelly units. Winter season guava fruits are known to contain higher amounts of pectin with more jelly units than the rainy season crop (Dhingra et al. 1983). Half-ripe guava fruits yield pectin having higher jelly units than the unripe ones. On hydrolysis, guava pectin yields 72% D-galacturonic acid, 12% D-galactose, and 4% L-arabinose (Chang et al. 1971).

Guava is a good source of antioxidant carotenoids (cryptoxanthin, lycopene, and β-carotene) and it contains about 140 μg retinol equivalents/100 g of provitamin A (Setiawan et al. 2001; Goodwin and Goad 1970). Among the commonly consumed foods, ripe fresh guava is an excellent source of dietary fiber (12.72 g/100 g) (Li et al. 2002). Pulp and peel fractions are known to contain high contents of dietary fiber (48.55–49.42%, dry basis) and extractable polyphenols (2.62–7.79%, dry basis) (Jimenez-Escrig et al. 2001). The highest phenolic content has been reported in the guava skin (10.36 g/100 g, dry basis) and the lowest (1.47 g/100 g, dry basis) in the jam (Marquina et al. 2008). Gorinstein et al. (1999) compared the total polyphenols and dietary fiber in tropical fruits and persimmon. Guava had a total polyphenol content of 495 mg/100 g fresh fruit, gallic acid being 374.3 mg/100 g fresh fruit. The guava had a total dietary fiber and soluble dietary fiber contents of 5.6 and 2.70 g/100 g of fresh fruit, respectively. They suggested that in addition to lychee and ripe mango, guava can be a suitable fruit for the dietary prevention of cardiovascular disease. Frequent use of guava has been shown to have insulin-like activity but had little or no effect on insulin action (Owen et al. 2008). Negligible effect on the vitamin C, total carotenoids, total anthocyanins, and total phenolics contents of guava juice have been reported during the various stages of processing and storage (Fernandes et al. 2009a).

The flavor of guava is determined by the type and quantities of sugars, acids, phenolics, volatile, and aroma active

Table 33.3. Total Phenolics, Flavonoid, Proanthocyanidin, Carotenoid, Vitamin C Contents, and Antioxidant Activities of Guava, Lychee, and Papaya

Chemical Constituent	Guava, White Flesh (*Psidium guajava*)	Lychee (*Litchi chinensis*)	Papaya (*Carica papaya*)
Total phenolics[a,b]	2473 ± 45	288 ± 17	576 ± 41
Flavonoids[a,c]	209 ± 10	94 ± 6	376 ± 15
Proanthocyanidins[a,d]	263 ± 31	100 ± 9	208 ± 21
Vitamin C[a,e]	1426 ± 26	138 ± 15	929 ± 19
Cryptoxanthin[f,g]	66	–	180
Lycopene[f,g]	1150	–	5750
β-carotene[f,g]	984	–	440
TEAC[h]	17 ± 2	5 ± 1	10 ± 2
FRAP[i]	14 ± 1	3 ± 1	2 ± 0

[a] Data from Luximon-Ramma et al. (2003), mean ± SE with $n = 3$.
[b] μg gallic acid per g fresh weight.
[c] μg quercetin per g fresh weight.
[d] μg cyaniding chloride per g fresh weight.
[e] μg ascorbic acid per g fresh weight.
[f] Data from Setiawan et al. (2001), average of three samples.
[g] μg per 100 g wet weight edible portion.
[h] μmol Trolox per g fresh weight.
[i] μmol Fe(II) per g fresh weight.

compounds present. Jordan et al. (2003) characterized the aromatic profile of fresh guava fruit puree and identified about 48 components with the predominance of terpenic hydrocarbons and 3-hydroxy-2-butanone. However, using gas chromatograph and mass spectrometer (GC–MS), Pino et al. (2002) characterized about 173 components in aroma concentrate of Costa Rican guava in which (E)-β-caryophyllene, α-terpineol, α-pinene, α-selinene, β-selinene, δ-cadinene, 4,11-selinadiene, and α-copaene were the major constituents. Amounts of aliphatic esters and terpenic compounds were mainly responsible for the unique flavor of this fruit. Chen et al. (2006) characterized volatiles in guava from Taiwan and attributed the unique flavor of guava due to aldehydes, alcohols, ethyl hexanoate, (Z)-3-hexenyl acetate, terpenes, and 1,8-cineole. Recently, Sinuco et al. (2010) reported presence of similar compounds (C_6 aldehydes) in white- and pink-fleshed guava fruits.

POSTHARVEST HANDLING AND STORAGE

Mature guavas do not keep well and are transported rapidly to the fruit processing factories. Guava fruits are usually shipped in small boxes rather than in bigger crates, as these fruits are easily crushed or bruised and the damaged fruit deteriorates fast. Fully mature fruits can be refrigerated during shipment. Guava, like most other tropical fruits, is highly chill sensitive. In general, a temperature of 8–10°C is considered to be the critical limit for chilling injury for most of the cultivars. Varietal differences in shelf life of guava fruit during cold storage have been reported (Mahajan et al. 2009). Allahabad Safeda cultivar stayed acceptable for 6 days compared with 9 days for Chittidar and Sardar cultivars when stored at 18°C ± 2°C and 80–85% relative humidity (Singh et al. 1990).

Storage of fruits under modified atmosphere (MA), as in polybags, or under modified atmosphere packaging (MAP) in polymeric films prolongs the shelf life (Kader et al. 1989; Parihar and Kumar 2008; Singh and Pal 2008). Guava fruits packed in 300-gauge polyethylene bags can be stored at room temperature for about 10 days (Khedkar et al. 1982). The MA treatments lead to CO_2 buildup and a depletion of O_2 within the internal atmosphere of the package. In most cases, respiration and ethylene production by the fruit is reduced, and ripening is delayed leading to markedly extended shelf life. Another advantage of MAP is that it reduces the incidence of diseases. In case of guava, ascorbic acid decreases during ripening, but MAP minimizes this loss (Mohamed et al. 1994). Cellulose- or carnauba-based emulsions delay color development and suppress the increase in the level of TSS during MA coating of mature green guava fruits (McGuire and Hallman 1995). Coating guava fruits with 2% or 4% hydroxypropyl cellulose is more effective than the 5% carnauba formulation in retarding softening, but both are effective in preventing water loss.

Other treatments such as vacuum infiltration of MAP fruits in 10% $CaCl_2$ at room temperature retarded loss of firmness and suppressed increase in soluble pectin and titratable acidity (TA) but had little effect on the incidence of disease as compared with the control fruits (Lazan and Ali 1997). A few other postharvest treatments of guava fruit that have been investigated include dipping in sugar syrup (Mudahar and

Bhatia 1983), metabisulfite solution (Ahlawat et al. 1980), 1% calcium nitrate (Singh et al. 1981), and 1000 μL/L cycocel (Tandon et al. 1984).

PROCESSED PRODUCTS

Guava fruit lends itself to production of a number of processed products such as nectar, clarified juice, concentrates, canned, dehydrated powder, jam, jelly, guava cheese, and blends with other juices.

Puree

Slightly overripe guava fruits having fully yellow skin with brown spots and soft flesh having intense distinct musky odor are preferred raw material for puree. Guava fruits are inspected, seriously spoiled ones are discarded, and the under ripened are kept aside for further ripening. Fruits that have passed the inspection are washed and inspected before maceration. The washed guavas are processed in a paddle pulper fitted with 0.008–0.11 cm screens. This pulp is then passed through a finisher fitted with 0.05 cm screens to remove stone cells (Luh 1971). It is deaerated and pasteurized for 60 seconds at 90°C. It can be canned in enameled cans, or preserved by freezing to –29°C and storing at –18°C, or aseptically packaged, or dehydrated. Deaerated aseptically packaged guava pulp retains ascorbic acid much better during up to 6 months storage (Chan and Cavaletto 1986). Foaming agents such as egg albumen, glycerol monostearate, guar gum, and carboxymethyl cellulose are dissolved in a small amount of water and blended with guava puree and foamed/whipped in a mixer using a wire whip. The whipped foam is placed on to trays and dried in a vacuum-shelf drier. The dried product is scraped off the trays and packaged in airtight containers. Guava puree is a starting material for many products such as nectar, juice, leather (also called as cheese), jam, and jelly (Sanchez et al. 2009).

Juice

Guava juice can be produced either from fresh fruits or from puree. For juice extraction, fully ripe fruits are cut into small pieces followed by the addition of 0.2 g citric acid and 250 mL water/kg. The mix is cooked while stirring constantly, strained through a muslin cloth, and the juice is collected. Juice yield can be increased to more than 80% by using 700 ppm of Pectinex (Ultra SP-L Registered, Novozymes, USA) and pectic enzymes (Chopda and Barrett 2001). In preparation of clarified guava juice, use of PG enzyme caused slight decrease in vitamin C but an increase in acidity, reducing sugar, TSS, and volatile compounds (Pong et al. 1996). Kaur et al. (2009) optimized the enzymatic hydrolysis pretreatment conditions for enhanced juice recovery from guava using response surface methodology and recommended the use of enzyme concentration of 0.70 mg/100 g guava pulp, incubation time of 7.27 hours, and incubation temperature of 43.3°C.

The chemical composition of guava juice is similar to guava puree. Guava juice has 11% TSS, 6.64% total sugars, 6.02% reducing sugars, 0.76% acidity (as citric acid), 3.85 pH, 243 mg/100 g ascorbic acid, and 1.02% pectin (Sandhu and Bhatia 1985). Guava juice can be further processed and utilized for producing concentrates, beverages, jelly, powder, and other products. An acceptable quality whey beverage with 0.5% acidity and 20% TSS using 25% guava fruit juice has been prepared (Gagrani et al. 1987).

The shelf life of guava juice has been studied by several researchers. Single-strength guava juice retained higher amounts of ascorbic acid (35%) than guava juice with 25% added sugar at the end of 270 days of storage (Shaw et al. 1975). Guava juice stored with added sodium citrate retained good color and flavor. Bottled frozen guava juice and acerola juice blends when stored at –18°C for 8 months retained 90% of the original ascorbic acid (Fitting and Miller 1959). However, Orr and Miller (1954) reported that unfrozen bottled guava juice retained only 70% of the original ascorbic acid during 11 months of storage compared with 80–85% retention of ascorbic acid in frozen bottled guava juice after 12 months of storage. Higher retention of ascorbic acid content in guava juice has been reported in samples treated with carbonation and sonication as compared with control, but these treatments were not effective for inactivation of microorganisms and in reducing the polyphenoloxidase (PPO) activity (Cheng et al. 2007). Guava juice has been shown to blend very well with other fruit juices such as Kinnow mandarin, pear, grape, mango, and pineapple for preparation of good quality multifruit beverages with 15% juice content (Sandhu and Sidhu 1992). Ready-to-serve (RTS) beverages made from guava and papaya pulp blend (70:30) have high vitamin C, carotenes, and also have better sensory (flavor and consistency) characteristics (Tiwari 2000).

Uddin Paracha et al. (2009) developed a low calorie guava squash using nonnutritive sweeteners (saccharin, aspartame, and cyclamate); saccharin and aspartame produced acceptable products. Similar guava drink with sucrose and nonnutritive sweeteners has been prepared by Fernandes et al. (2009b); guava drinks made with sucrose and aspartame were preferred by taste panelists. Divya (2009) prepared a paneer whey-guava beverage (containing 25% guava pulp, 10% sugar, 65% paneer whey) that had a shelf life of about 45 days at room temperature.

Concentrate

To facilitate overseas shipment and for long-term storage, it is advantageous to produce concentrate from guava puree or clarified guava juice. A falling film evaporator, a rising film evaporator, and a centrifugal evaporator are the equipment required for this purpose. Before concentration, guava puree is treated with pectic enzymes to reduce its viscosity. Depectinized puree can then be easily concentrated to 34°Brix,

as it remains flowable in an evaporator (Brekke and Myers 1978). However, the clarified juice can be concentrated to 66°Brix (Muralikrishna et al. 1968). The loss of flavor during evaporation is compensated by cutting back the product to a lower concentration, by diluting it with single-strength fresh pasteurized puree or clarified juice. As water is lost during the concentration process, TSS, acidity, sugars, pectin, and ascorbic acid increase in the finished product but color changes to brown due to the browning reaction (Sandhu and Bhatia 1985). Guava juice concentrate is suitable for drying to guava juice powder as well as for the preparation of RTS beverages. Guava concentrates should be packaged in low oxygen permeable containers to maintain flavor and color during storage.

Nectar

Guava nectar, cloudy or clarified, is a very popular beverage that can be prepared from puree, clarified juice, or concentrate with sugar syrup, citric acid, and other flavoring additives. Cloudy guava nectar is more popular than the clarified nectar. Guava nectar is prepared using 15% pulp, 14% soluble solids, and 0.25% acidity (Kalra and Tandon 1984). It can be fortified with vitamin C (100 mg/100 g) and packaged in glass bottles or tetra packs. Guava nectar can also be diluted (four times its volume with water) to prepare good quality bottled RTS (ready-to-serve) beverage (Jain and Borkar 1966), or this beverage can also be prepared from fresh or preserved pulp using 1 kg of sugar, 6 L water, and 20 g of citric acid for every kilogram of pulp.

To improve the consistency of cloudy guava nectar, use of piston-type homogenizer or an ultrasonic homogenizer is essential, but the homogenized nectar should be vacuum deaerated as soon as possible to retain the ascorbic acid and flavor. Subsequently, the nectar is either pasteurized or commercially sterilized for better shelf life. For pasteurization, guava nectar is heated in a plate heat exchanger at 93°C with 36-seconds hold, cooled to room temperature, and filled in tetra packs. For commercial sterilization, guava nectar is heated up to 93°C, held for 45 seconds, and then filled at a temperature higher than 86°C into enameled tin cans. These cans are sealed, inverted, held for 3 minutes, cooled to 40°C by spraying water, and then air-cooled to ambient temperature. Under common ambient storage conditions, canned guava nectar has a shelf life of 6 months. During ambient storage, white-fleshed cloudy guava nectar deteriorates in quality due to nonenzymatic browning reactions through the involvement of ascorbic acid and tannins (Chen et al. 1994). However, lowering the pH or the addition of L-cysteine to the nectar formulation effectively reduces the rate of browning (Chen and Wu 1991).

Canned Guava

Canned guava is a popular product in India, Pakistan, and Indonesia. The general canning procedure for guava shell is described by Lal et al. (1986). Fully ripe guava fruits are either peeled with a knife or lye-peeled (by dipping for 15 seconds in boiling solution of 2.5% sodium hydroxide). After rinsing with water, it is dipped in 0.5% solution of citric acid to neutralize the remaining alkali. The fruit is cut into halves or quarters and the seed core are removed to obtain the shells. The shells are firmed by dipping in 2% $CaCl_2$ solution for 1 hour. After rinsing, the shells are canned in 40°Brix sugar syrup containing 0.25% citric acid. The cans are exhausted at 82–100°C for 7–10 minutes so that the temperature in the center of the can is 74°C. The cans are sealed, sterilized in boiling water for 20–25 minutes, and then cooled to room temperature.

The suitability of guava cultivars for canning varies. Allahabad seedless cultivar from India has been reported to be suitable for canning (Siddappa 1982). The addition of calcium has been shown to improve texture and minimize the negative effects of thermal processing during canning of guava (Sato et al. 2006). Canned guava in syrup had a higher rupture stress and strain than fresh fruit, indicating an increase in hardness and elasticity of the canned product.

Dehydrated Guava Products

Guava slices or chunks can be dehydrated by air-drying, osmotic dehydration, or osmovac dehydration. In the first procedure, guava slices are blanched in boiling water for 4 minutes, sulfuring is done for 20 minutes, and then air-dried at 71°C until final moisture of 6–7% is achieved. This usually takes about 15 hours (Campbell and Campbell 1983). To prevent browning of slices during drying process, there are a number of treatments such as chemical blanching with 0.1% potassium metabisulfite (KMS) + 2% $CaCl_2$ at 100°C for 3 minutes, or sulfiting with 1% KMS for 5 minutes, or sulfuring with 2 g sulfur/kg of fruit slices for 4 hours. Khurdiya and Roy (1974) dried guava slices in a cabinet drier at 60°C ± 5°C for about 18 hours to achieve a final moisture content of 3% in the finished product.

Glazed guava slices are prepared by osmotic dehydration technique. Guava slices are heated in an equal amount of 70°Brix sugar syrup containing 0.1% KMS at 90°C for 3 minutes. After cooling to room temperature, this mixture is allowed to stay overnight. Then, slices are drained and spread in glycerine-coated trays for drying at 80°C for 1 hour. The air temperature is then lowered to 65–70°C for the next 7–8 hours. Kannan and Susheela (2002) have investigated the storage behavior after osmotic dehydration of guava. Acidity increased and pH decreased in all their samples during storage. Total sugar content decreased slightly, but the ascorbic acid content was reduced significantly by 6 months of storage. As far as appearance, color, texture, and flavor are concerned, Luchnow-49 cultivar was rated higher in sensory quality. Mehta and Tomar (1980a, 1980b) standardized a procedure for the dehydration of guava slices in 70°Brix sugar syrup containing 1000 ppm of sulfur dioxide. The dehydrated

guava slices were of very good quality but only about 6% of the original ascorbic acid was retained in the finished product.

A number of studies have been reported on the osmotic dehydration of guava slices. Temperature, time, and pressure regimen were shown to significantly influence the product flavor. The color and firmness of guava treated at 40°C for 60 minutes under pulsed vacuum were not significantly altered (Panades et al. 2007; Correa et al. 2010). Pereira et al. (2006) have investigated the osmotic dehydration of guava, melon, and papaya using sucrose and maltose solutions. Higher temperature caused greater sugar gain, but its uptake was reduced in the presence of maltose. Addition of calcium ions had a strong effect on the fruit texture and color. While studying the microscopic features, mechanical and thermal properties of osmotically dehydrated guava slices, Pereira et al. (2009) have reported that the addition of calcium lactate promoted the maintenance of guava structure. As confirmed by differential scanning calorimetry (DSC) experiments, the increase in hardness resulted from the bonding between calcium ions and the cell wall pectin. It is suggested that the phenolic infiltration during thermal processing might improve the texture and antioxidant capacity of processed guava slices through phenol–pectin interaction (Tsai et al. 2010).

Guava fruit powder is prepared by grinding the dehydrated slices. After blanching, the shells are dried at 54°C for about 10–12 hours and packed in moisture-impermeable containers. During storage of guava powder for 6 months, a significant decrease in ascorbic acid has been observed with a slight increase in moisture content (CFTRI 1990). The rate constant of ascorbic acid degradation has been reported to increase with the increasing temperature and water activity (Uddin et al. 2002). Guava powder can be used in the preparation of guava juice, RTS beverage, or milk shake. Cabral et al. (2007) have studied the effect of apparent viscosity on the fluidized bed drying process parameters of guava pulp. According to them, the increase in pulp apparent viscosity caused a considerable increase in the vibro-fluidized bed pressure during pulp drying, resulting in larger value of minimum vibro-fluidization velocity. However, the negative effect of increased apparent viscosity can be attenuated by increasing the fluidized bed vibration intensity and that could prevent stickiness between dried particles. Recently, Kong et al. (2009a) have optimized the oven drying conditions for lycopene content and lipophillic antioxidant capacity of a by-product of the pink guava puree industry using response surface methodology. They reported the optimum oven drying conditions for drying with minimum lycopene degradation were 43.8°C for 6.4 hours with a predicted lycopene content of 14 mg/100 g and lycopene equivalent antioxidant capacity (LEAC) of 21 μmol LEAC/100 g.

Guava Fruit Leather (or Cheese)

Guava fruit leather or cheese is prepared from firm ripe fruits. The fruits are washed, sliced, and cooked in equal amounts of water to soften the fruit. The pulp is screened to remove the skins and the seeds. For every kilogram of pulp, 1.25–1.50 kg sugar, 2.2–3.3 g citric acid, and 56 g butter are added. This mixture is cooked to a thick paste. To improve the appearance of the final product, small amounts of permitted color and common salt are added. The hot cheese is spread on a greasy tray and is allowed to set. After cooling, it is cut into small pieces and wrapped in moisture-proof paper (Lal et al. 1986). Guava cheese prepared from pulp can be stored at 4°C for about 4 months without the loss of sensory quality (Singh et al. 1983).

Banarsi Surkha guava cultivar from India was found to produce better quality cheese than the Allahabad Safeda (Sandhu et al. 2001). They prepared cheese from guava pulp and sugar mixture by drying it in a cabinet drier at 50°C ± 5°C for 4 hours to moisture content of about 29.3%. The product wrapped in butter paper and packed in polyethylene bags was acceptable for 3 months at room temperature. Similarly, Vijayanand et al. (2000) found that guava cheese bars packaged in polyester–polyethylene laminate or pearlized biaxially oriented polypropylene retained their sensory and textural properties for about 3 months at room temperature.

Jelly

For the preparation of jelly, slightly under-ripe guava fruits are used. The fruits are crushed, juice is extracted, and allowed to settle overnight. Clear juice is decanted and boiled with sugar. The ratio of sugar to guava juice depends on its pectin content. Usually, 0.75 kg sugar/kg of pectin-rich juice and 0.5 kg sugar/kg of low-pectin juice are used. Boiling is continued until the temperature reaches 105°C or it forms a sheet when a small portion is cooled off in a spoon. The hot jelly is filled into glass jars and sealed (Lal et al. 1986). The use of whey in jelly preparation has been suggested by Joshi et al. (1985). Guava jelly with attractive color, pleasant taste, and aroma has been prepared by blending it with red grape cultivars, which alone did not produce a good jelly (Aggarwal et al. 1997). Menezes et al. (2009) have investigated the use of various chemical preservatives and other combined preservation methods on the physicochemical characteristics of guava preserves. Their results indicated that the citric acid concentration and pulp:sugar ratio must be increased to obtain preserve with firm texture and greater yield. Prati et al. (2009) prepared a mixed fruit jam containing yacon, guava, and West Indian cherry but with no added sugar. The product was acceptable to consumers and remained microbiologically stable for 90 days at room temperature.

BY-PRODUCTS FROM GUAVA PROCESSING

The use of waste produced from guava processing can be a source of natural additives and functional food ingredients (Schieber et al. 2001; Costa et al. 2009; de Souza Abud and Narain 2009). Extraction of lycopene is one such

possibility (Bortlik et al. 2002). Guava is one of the best natural sources of food-grade pectin, which finds uses in various food product formulations as a thickening and gelling agent (Pruthi et al. 1960). Pectin can be obtained from guava fruits by boiling with water and then precipitating with ethanol. Use of sodium hexametaphosphate (0.25–0.75%) or a 1:1 mixture of ammonium oxalate and oxalic acid (0.25–0.75%) increases the yield of high jelly grade pectin (Dhingra and Gupta 1984).

Guava seed powder is reported to contain 9.37% protein, 57.6% crude fiber, 79.37% dietary fiber, 20.37% lignin, 41.28% cellulose, and 17.7% hemicellulose. Guava seed oil is very rich in oleic (54%) and linoleic (29%) acid (Swailam et al. 2006). Prasad and Azeemoddin (1994) have solvent extracted seed oil from processing plant wastes and reported an oil content of 16% in guava seeds. Guava seed oil can be easily refined and bleached to produce a light colored bland oil of edible quality. Protein isolate from guava seeds having good nutritional quality and functional properties is another possibility (Bernardino-Nicanor et al. 2005, 2006; Fontanari et al. 2007). Guava seed as an adsorbent and as a precursor of carbon for the efficient adsorption of acid dyes has been suggested by Elizalde-Gonzalez and Hernandez-Montoya (2009). The Abd-El-Aal (1992) has obtained guava seed flour and isolate, which were low in sulfur-containing amino acids and lysine but contained other essential amino acids. Supercritical fluid extraction (SFE) with carbon dioxide and with ethyl acetate and ethanol as co-solvents has been applied to obtain phenolic fraction from guava seeds (Castro-Vargas et al. (2010). Compared with traditional soxhlet extraction, they obtained higher yields of phenolic fraction (0.380 to 1.738% w/w) using SFE. Due to the susceptibility of mature ripe fruits, a high proportion of damaged (unsaleable) guava fruits are generated during transportation to processing plants, which can be fermented using *Saccharomyces cerevisiae* for ethanol production (Srivastava et al. 1997). A yield of 5.8% (w/v) ethanol has been obtained from such waste products of guava processing plants.

An antimicrobial substance with high antibacterial activity has been isolated from guava fruit, flowers, leaves, stems, branches, or roots with water, alcohol, or a water/alcohol mixture (Fukumoto et al. 2006). This antibacterial substance can be used in preserving various packaged foods and beverages or cosmetics. Jo et al. (2009) extracted antibacterial compounds from the guava fruits, branches, leaves, and seeds with various solvents. These extracts showed significant antibacterial activities against foodborne gram-positive microorganisms. In another study, Hoque et al. (2007) reported use of alcohol extract of neem (*Azadirachta indica* A. Juss.) and guava to control foodborne pathogens and spoilage bacteria.

FUTURE RESEARCH NEEDS

Because of its flavor and nutritional quality, guava has the potential to become a commercially important tropical fruit crop not only for fresh consumption but also for processing into value-added products. However, guava fruit is not as commercially successful as other tropical fruits such as, mango, papaya, and pineapple. Some of the major constraints that have limited its potentials are related to pests and diseases, unavailability of good quality cultivars, and higher susceptibility of guava fruit to damage during transportation and storage. Good management and cultural practices need to be developed to check pests and diseases at the preharvest stage. Most of the guava cultivars are wild and low in quality, and guava trees cannot be grafted as easily as other fruit trees. This problem can be tackled by making use of the recent advances in tissue culture techniques as well as recombinant DNA technology. With the current postharvest technology, the shelf life of guava fruit can only be extended up to 3 weeks. This is not enough if this fruit has to be exported to distant markets. So the existing technology needs to be upgraded to improve the shelf life of fresh guava fruit. Due to the higher nutritional content of pink-flesh guava fruits, more efforts are needed to popularize and market this fruit as fresh as well as processed products.

SECTION 2: LYCHEE

INTRODUCTION

Lychee, also called Litchi or litchee (*Litchi chinensis* Sonn.), a subtropical evergreen tree belongs to family Sapindaceae or soapberry. Lychee is believed to have originated in the Kwantung Province of China where it has been grown for the past forty centuries (Tao 1955). Later, it spread to many tropical and subtropical countries. China, Taiwan, Vietnam, Thailand, India, Pakistan, Indonesia, Madagascar, South Africa, and Australia are the major lychee producing countries of the world (Menzel et al. 1988). According to the FAO estimates (FAO 2003), the top five countries producing lychee are China (1.2 million metric tons [MMt]), India (455,000 Mt), Thailand (85,000 Mt), Vietnam (50,000 Mt), and Bangladesh (12,755 Mt).

Lychee trees reach a height of 9–12 m and the fruit is borne in bunches. When the fruit is fully ripened, its pericarp is thin, hard, and somewhat warty in texture. Depending on the cultivar, the lychee fruit pericarp (LFP) may be pale green, bright red, or rose colored. Lychee fruit is round to oval in shape, measures about 2.5–4 cm, and has a large glossy brown seed. Lychee fruit normally contains one seed, but in some cultivars, a high proportion of seeds may be abortive. These abortive seeds are small and shriveled. The fruits with such seeds are preferred as they yield higher proportion of flesh and often fetch a higher price (Menzel and Simpson 1993). Lychee is a nonclimacteric fruit, which is harvested during the summer months (May–July in the Northern Hemisphere, November–February in the Southern Hemisphere). The pulp is white to cream colored, very succulent, and has aromatic, sweet, and acidic taste.

Lychee grows well in a variety of soil conditions but a rich, loamy soil or sandy loam is preferred. The lime content of soil is important, as the soil with about 30% lime content is best suited for lychee cultivation. Acidic soil pH favors the growth of mycorhizal fungi on roots, which greatly influences the fruit quality. An ideal climate for lychee cultivation should be free from frost during winter season and hot, dry winds during summer months. The young plants are initially protected from frost during winter months. The dry heat during ripening leads to cracking of fruits and is prevented by frequent irrigation during dry season (Maiti 1985). Although budding and grafting on seedling rootstock is also practiced, air layering is the most common method of lychee propagation. Plants produced from seed generally do not bear fruits until eighth or ninth year or sometimes not at all, whereas the trees propagated through air layering bear fruits after fourth year, but these do not develop a good root system. During air layering, the use of a rooting hormone (200 ppm of α–naphthalene acetic acid) gives higher success in root formation (Singh 1951).

CULTIVARS

There are many lychee cultivars grown in the world. A cultivar may set fruit with different characteristics in different growing areas and may cause confusion on its identity. Menzel and Simpson (1991) have described the important cultivars being grown in the major lychee producing countries of the world. The major cultivars being grown in China, Australia, Taiwan, and other Southeastern countries have the same original Chinese names, such as "Haak Yip," "No Mai Chee," Kwai Mi," and "Wai Chee" (Anon 1961). In Hawaii, a few other cultivars such as Hak Ip, No Mai T'sz, Brewster, Pat Po Hung, and Groff are also recommended for planting because of their quality and higher yield (Hamilton and Yee 1970). Brewster (Chen purple) and Mauritius cultivars are also grown in Florida. Among the 12 lychee cultivars grown in India, Dehra Dun, Early Large Red, Kalkattia, and Rose scented are the most popular ones. Mauritius is the only cultivar commercially grown in South Africa (Knight 1980). Among the various cultivars grown in Pakistan, Dehra Dun is considered the best (Ahmed 1961). Advancement of research on lychee and longan germplasm resources in China has extensively been reviewed by Wu et al. (2007).

PHYSIOLOGY, RIPENING, AND FRUIT CRACKING

The terminal panicles of new shoots in lychee bear two types of flowers, staminate and hermaphrodite. Staminate flowers open before the hermaphrodites. Fruit set is quite low in lychee, as only a small percentage of flowers set fruit. The growth of lychee seeds in fruit occurs initially at a higher rate, followed by membranous mesocarp and aril, which grow fast toward the later stages. Lychee fruits start ripening when the atmospheric temperature is high. Respiration rate of lychee fruits decreases progressively during fruit development, with immature fruits (20 days after anthesis [DAA]) having a rate eight to ten times higher than that of the mature fruits (Akamine and Goo 1973). Lychee produces low levels of ethylene; most of it comes from the pericarp. Use of low temperatures (5°C) significantly reduces the respiration and ethylene production by lychee fruits, but they increase rapidly above that at harvest when the fruits are transferred to 25°C (Jiang-Ping et al. 1986). To prevent the infection by *Peronophythora litchii* of lychee fruit while ripening on the tree, spray of adenosine triphosphate (ATP) has been suggested (Yi et al. 2009). Enhanced disease resistance of lychee fruit by the application of exogenous ATP could involve the levels of free fatty acids and esterase activity in the fruit.

Mature lychee fruits are characterized by a uniform red pericarp color. Four anthocyanin pigments have been found to be associated with the development of red pigments of ripened lychee fruits. Anthocyanin, the main red pigment is synthesized in the pericarp at around 60–80 DAA, when the chlorophyll is simultaneously degraded (Maiti 1985; Underhill and Critchley 1992). Pericarp browning, which involves PPO, peroxidase (POD), phenylalanine ammonialyase (PAL), and a number of phenolic compounds, is a major factor in lychee storage and transportation (Sun et al. 2009; Ruenroengklin et al. 2009). Total anthocyanin content declines from 1.77 to 0.73 mg/kg fresh weight and individual anthocyanins also decrease during storage period. Decline in anthocyanins is accompanied by an increase in browning. Polymeric pigments gradually increase from 20.9% to 53%. Chlorophyll is still present in the mature lychee fruits, though only in small amounts (Lee and Wicker 1990). Cyanidin-3-rutinoside is the major anthocyanin found in the skin of lychee fruits, although cyanidin-3-glucoside and malvidin-3-acetylglucoside are also identified. Polymerized anthocyanin pigment is also present and contributes to the brownish-red color of lychee fruit skin (Lee and Wicker 1991; Rivera et al. 1999). Rapid pericarp browning and decay of lychee fruit during storage are the major problems affecting its market value. Application of 2–4 mM oxalic acid spray on lychee fruit can effectively control the pericarp browning of lychee fruit during storage and marketing (Zheng and Tian 2006). Use of citric acid and chitosan has been suggested to preserve the red color of pericarp of lychee fruit during storage and long distance transportation (Ducamp-Collin et al. 2008).

Since lychee fruit maturity does not change after harvest, the fruit must be harvested at optimal visual appearance and eating quality (Reichel et al. 2010). While the pericarp color is most commonly used harvesting index, the relationship between the pericarp color and lychee fruit maturity varies with the cultivar, region of cultivation, and other agricultural practices (Underhill and Wong 1990). Batten (1989) has suggested a number of maturity criteria for lychee fruits. Lychee fruits are usually analyzed for Brix and TA but Brix is not

a suitable maturity indicator, whereas TA and the Brix/TA ratio are both good predictors of taste. Dry heat during fruit ripening, especially during windy conditions, is disastrous for a lychee crop. The fruits have been shown to crack prematurely under such desiccating environmental conditions (Maiti 1985; Underhill and Simons 1993). Under such conditions of low humidity, frequent irrigations are necessary to maintain the desired humidity conditions during fruit ripening periods. Although, calcium concentration in cracked fruit has been found to be significantly lower than in the healthy fruit, but spraying calcium on the fruit-bearing tree has not been an effective way of increasing structural calcium in lychee pericarp to prevent fruit cracking (Huang et al. 2008).

CHEMICAL COMPOSITION

Although considerable variation is found in the chemical composition of lychee fruits, the most data for moisture ranges from 77% to 83% (Mathew and Pushpa 1964; Wenkam and Miller 1965). Lychee contains about 0.9% protein and less than 1% fat (Wenkam and Miller 1965). The proteins present in lychee flesh have been reported to cause allergic reaction in certain individuals (Hoppe et al. 2006). Sugar content varies considerably among lychee cultivars. The highest sugar content of 20.6% in Kwai Mi is reported by Miller et al. (1957), whereas most Indian cultivars have a sugar content between 10% and 13% (exception that of 18% soluble solids in Calcutta Late and Seedless No. 1) (Chadha and Rajpoot 1969). The total sugar content of six Indian varieties is reported to vary from 55.92% to 61.37% of the fruit on dry basis, and reducing sugar content of 41.52–43.45% (Mathew and Pushpa 1964). Thus, more than 70% of the sugars were present as reducing sugars in lychee fruits. However, Chan et al. (1975a) have reported a higher proportion of sucrose, roughly 51% of the total sugars. This discrepancy in their findings was attributed to the presence of invertase enzyme in lychee fruit, which, if not inactivated prior to analysis, catalyzes the inversion of sucrose. This invertase enzyme has been characterized by Chan et al. (1975a) and found to have an optimum pH of 2.6 considerably lower than other invertases and also lower than the normal pH (4.6) of lychee fruit. The optimum temperature for this enzyme was 55°C.

Fruit acidity in 12 Indian varieties of lychee ranged from 0.20% to 0.64% (Mathew and Pushpa 1964). Acidity is known to decrease as the fruit ripens. Following harvest, acidity again decreases during storage (Joubert 1970). The Brix/acid ratio increases during ripening and storage, and may reach as high as 80:1 before fruit rotting sets in. Malic acid is the predominant acid (80% of the total acids) analyzed followed by citric, succinic, levulinic, phosphonic, glutaric, malonic, and lactic acid (Chan and Kwok 1974).

Lychee fruit is a good source of ascorbic acid. Wenkam and Miller (1965) found 40.2 mg/100 g ascorbic acid in Kwai Mi and 80.8 mg/100 g in Brewster. Similarly, 44 mg/100 g in Calcutta Late (Chadha and Rajpoot 1969) and 90 mg/100 g in an unspecified variety (Thompson 1955) have been reported in the literature. The ascorbic acid content decreases as the temperature and storage time are increased (Thompson 1955). Lychee's chief nutritional asset is its high ascorbic acid content, as it is not a significant source of thiamin, riboflavin, calcium, phosphorus, or iron. It is totally lacking in provitamin A. However, variety Kwai Mi was found to be a good source of niacin (Wenkam and Miller 1965). A small amount of pectin (0.424%) has been reported in lychee fruit.

The volatile profile of lychee fruit has been studied by Johnston et al. (1980). Of the 42 compounds identified, β-phenethyl alcohol, its derivatives, and terpenoids comprise the major and characteristic portions of these volatiles. In a recent study, Chyau et al. (2003) have identified 25 free and glycosidically bound aroma compounds (GBAC) from the lychee juice using GC and GC–MS. Free aroma compounds (FAC) were rich in acetoin, 3-methyl-2-buten-1-ol, and geraniol (874, 445, and 454 mg/kg pulp, respectively); GBACs were rich in geraniol, geranial, neral, and 2-phenylethanol (1162, 125, 60.4, and 54.2 mg/kg pulp, respectively). Total levels of volatile compounds in FAC and GBAC were 2907 and 1576 mg/kg pulp, respectively; and 25 compounds identified in both the fractions were 1 ester, 14 alcohols, 2 aldehydes, 4 acids, 2 ketones, and 2 terpenes. While evaluating aroma, FAC had a fresh, fruity, lychee-like aroma, whereas GBAC was odorless until enzymatic hydrolysis. The combination of FAC and hydrolyzed GBAC fractions gave a strong fruity, lychee-like aroma, suggesting that controlled application of glycosidase during lychee processing could enhance the characteristic flavor of lychee juice and other juice-based products.

ANTIOXIDANT COMPOUNDS IN LYCHEE

A large amount of polyphenolic compounds with strong antioxidant activity have been reported to be present in pericarp of the mature lychee fruits (Duan et al. 2007; Liu et al. 2007; Sun et al. 2010). Zhao et al. (2006) have identified a number of flavonoids (proanthocyanidin B4, proanthocyanidin B2, and epicatechin) in lychee pericarp which exhibited antioxidant capability. The hydroxyl radical and superoxide anion scavenging activities of proanthocyanidin B2 was greater than the other two compounds. However, epicatechin showed the highest DPPH scavenging activity. The LFP extract has potential anticancer activity against hepatocellular carcinoma *in vitro* and *in vivo* through proliferating inhibition and apoptosis induction of cancer cells (Wang et al. 2006a). In a few of the other studies, the LFP extract has shown potential anticancer activity toward human breast cancer cells (Wang et al. 2006b; Zhao et al. 2007).

Yang et al. (2006) have purified a number of polysaccharides from the pericarp of lychee fruit but a neutral

polysaccharide with a molecular weight of 14 kDa exhibited the highest antioxidant activity. This neutral polysaccharide composed of 65.6% mannose, 33.0% galactose, and 1.4% arabinose. Kong et al. (2009b) have isolated three fractions of water-soluble polysaccharides from the LFP and one of the fractions with a molecular weight of 2.9×10^4 Da showed the highest antioxidant activity.

Lychee-flower-water extract (LFWE) contains phenols, flavonoids, tannins, which may offer cardio-protection (Yang et al. 2010). Drinking LFWE lowered the serum malondialdehyde (MDA) contents in high-fat/cholesterol-dietary hamsters indicating that LFWE had a protective effect on the cardiovascular health *in vivo*.

One of the serious drawbacks for lychee fruit processing into value-added products is its big-sized seed, which is a waste product. Efforts have been made by Prasad et al. (2009) to investigate the potential of lychee seeds for the extraction of natural antioxidant compounds using various solvent systems. Five phenolic compounds, namely, gallic acid, procyanidin B2, (-)-gallocatechin, (-)-epicatechin, and (-)-epicatechin-3-gallate, have been identified in the 50% ethanol extract, which showed the highest total antioxidant capacity, scavenging the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical and inhibitory activity against lipid peroxidation. Xu et al. (2010) have isolated eudesmane sesquiterpene glucosides from lychee seed which possess cytotoxic activity and may work as natural phytochemicals having anticancer properties.

POSTHARVEST HANDLING AND STORAGE

Maintaining quality of fresh lychee is a challenge as desiccation accompanied by loss of red shell color and the development of pericarp browning can occur quickly (Hanekom et al. 2010). A number of enzymatic color changes can occur during the postharvest storage and transportation of lychee fruit. The decrease in POD and increase in PPO activities coincided with the onset of discoloration of fruits (Huang et al. 1990). Postharvest physiological characteristics of lychee fruit are described in Table 33.4. Two principal strategies can be employed: reducing the water loss by various methods and the prevention of browning by chemical or physical treatments. If left unpackaged at room temperature, the shelf life of lychee fruit is about 72 hours or less (Macfie 1954). Radiation treatment (0.5 kGy) of lychee fruit in combination with low temperature (4°C) storage has been suggested to achieve a shelf life of nearly 1 month (Hajare et al. 2010).

Refrigerated Storage

Lychee fruit that is quickly cooled to 3°C and then held at low temperature (5°C) tend to be less susceptible to moisture loss and decay. It takes about 2 days for the packaged fruit to reach 5°C in the refrigerated storage (Bagshaw et al. 1994). Cooling methods and shipping containers used affect the lychee fruit quality. Lychee stored without the panicle had higher pulp quality in terms of total TA, pH, and TSS content compared with those stored with the panicles attached (Pornchaloempong et al. 1997). Storage of lychee at 4°C or 10°C increased ethylene production by as much as 8.6 times compared with the control samples stored at 25°C. The green fruit was most responsive to chilling in terms of ethylene production (Chan et al. 1998). Forced-air cooling requires a high-capacity cold room and takes about 12 hours. To avoid fruit desiccation, the cold room must have a relative humidity of 95%. Precooling of lychee fruit is most effective, if done before packing (Watkins 1990). In comparison, hydrocooling is a faster method than the forced-air cooling. It avoids the problem of fruit desiccation and is a relatively less expensive technique. Commercial hydrocooling is being progressively adopted in Australia and Thailand for extending the shelf life of fresh lychee fruits (Bagshaw et al. 1994).

One of the simplest and most commonly used techniques of controlling pericarp browning is to reduce water loss. Traditionally, lychee fruit was stored in woven bags, clay jars, and bamboo baskets. Large bamboo and reed baskets lined with newspapers are still in use in parts of India and Southeast Asia (Singh 1957). Packing of lychee fruit in plastic containers and over wrapping with a semipermeable membrane reduces fruit desiccation with minimum condensation. This practice when used in combination with refrigerated storage is one of the most effective nonchemical means of controlling pericarp browning (Wara-Aswapati et al. 1990; Wong et al. 1991). Lychee fruits coated with low-pH cellulose formulations designed to lower surface pH to 4.0 prolonged the red color of the fruits throughout the cold and ambient temperature storage (McGuire and Baldwin 1996).

Lychee is usually stored at 5°C (Jacobi et al. 1993), but there are several reports of fruit being stored at a temperature as low as 0°C for 3 weeks (Sandhu and Randhawa 1992). During the refrigerated storage of lychee fruits, usually a relative humidity of 95% is maintained. Shah and Nath (2006; 2008) have investigated the effect of dipping in preservatives and vacuum packaging on the physicochemical, sensory, and microbiological quality of lychee during refrigerated storage. Use of preservatives and vacuum packaging improved the appearance scores and reduced the microbial growth on lychee fruits during refrigerated storage.

Chemical Treatments

A number of chemical treatments have been reported in the literature to increase cell wall strength or to delay fruit senescence, but with little success in retarding the rate of pericarp browning. Patra and Sadhu (1992) investigated the use of calcium nitrate (up to 5%) as a postharvest application to reduce the rate of whole fruit weight loss and to extend the

Table 33.4. Postharvest Physiological Characteristics of Lychee Fruit

Characteristic	Activity/Concentration	Reference Source
Chlorophyll, mature green fruit		
Chlorophyll a	80 μg/100 mg	Jaiswal et al. (1987)
Chlorophyll b	110 μg/100 mg	Jaiswal et al. (1987)
Total chlorophyll	190 μg/100 mg	Jaiswal et al. (1987)
Chlorophyll, mature red fruit		
Chlorophyll a	25 μg/100 mg	Jaiswal et al. (1987)
Chlorophyll b	14 μg/100 mg	Jaiswal et al. (1987)
Total chlorophyll	40 μg/100 mg	Jaiswal et al. (1987)
Anthocyanins (ACY)		
Cyanidin-3-glucoside	>10% of total ACY content	Prasad and Jha (1978)
Cyanidin-3-galactoside	>10% of total ACY content	Lee and Wicker (1991)
Cyanidin-3-rutinoside	67% of total ACY content	Lee and Wicker (1991)
Pelargonidin-3-glucoside	>10% of total ACY content	Prasad and Jha (1978)
Pelargonidin-3,5-diglucoside	>10% of total ACY content	Prasad and Jha (1978)
Malvidin-3-acetylglucoside	15% of total ACY content	Lee and Wicker (1991)
Sugars		
TSS	13°–20°Brix	Nagar (1994)
Fructose	1.6–3.1 g/100 g fruit weight	Chan et al. (1975a)
D-Glucose	5.0 g/100 g fruit weight	Chan et al. (1975a)
Sucrose	8.5 g/100 g fruit weight	Chan et al. (1975a)
Enzyme activity		
Polyphenol oxidase[a]	0.01 $\Delta OD_{410\ nm}$ 0.3 $\Delta OD_{410\ nm}$	Zauberman et al. (1991)
	0.5 μmol O_2/min/mg protein	Underhill and Critchley (1995)
Peroxidase[a]	0.3 $\Delta OD_{410\ nm}$/min/g fruit wt	Zauberman et al. (1991)
	0.01 $\Delta OD_{418\ nm}$/min/mg protein	Underhill and Critchley (1995)
Cellulase	0.18–0.25 mg Glu/h/g fruit wt.	Nagar (1994)
Pectinmethylesterase	1.5–2.0 μequi/min/g fruit weight[b]	Nagar (1994)
	1.0–1.4 μequi/min/g fruit weight[c]	Nagar (1994)
Ethylene production	1–5 μL/kg/h at 25°C	Underhill and Critchley (1993)
Respiration (CO_2)	20 μL/kg/h at 25°C	Nagar (1994)
Ascorbic acid	40–50 mg/100 g aril	Nagar (1994)

Note: All units are as cited by authors. Data relate to activity or concentration prior to storage.
[a]Pericarp PPO and POD activity.
[b]PME activity in the aril.
[c]PME activity in the pericarp.

shelf life. In another study, Roychoudhury et al. (1992) reported similar fruit loss during storage using 1% calcium nitrate without any effect on the fruit quality. Both these researchers made no specific reference to pericarp browning in their findings. The use of 1% calcium nitrate for 5 minutes was reported to have no effect on the rate of pericarp browning (Duvenhage et al. 1995). Similarly, a number of wax emulsions for coating lychee fruits have not met with any significant success in reducing either the rate of desiccation or the discoloration of pericarp (Bhullar et al. 1983). Underhill and Simons (1993) observed the development of microcracking shortly after harvest. Similar cracking was also noted in wax-coated fruits after 24 hours, which led to enhanced desiccation. This may explain the ineffectiveness of current commercial wax coatings to reduce water loss and thereby to inhibit pericarp browning.

Sulfur dioxide is used as an alternative treatment to control physiological browning in fruits, but the method of application is critical to treatment success. Burning sulfur powder is the most commonly used method, but regulating the dosage is a problem. Fumigation using gaseous sulfur dioxide tends to be more accurate (Duvenhage et al. 1995). The main problem with it is that sulfur dioxide rapidly bleaches the pericarp surface due to the formation of a colorless anthocyanin–SO_3H complex (Zauberman et al. 1991). To overcome this problem, they suggested immersing of fruit in 1% HCl for 2 minutes,

which leads to complete color recovery within 24–48 hours. The SO_2/low-acidity treatment not only leads to a permanent red color of the pericarp but is also very effective in controlling postharvest fungal diseases. In those countries where lychee industry is export oriented, significant advances in the commercialization of SO_2-based technologies have been made. It is, however, unrealistic to consider the use of sulfur dioxide as a long-term commercial solution because of the safety concerns.

Immersion of lychee fruit in hot water (98°C) for 30 seconds followed by a low-pH treatment is reported to improve the pericarp color retention during ambient storage (Kaiser 1995). To avoid the need for sulfur dioxide fumigation, the lychee fruits can be sprayed with hot water while undergoing mechanical brushing in a revolving drum, and then dipped in a 4% food grade hydrochloric acid +0.2% prochloraz fungicide solution (Lichter et al. 2000). The quality of lychee, particularly the pericarp color, can be preserved by treating fresh lychee with cold water, then hot water followed by hydrochloric acid, prior to drying the liquid off the surface of the fruit (Moran 2000). Jiang (2000) has suggested that the anthocyanin–PPO–phenol reactions are involved in lychee pericarp browning. Ascorbic acid content of the pericarp decreased significantly with increasing peel-browning index. As long as ascorbic acid was present, the anthocyanins remained unaltered, but the degradation of anthocyanins started as soon as all the ascorbic acid was consumed; simultaneously, the oxidation products of phenolic extract started to appear.

MAP using bioriented polypropylene (BOPP-1 or BOPP-2) in combination with antimicrobial agents on the postharvest quality retention of lychee fruit has been assessed as possible replacement for sulfur dioxide fumigation (Sivakumar et al. 2008). Among all the combination treatments they had studied, *Bacillus subtilis* + BOPP-1 had shown the best potential to control decay and to retain color as well as the overall quality during the marketing period of 20 days. Similar extension in postharvest shelf life of lychee fruit has also been obtained by MAP (using BOPP) along with the application of 1-methylcyclopropene (Reuck et al. 2009; Sivakumar and Korsten 2010).

PROCESSING OF LYCHEE

Lychee is most desirable as a fresh fruit. It is also processed into canned fruit, juice, and dehydrated products. Dried lychees are known as "Lychee nuts." During drying, the pulp shrivels around the seed and is very pleasant in flavor and develops raisin-like texture. Janjai et al. (2011) have reported thin layer drying of lychee fruit with acceptable quality. However, one of the best methods to retain the fresh flavor of lychee is freezing. The fruit can be frozen without peeling or the fruit may be peeled and seeded or left unseeded and frozen in syrup. Hand peeling is commonly used, but Chan and Cavaletto (1973) have successfully employed a combination of a hot-lye dip and mechanical peeling for lychee fruits. Lychee can be fermented for making Chinese medicine or used for making lychee wine, pickles, and preserve in China (Ong and Acree 1999; Karuwanna et al. 1994). The lychee fruit can be preserved by canning in syrup. Jelly can also be prepared from lychee fruit (Kuhn 1962), or it can be used in the preparation of sherbet and ice cream (Shaw et al. 1955). Lychee fruit can also be preserved as a highly flavored squash during the peak season (Sethi 1985; Jain et al. 1988).

Canning of Lychee

The general canning process for lychee fruits involves washing, peeling, pitting, and filling fruits into enameled cans. Light sugar solution of about 30°Brix is added to improve flavor; 0.1–0.2% citric acid is added to lower the pH to 3.8. The filled cans are exhausted to an internal temperature of 80°C, vacuum sealed, processed in boiling water for 12 minutes, followed by rapid cooling to room temperature. Alternately, a high-speed spin cooker at 90.6°C for 2–3 minutes can be used for obtaining a better quality product (Luh et al. 1986). If sugar content in syrup (containing 0.2% citric acid) is similar to that of the lychee fruit, pink discoloration, which is a serious problem of canned lychee, can be reduced (Wu and Chen 1999).

The sterilization temperature and pH have strong effect on pink color development (Wu and Fang 1993). Pink discoloration in canned lychee is due to hydrolysis of condensed tannins to catechin and leucoanthocyanin, which further degrade to anthocyanin. The cultivar and maturity stage are also reported to influence the discoloration (Hwang and Cheng 1986). Flavanone-3-hydroxylase and dihydroquercetin-4-reductase from lychee flesh play a key role in the biosynthesis of leucoanthocyanin (Wu 1992). According to Wu, the flavonones in mature lychee are converted to eriodictyol-containing compounds and then hydrolyzed by flavonone-3-hydroxilase to dihydroquercetin-containing compounds. These compounds are further reduced to leucocyanidin-containing compounds by dihydroquercetin-4-reductase, and during heat processing, these are finally converted into cyanidin-containing colored compounds. However in addition to the above, during storage of canned lychee, leucocyanidin-containing compounds may also develop through some other pathways (Hwang and Cheng 1986). To prevent pink discoloration in canned lychee, addition of 0.1–0.15% of citric acid to the packing medium (30°Brix syrup) and restricting the processing time in boiling water to less than 10 minutes have also been suggested (Chakravorty et al. 1974). Shortening the lapse of time between peeling and heating and immersing the lychee flesh in sodium bisulfite solution prior to heat processing are also known to reduce the extent of pink discoloration (Hwang and Cheng 1986).

Lychee Juice

Juice from lychee fruits is used for preparing juice blends or diluted into juice drinks, which are popular among consumers in Taiwan, China, Japan, South Africa, and in many Southeast Asian countries. The fruits for juice extraction are delivered to the factory shortly after harvesting, without much postharvest treatment. Peeling is a necessary step prior to juice extraction to avoid a bitter taste coming from the peels (Redlinghuys and Torline 1980). As hand peeling is labor intensive, delays production, lowers juice quality, and leads to microbial spoilage, mechanical peeling is desirable. Pitting of peeled fruit is not necessary. The peeled fruits are directly fed to a two-stage, paddle-type pulper finisher for juice extraction. By adjusting the clearance between the paddles and screen, the amount of broken seeds is reduced to less than 2%, and these seed fragments can be removed from the juice by the finishing screen. As the acidity of lychee fruit is low, pH of extracted juice is adjusted to 4.0 by adding citric acid prior to pasteurization at 95°C for 30 seconds. The pasteurized single-strength juice can either be hot-packed in 20-L tin cans or be frozen in 20-L plastic drums. Lychee juice may also be vacuum concentrated to double strength, shipped overseas as frozen concentrate at temperatures lower than –18°C. Taiwan, South Africa, and China are the major producers of lychee juice in the world.

The browning of lychee juice during processing and storage is a serious problem affecting the marketing of such processed products. Huang et al. (2006) suggested that polyphenol content, pH, metal ions (Fe^{3+}, Cu^{2+}, and Sn^{2+}), packaging, and storage temperature were the major factors involved in the nonenzymatic browning of lychee juice during processing and storage. Lychee juice flavor is known to be affected during various processing operations that the lychee fruit undergoes during its conversion to different processed products. Li et al. (2009) have observed a significant decrease in aroma compounds during processing. The major loss in aromatic compounds of clarified lychee juice was due to ultrafiltration and sterilization processes. They found an ultrafiltration membrane with larger pore size to be better than a smaller pore size ultrafiltration membrane, and a high-voltage pulsed electric field processing to be better than thermal sterilization.

FUTURE RESEARCH NEEDS

Fresh lychee fruit is most valued for its excellent flavor and textural qualities, but the maintenance of market quality of fresh lychees is a serious problem for the fruit handlers when the fruit has to be shipped great distances. Desiccation of fruits with its accompanying loss of red color of fruit skin and the development of pericarp browning can occur very quickly. The development of browning renders the fruit unsaleable and results in commercial loss to the fruit handler. The chemical changes that lead to browning of pericarp need to be further investigated for improving the shelf life of fresh fruit. Pink discoloration in canned lychee is another problem that needs to be tackled to enhance the scope of producing value-added products from lychee. The lychee trees are environmentally exacting, and reach fruiting stage very slowly from seed, and most seedlings do not produce fruits of commercially acceptable quality. Therefore, the development of good quality cultivars and establishment of an industry have been slow to develop. Nevertheless, concerted research efforts with this crop have to be continued, to evolve good cultivars for the successful growth of the lychee processing industry. The presence of phytochemicals in LFP as well as in seeds needs to be further investigated for their use in the formulation of health-promoting foods.

SECTION 3: PAPAYA

INTRODUCTION

Papaya (*Carica papaya* L.) a native to Central America is now distributed throughout the tropical areas of the world. Ripe papaya is mostly consumed fresh, but unripe and green papaya can be consumed as vegetable or used in preserves, sauces, etc. From the raw fruit latex, papain enzyme is produced, which finds extensive uses in the food and pharmaceutical industry. Apart from being an excellent source of ascorbic acid, the fruit is also a good source of provitamin A, B complex vitamins, and phytochemicals having antioxidant properties (Murcia et al. 2001; Leong and Shui 2002). Pureed papaya is a good source of β-carotene and iron for the lactating women (Ncube et al. 2001). India, Brazil, Mexico, Nigeria, Indonesia, and Ethiopia are the leading producers of papaya (Table 33.5). However, Columbia, Congo, Guatemala, the Philippines, United States, Taiwan, Puerto

Table 33.5. Major Papaya Fruit-Producing Countries of the World (in 2007)

Country	Production (MT)
World	6614
India	2685
Brazil	1811
Mexico	919
Nigeria	765
Indonesia	621
Ethiopia	260
Columbia	223
Congo, Democratic Republic of	219
Guatemala	184
Philippines	164

Source: FAOSTAT (2010).

Rico, Peru, Bangladesh, and Australia are also producing sizeable quantities of this fruit (FAOSTAT 2010).

CULTIVARS

Papaya is a rapid-growing, hollow-stemmed, and short-lived perennial tree, belonging to the family Caricaceae, which is usually propagated from seeds. Because of open pollination, papaya is a notoriously difficult crop to maintain as a pure or true cultivar. This family includes 4 genera and about 20 species of *Carica* native to tropical and subtropical areas of the world. Papaya attains a height of about 10 m under favorable growing conditions. The plant is dioecious, with either male or female flowers, though trees with hermaphrodite flowers also occur (Samson 1986). The fruit is a large, fleshy, hollow berry with small numerous seeds and weighs around 0.5–2.0 kg. Seedless cultivars have also been developed. Apart from Waimanalo, Solo is another important commercial variety of papaya, which produces hermaphrodite and female plants. The fruits from this variety have excellent quality for fresh consumption as well as for processing. Hortus Gold of South Africa, Improved Peterson of Australia, Betty, Solo Blue Stem, Red Rock, Cariflora of Florida (Conover et al. 1980), Semank of Indonesia, Sunny Bank, Guinea Gold, Hybrid-5 of Queensland are other important cultivars. Washington, Honey Dew, Coorg Honey Dew, Pusa Delicious, Pusa Majesty, Pusa Giant, Pusa Nanha, Pusa Dwarf, CO1, CO2, CO4, CO5, and CO6 are grown extensively in India. Pusa Giant is well suited for canning (Muthukrishnan and Irulappan 1985). Panama Red and Solo No.1 are commercially grown in Taiwan. Solo 62/3, Sunrise, and Solo cultivars are popular in Trinidad. About 10–15% of male trees are planted for pollination of female trees in a dioecious planting.

PHYSIOLOGY AND RIPENING

Papaya trees are fast growing and prolific fruit bearers. The first fruit is ready in 10–14 months from the time the plants are transplanted into the orchard (Sommer 1985). Most cultivars in India take about 135–155 days from pollination to fruit maturity (Selvaraj et al. 1982a, b), and 168–182 days in Hawaii. However, in a warm, hot climate, "Washington" papaya takes 145–150 days to reach the skin-color-turning stage (Ghanta et al. 1994). The fruit weight (Selvaraj et al. 1982a, b; Ghanta et al. 1994) as well as fruit length (Ong 1983) shows a typical double sigmoid type of growth curve. Increased fruit numbers could be attributed to improved fruit set and retention induced by the application of boron, and to increased production of indole acetic acid (IAA) induced by zinc application. IAA is known to affect flower production and fruit set in papaya (Kavitha et al. 2000a). The application of these two minerals is known to affect the biochemical and quality characters of papaya (Kavitha et al. 2000b). Treatment with zinc and boron produced higher levels of TSS, total sugars, reducing sugars, and nonreducing sugars (approximately 12.9%, 6.6%, 5.6%, and 1%, respectively). The TA and ascorbic acid in treated fruits averaged approximately 0.29% and 47.1 mg/100 g. Similarly, uptake of calcium by "Sunset" papaya fruit plays an important role in its ripening process. Mesocarp Ca concentration of about 130 μg/g of fruit weight was associated with slower fruit softening rate than in fruit with a lower Ca concentration (Yunxia et al. 1995).

Yield and quality of papaya fruits are greatly influenced by nitrogen–phosphorus–potassium (NPK) fertilizer application. Use of N at 200 g, P at 50 g, and K at 100 g per tree was found to be the most effective dose for increasing fruit yield and quality (ascorbic acid, TSS, and sugar) of mature papaya fruits (Lavania and Jain 1995). Application of micronutrients during fruit growth and ripening are known to influence the fruit quality (Chattopadhyay and Gogoi 1992). Micronutrients (B, Zn, Cu, Fe, and Mn) affected TSS, maximum levels (11.2%) were found in fruits treated with 40 ppm of boron. Treatment with 40 ppm of boron also increased total sugars (7.69% vs. 6.6%) and ascorbic acid (65.63 vs. 60.84 mg/100 g pulp). Treatment with B, Cu, and Zn (all 40 ppm) reduced TA. Carotene content was found to be higher in treated fruits (2.07–2.33 vs. 2.01 mg/100 g). Chattopadhyay and Gogoi (1992) recommended a combined foliar application of these micronutrients (40 ppm of each) to obtain good quality papaya fruits.

Various hydrolases play an important role in the modification of cell walls and softening of tropical fruits. Lazan and Ali (1993) have reviewed the biochemistry of softening process (depolymerization of pectin and hemicellulose), activity of cell wall hydrolases, role of PG, and β-galactosidase in mango and papaya softening, and the isolation of the β-galactosidase gene from mango and papaya. Mesocarp softening during papaya ripening was impaired by heating at 42°C for 30 minutes followed by 49°C for 70 minutes, with the areas of the flesh failing to soften (Paull and Chen 1990). Disruption of the softening process varied with the stage of maturity and harvest date. The respiratory climacteric and ethylene production were higher and occurred 2 days earlier in the injured fruit than in the noninjured fruit that was exposed to 49°C for only 30 minutes. Skin degreening and internal carotenoid synthesis were unaffected by the heat treatments. Exposure of ripening fruits to either 42°C for 4 hours or 38–42°C for 1 hour followed by 3 hours at 22°C gave thermotolerance to heat treatment at 49°C for 70 minutes. Although several physical methods such as reflectance measurement, delayed light emission intensity, and body transmission spectroscopy have been tried to measure fruit maturity, skin color change is usually used to determine maturity (Calegario et al. 1997). Once the major accumulation of TSS and DM has occurred after 120 DAA, and papaya fruit does not accumulate starch, commercial fruit quality is ensured if these fruits are harvested at 145 DAA, when the

first yellow coloration appears in the peel and the seeds turn black. Softness to touch is another indicator used as a ripening index. Among the physicochemical determinants, pH and Brix are very good indicators of ripening of the papaya fruit (Camara et al. 1993). Change of latex color from white to watery is another index of maturity of papaya fruit (Akamine and Goo 1971).

At harvest, water content varied from 87% to 97%, carbohydrates from 2% to 12%. The DM, which was 7% at 15 days after pollination, increased to 13% at harvest. Alcohol-insoluble solids, starch, and several minerals decreased, whereas total sugars increased during this time. The total and nonvolatile acidity decreased to a minimum at the fully ripe stage of harvest (Selvaraj et al. 1982a). The organoleptic qualities, volatile profiles, and lipid content of papaya have been shown to be highly dependent on the degree of fruit maturity (Blakesley et al. 1979). Soluble sugars accumulate mainly when papaya fruits are still attached to the plant. Sucrose synthesis still occurs even after harvest, as sucrose-phosphate synthase activity is highly correlated to sucrose content. Sugar content and sweet sensory perception are dissociated, while pulp softening has a strong correlation with sweetness, probably due to the easier release of cellular contents in fully ripe tissues (Gomez et al. 2002).

Ethylene Production

Being a climacteric fruit, papaya shows a typical respiratory and ethylene production pattern during ripening. Respiration rises to a maximum at the onset of ripening (the climacteric peak) but subsequently declines slowly. Respiratory climacteric is just preceded with a similar pattern of increased ethylene production (Paull and Chen 1983). The climacteric peaks in four papaya cultivars (Coorg Honey Dew, Pink Flesh Sweet, Sunrise, and Washington) have been observed between 120 and 150 DAA, when the fruit skin color started to turn yellow (Selvaraj et al. 1982b). An increasing trend of mitochondrial protein and RNA content until harvest maturity are associated with an increased synthesis of enzymes responsible for catalyzing the ripening process (Pal and Selvaraj 1987). Ethylene-forming enzyme (EFE) activity has been observed to be at the maximum in the exocarp of three-fourth ripe papaya fruits, but the EFEs in the mesocarp and endocarp were more heat sensitive than the EFE in the exocarp (Chan 1991). Slicing and deseeding increases respiration, ethylene production, skin degreening, and flesh softening (Paull and Chen 1997). Fruit with 60–80% skin yellowing had higher initial ethylene production, and respiration than the other ripening stages. Ethylene production and respiration of halved and deseeded fruits declined rapidly within 1 day during storage at 4°C. Fruits with 55–80% skin yellowing and less than 50 N flesh firmness had more than 50% edible flesh and easily removable seeds. Such fruits were suitable for minimal processing when combined with low storage temperature of 4°C.

CHEMICAL COMPOSITION

Papaya is a wholesome fruit, rich in sugars, and vitamins C, A, B_1, and B_2. Papaya is second only to mango as a source of β-carotene, a precursor of vitamin A. The physicochemical quality of papaya fruits (such as mean fruit weight, pulp yield, pulp–peel ratio, Brix, vitamin C, and total carotenoids) is influenced by various agronomic practices, planting time of the year being an important parameter (Singh and Singh 1998). September planting produced heavier mean fruit weight (2.30 kg), maximum TSS (11.2°Brix), vitamin C (74.55 mg/100 g) and total carotenoids (1152.50 mg/100 g), higher pulp–peel ratio than the fruits planted in other months. A typical composition of ripe papaya fruit is presented in Table 33.6.

Sugars

Among the carbohydrates, sugars are the major constituents of papaya fruit but amounts vary considerably depending on the cultivar and agronomic conditions. Indian cultivars have higher sugar content (10–10.2% TSS) than the papaya cultivars grown in the United States (5.65–7.1%) (Pal and Subramanyam 1980; Madhav Rao 1974). The presence of invertase enzyme in papaya resulted in the discrepancies in nonreducing sugar contents reported by different researchers (Chan and Kwok 1975). This enzyme was inactivated with microwave heating before sugar extraction, and out of the total sugar content, the papaya fruit had 48.3% sucrose, 29.8% glucose, and 21.9% fructose. Frederich and Nichols (1975) have reported that the papaya contained 30 calories, 10 g carbohydrates, 1.1 g fat, 0.6 g protein, and 0.9 g crude fiber

Table 33.6. Nutritional Value of Papaya (Per 100 g of Edible Portion of Raw Fruit)

Constituent	Content
Water (g)	88.7
Food energy (kJ)	165
Protein (g)	0.6
Fat (g)	0.1
Total carbohydrates (g)	10
Fiber (g)	0.9
Ash (g)	0.6
Calcium (mg)	20
Phosphorus (mg)	16
Iron (mg)	0.3
Sodium (mg)	3
Potassium (mg)	234
Vitamin A (IU)	1750
Thiamine (mg)	0.04
Riboflavin (mg)	0.4
Niacin (mg)	0.3
Ascorbic acid (mg)	56

Source: USDA (1968).

per 100 g of fruit flesh. Slightly different values reported by Munsell (1950) for 100 g of papaya fruit flesh are 88.6–89.3% moisture and 0.6–0.7 g crude fiber. In addition to invertase, papaya also contains other enzymes such as papain, esterase, PG, myrosinase, and acid phosphatase, which have effect on quality and stability of processed products made from papaya (Jagtiani et al. 1988).

Acids and Volatiles

The pH of papaya pulp ranges between 5.5 and 5.9 and it is low in acidity. The TA as citric acid is reported to be 0.099% (Jagtiani et al. 1988). Citric and malic acids are the major acids with smaller quantities of ascorbic acid and α-ketoglutaric acid (Chan et al. 1971). Apart from contributing flavor to the fruit, these acids may be used as a substrate in respiration when sugars have been exhausted. Among the 106 volatile compounds in papaya, linalool is the major constituent giving odor characteristic of fresh papaya. Linalool was found to be formed by the enzymatic activity during cell disruption. The compounds that are significant to papaya flavor include the major volatile component, linalool; several esters, because of their fruity flavors; lactones (γ-hexalactone, γ- and δ-octalactones); and β-ionone, because of their flavor threshold. Another major constituent, benzyl isothiocyanate, has a pungent off-flavor. Butyric, hexanoic, octanoic acids, and their respective methyl esters are the other components responsible for off-flavor in papaya puree (Flath and Forrey 1977). Among the 18 additional compounds reported by Macleod and Pieris (1983), methyl butanoate was found to be responsible for the sweet odor of some papaya fruits. Volatile aroma compounds emanating from fresh-cut papaya cv. Solo over a 3-day storage period at 20–22°C were found to be linalool (sweet + flowery) and benzaldehyde (almond), with smaller quantities of *cis*- and *trans*-linalool oxides, cyclohexane, hexanoic acid, and benzene methanol (Mohammed et al. 2001). After this storage period, the relative amounts of these compounds changed by nearly 50%, with benzyl acetate being the dominant aroma volatile component.

Vitamins and Minerals

Papaya fruit is known to be a rich source of ascorbic acid, provitamin A pigments, and many minerals (Wall 2006). Ascorbic acid present in fruits is more stable in the acidic medium of natural fruit juice than in vegetables. Furthermore, fruits are always eaten as fresh, thereby minimizing loss due to cooking process. During the development of papaya, ascorbic acid increases gradually, reaching the maximum value of 55 mg/100 g at full maturity (de Arriola et al. 1975). The change in outer color of the skin of fruit is an indicator of ripeness, and this change is considered mainly due to an increase in the carotene content and a decrease in chlorophyll. The total carotenoids content increases many folds from the original in the mature green stage to nearly 4 mg/100 g at the fully ripe stage of maturity (Selvaraj et al. 1982b; Birth et al. 1984). Carotenoids contents differ between the yellow- and red-fleshed papaya fruits (Cynthia et al. 2000). The red-fleshed papaya has 63.5% of total carotenoids as lycopene, which is absent in yellow-fleshed fruit (Yamamoto 1964). Munsell (1950) has evaluated two samples of Guatemalan papaya to contain 0.025 and 0.030 mg of thiamin, 0.029 and 0.038 mg of riboflavin, and 0.238 and 0.399 mg niacin per 100 g of fruit, but Asenjo et al. (1950) found niacin to range between 0.17 and 0.64 mg with an average of 0.320 mg per 100 g of papaya fruit. The antioxidant potential of Iranian *C. papaya* juice *in vitro* and *in vivo* has been reported to be comparable with α-tocopherol (Mehdipour et al. 2006). The free-radical scavenging action of papaya pulp is correlated with its superoxide and hydroxyl radicals, and because of this, the papaya pulp had shown bacteriostatic activity against many pathogenic microorganisms (Osato et al. 1993). Their results were indicative of the pathophysiological role of these reactive oxygen species in gastrointestinal diseases and papaya's ability to mitigate the harmful effects of oxidative stress. Fermented papaya preparation, which contains some immune-stimulating and antioxidant agents, has been reported to have the ability to modulate oxidative damage to DNA caused by reactive oxygen species (Aruoma et al. 2006). In a recent study, fermented papaya preparation has been reported to upregulate the redox defense activity of brain of spontaneously hypertensive rats (Yoshino et al. 2009).

Papaya fruits are also good sources of many minerals (K, Mg, and B) in human diet (Hardisson et al. 2001). The most abundant mineral is potassium, which is found combined with various organic acids. Awada and Suehisa (1973) reported the following minerals (in %) in papaya flesh from Hawaii: N, 0.12; P, 0.01; K, 0.21; Ca, 0.03; and Mg, 0.02.

Pectin

Reduced firmness or softening of the fruit observed during the ripening process is due to the hydrolytic change of protopectin to pectin. The enzymatic demethylation and depolymerization of protopectin lead to the formation of low-molecular-weight compounds with less methoxyl groups, which are insufficient to maintain the firmness of fruit. In these textural changes, PG and PME enzymes play an important role (Kertesz 1951). Loss of firmness is not uniform in papaya fruit, as sometimes the fruit becomes soft before the complete development of TSS (Pelag 1974). During the ripening process, water-soluble pectin content increases, reaching a maximum 2 days after the fruit starts to ripen. The increase in water-soluble pectin corresponds well with the decrease in protopectin of papaya fruit during ripening (de Arriola et al. 1975; Pereiraa et al. 2009). β-galactosidase-I is undetectable in immature fruits but appears to specifically accumulate during ripening (Ali et al. 1998). β-Galactosidase-II is present in developing fruits, but its levels seem to decrease during ripening. β-Galactosidase-I seems to be an

important softening enzyme, its activity increases four- to eightfold during early ripening stages. β-Galactosidase-II may also contribute significantly to the softening of papaya fruit because of its ability to catalyze increased solubility and depolymerization of pectin as well as the alkali-soluble hemicellulose fraction of the cell wall. The degree of methyl esterification of pectin molecules has been reported to be inversely related to the firmness values for green (95.42 N), intermediate (50.70 N), and ripe (9.61 N) papaya fruits (Manrique and Lajolo 2002). Hemicellulose modification and pectin hydrolysis are involved in the softening of papaya fruit, the latter apparently being more important during the late phase of fruit softening (Paull et al. 1999). The variety of fruit, the growing conditions, and the state of development at the time of harvest influence the chemical composition of pectin (Lassoudiere 1969a, 1969b).

Pigments

During ripening, the color of papaya flesh turns yellow or reddish. The carotenoids content (as β-carotene) showed a five- to tenfold increase in yellow-fleshed cultivars as the green ripe fruit matured to full ripe stage (Selvaraj et al. 1982a, b). However, in red-fleshed cultivars, the change of color was due to the marked increase in lycopene content (Bramley 2000; Sesso et al. 2004). The major difference between yellow- and red-fleshed cultivar is the total absence of lycopene in the yellow-fleshed papaya. Various carotenoids such as β-carotene, lycopene, β-cryptoxanthin, and β-zeacarotene are present in varying amounts in different cultivars (Chan 1983; Irwig et al. 2002; Cano et al. 1996; Wilberg and Rodriguez-Amaya, 1995a, 1995b; Bhaskarachary et al. 1995; Sugiura et al. 2002). The retention of β-carotene was found to be higher in papaya fruit treated with citric acid solution than with sodium hydroxide solution during refrigerated storage (Dutta et al. 2006). Carotenoids, which are relatively heat stable, showed higher retention than anthocyanins after blanching and drying of fruits (Sian and Soleha 1991). Levels of carotenoids and anthocyanins decrease progressively in pineapple and papaya as blanching temperature and time increased. Pretreatment with sodium metabisulfite prevented the oxidation of carotenoids but caused bleaching of anthocyanins. Orthophosphoric acid also changed the color intensity of anthocyanins but showed no effect on carotenoids. Carotenoids are more protected in a system in which a higher moisture level is maintained by glycerol and sugar. Anthocyanins, however, are stable only within a certain range of moisture contents. The consumption of major carotenoids present in mango and papaya juices, such as lutein, α-carotene, and β-carotene, can contribute to improve the vitamin A status of the consumers as they have higher bioavailability than other common sources (Gouado et al. 2007). In another study, the total carotenes and β–carotene contents of ripe papaya were found to be 2464 and 868 μg per 100 g, respectively (Chandrasekhar and Kowsalya 2002).

POSTHARVEST HANDLING AND STORAGE

Papaya fruit is highly perishable and is susceptible to fungal attack during storage and transportation. Al-Eryani et al. (2009) investigated the effect of calcium and chitosan treatments on control of the fungal diseases for improving postharvest quality of papaya fruits during storage. Combination of 2.5% Ca with 0.75% chitosan completely inhibited the spore germination and significantly inhibited the mycilia growth of *Colletotrichum gloeosporioides*, a pathogenic fungus on papaya fruits. Besides controlling the Anthracnose disease incidence, it also extended the storage life of papaya fruit to 33 days. Looze et al. (2009) purified and characterized a wound-inducible thaumatin-like protein from the latex of *C. papaya* which could have diverse functions like freezing tolerance, β-1,3-glucanase, carbohydrate-binding properties, and protection against osmotic stress.

Under cold storage, apart from the commonly encountered chilling injury (Wills 1990), papaya fruit also suffers from inability to ripen properly, lack of flesh color development, persistence of green color in skin, loss of firmness, and increased susceptibility of fruit to fungal attack. A range of storage temperatures has been suggested for different papaya cultivars harvested at the color break stage of maturity. Papaya fruit stored at 30°C has a maximum shelf life of only 7 days (Maharaj 1988). But at 10–15°C, it can be stored for 16 days (Aziz-Abou et al. 1975). de Arriola et al. (1980) have recommended 12°C as an optimum temperature for 2 weeks shelf life. Storage at a temperature lower than 10°C causes chilling injury (Ali et al. 1993). Papaya fruits are shown to ripen satisfactorily at temperatures between 20°C and 25°C, but storage above 32.2°C leads to delayed coloring and ripening, rubbery pulp texture, latex oozing, and surface bronzing (An and Paull 1990). According to the results of a study by Singh and Rao (2006), shrink wrapping (Cryovac D-955) alleviated chilling injury (CI) during 30 days of storage at 7°C, but the fruits failed to ripen properly and showed the CI symptoms of brown surface discoloration while ripening in storage. Paull et al. (1997) reviewed storage and handling of papaya (*C. papaya* L.), with reference to fruit quality (maturity, abrasion/impact, storage temperature, ethylene treatment, ripening conditions, heat treatment, diseases, and nonpathological disorders), postharvest losses, and observations in the market chain (Fig. 33.1). Goulao and Oliveira (2008) reviewed mechanisms of cell wall modifications during the ripening of different fleshy fruits. Bapat et al. (2010) reviewed the role of ethylene on ripening-related genes in fleshy fruits.

As would be expected, red-fleshed papaya is rich in lycopene, but this pigment is absent in yellow-fleshed papaya. The conversion of lycopene (responsible for red color) to β-carotene (having yellow color) is catalyzed by the β-cyclase. Devitt et al. (2010) cloned a β-cyclase gene in papaya that controls the color of flesh; this type of work has potential to

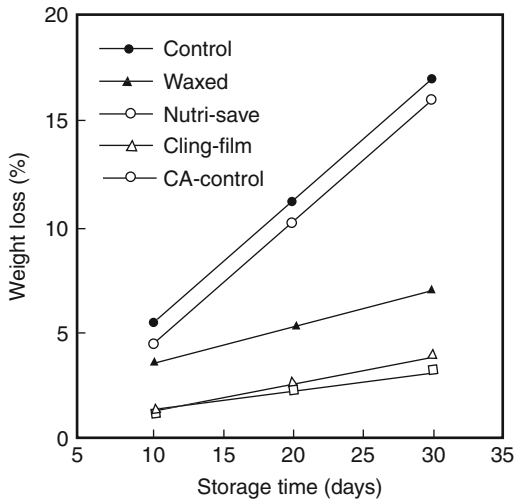

Figure 33.1. Weight loss of papaya during storage at 16°C under modified and controlled atmospheric conditions. (Adapted from Maharaj 1988.)

modify color and nutritional quality. Fabi et al. (2009) cloned and characterized various transcripts differentially expressed in the pulp of ripening papaya. This approach may be used to investigate differences in gene expression during ripening of papaya fruits.

Hatton and Reeder (1968) suggested controlled atmosphere containing 1% O_2 and 5% CO_2 during storage for 14 and 21 for maintaining market quality of papaya fruit. Maharaj (1988) reported that storage of papaya fruit at 16°C in an atmosphere of 1.5–2.0% O_2 and 5% CO_2 had lowest weight loss, minimum changes in firmness, and a longer time of ripening. If CO_2 level in controlled atmosphere exceeds 7%, off-flavors may develop in waxed and wrapped papaya fruits at the fully ripe stage of maturity (Paull and Chen 1989). Waxing serves two purposes: it reduces the weight loss and improves the fruit appearance. Fruits coated with Fresh Mark wax 51V (Fresh Mark Chemical Co., Florida, USA) were successfully stored for 29 days before the onset of fungal infection (Maharaj and Sankat 1990). Seal packaging is reported to modify both internal O_2 and external (in-package) atmospheres. A significant reduction in internal O_2 and a concomitant decrease in internal ethylene concentration are instrumental in delaying the ripening of sealed papaya fruits (Lazan et al. 1990). Use of methyl jasmonate vapor enhanced postharvest quality of papaya by reducing the loss of firmness, fungal decay and development of chilling injury, and increased retention of organic acids. Modified atmospheric packaging inhibited yellowing, together with the loss of water and firmness (Gonzalez-Aguilar et al. 2003).

Papaya fruits treated with gibberellic acid, vitamin K, silver nitrate, and cobalt chloride showed extended shelf life without any adverse effect on eating quality (Mehta et al. 1986). They attributed this improved shelf life to decreased rate of respiration due to lowered succinate and malate dehydrogenase activity in the tricarboxylic acid (TCA) cycle. At 20°C storage, use of a combination of hot water treatment with irradiation (75 krad) extended the shelf life of papaya fruits by an additional 8 days over the untreated controls (Brodrick et al. 1976). Gamma irradiations alone at 100–150 krad extended the shelf life of "Solo" papaya by an additional 3 days over the controls (Chye et al. 1980). Irradiated fruits are reported to have a slower rate of ripening (Camargo et al. 2007). Irradiated fruits exhibited reduced fungal infection, possibly due to the production of chlorogenic acid in the skin of fruit through the increased activity of phenylalanine ammonia lyase enzyme. Although a lower dosage of gamma irradiation extended the shelf life, it decreased the ascorbic acid contents in papaya fruits. On the other hand, higher irradiation dosages caused an excessive softening of fruit and increase in POD activity (Zhao et al. 1996; Paull 1996). The firmness of irradiated fruits was retained at least for 2 days more than the control, and the irradiated fruits also had a slower rate of softening (D'Innocenzo and Lajolo 2001). Incidence and severity of peel scald was increased by irradiation, regardless of storage and ripening (Miller and McDonald 1999). However, degree of severity was dependent on fruit maturity at the time of irradiation. Irradiation at quarter yellow stage of maturity causes the most serious incidence and severity of scald. Mature green fruit ripened at 25°C had the lowest incidence of hard areas in the fruit pulp ("lumpy" fruit). Quarter yellow fruits generally were only second to the irradiated mature green fruits stored at 10°C in incidence of lumpiness. Yordanov and Aleksieva (2007) reported that the shape and time stability of the electron paramagnetic resonance (EPR) spectra of γ-irradiated osmotically dehydrated papaya fruits is not a clear indication that these fruits have undergone radiation processing.

Brix, cellulase activity, and ethylene production were not affected by irradiation treatment of papaya fruits. The activities of PG, PME, β-galactosidase, cellulase, and 1-aminocyclopropane-1-carboxylate oxidase correlated to changes in firmness. Evidently, irradiation had no direct effect on firmness but acted by altering the ripening-induced synthesis of cell wall enzymes, mainly the PME. POD, PPO, and catalase enzymes are important during ripening as well as during frozen storage of papaya pulp. The POD reactivation in frozen papaya tissues is important during processing and could lead to undesirable changes in quality, especially in development of off-flavors (Cano et al. 1995). The use of gibberellic acid (150 ppm) was found to be very effective at reducing physiological loss in weight, TSS, and total sugar contents and in maintaining fruit firmness during storage of papaya fruits for 12 days at 30°C ± 2°C and 60–70% relative humidity. Further ripening parameters such as color and total carotenoid content were delayed, thus increasing the shelf life by an additional 4 days over that of control papayas (Ramakrishna et al. 2002).

PROCESSING OF PAPAYA

Papaya trees grow fast, start bearing fruit in less than a year, and are prolific bearers of fruits. All these qualities make papaya an important fruit crop for the processing industry. Besides consumption as a fresh fruit, papaya has many applications as a food material. As a consequence, a number of processed food products, such as puree, jam, jelly, candied fruit, juice, mixed beverages, baby foods, nectar, canned slices/chunks, concentrate, powder, dried slices/chunks, have been prepared from papaya on a commercial scale. Some of these products will be discussed later.

Fresh-cut Papaya

Globally, the tropical fruit consumption has been increasing during the last two decades. Today, the health conscious consumers demand natural products, especially the fresh-cut fruits and vegetables with desirable sensory quality and nutritive value. Most of the fresh-cut fruits rapidly deteriorate in quality during transportation, marketing, and storage. The deterioration of cut fruits is not due to injury caused by cold storage but due to the activities of several membrane and cell wall hydrolases, ethylene biosynthetic enzymes, and cell wall polyuronide degradation during low-temperature storage of papaya (Karakurt and Huber 2003). The fresh-cut processing (wounding) induces the expression of proteins involved in cell membrane degradation, free-radical generation, and enzymes involved in stress responses (Karakurt and Huber (2007). In a review, Toivoven and Brummell (2008) described the biochemical basis for color and texture changes in fruits and vegetables, such as enzymatic browning mediated by PPO, chlorophyll degradation, limiting cellular damage during processing of fresh-cut fruits and vegetables, continuation of cell wall disassembly events and declining cell wall strength, wound-response ethylene production, and the water loss. According to them, the wounding, water loss, and ripening-related turgor changes also lead to deterioration in the texture of fresh-cut fruits.

A number of approaches using chemical treatments have been suggested to preserve the quality of fresh-cut fruits (Rojas-Grau et al. 2009; Oms-Oliu et al. 2010). Use of alginate- and gellan-based coatings for improving barrier, texture, and nutritional properties of fresh-cut papaya (Tapia et al. 2008) and use of chitosan coating for fresh-cut papaya (Gonzalez-Aguilar et al. 2008) without adversely affecting the sensory quality of final product have been investigated. It is important to prevent contamination of fresh-cut fruits with pathogenic microorganisms, as *Escherichia coli* O157:H7 and *Salmonella* spp. are reported to survive on frozen cut mangoes and papaya for at least 180 days (Strawn and Danyluk 2010).

Papaya Puree

Papaya puree is the major semiprocessed product that finds use in juices, nectars, fruit cocktails, jams, jellies, and fruit leather. The initial step for the manufacture of puree is the removal of skins and seeds. A lye-peeling technique involves the use of hot caustic soda solution of 10–20% concentration, followed by water washing (Cancel et al. 1970). Machines have also been developed for the removal of skins and seeds (Brekke et al. 1973; Chan 1977). Earlier, the processing of papaya into puree was difficult mainly due to product gelation and off-flavor development. The development of undesirable odors due to the presence of butyric, hexanoic, and octanoic acids and their methyl esters was observed in puree prepared by commercial methods. In an improved method for processing puree, acidification and heat inactivation of enzymes prevented the development of these unpleasant odors and flavors (Chan et al. 1973). A number of treatments have been developed to prevent gelation in puree. Gelation develops due to PE activity, which can be prevented by heat treatment of pulp. Increasing the TSS of puree to 26°Brix by adding sucrose (Chang et al. 1965) or by lowering the pH of puree to 3.4 inhibits gelation (Brekke et al. 1973). To inactivate the enzymes and to stabilize the puree against deterioration in quality during frozen storage, the acidified puree is heated at 96°C for 2 minutes and cooled quickly to 30°C, packed and stored at –23°C or below. Before freezing for storage, the puree is passed through a 0.5-mm screen to remove fruit fibers. Brekke et al. (1972) developed a process to produce high-quality puree free from off-flavor and gelation problems. Microwave treatment of papaya puree produced a small change in qualitative and quantitative composition of carotenoid pigments, without significant alterations to the original color of the fruit puree (de Ancos et al. 1999). Deoxygenation by glucose oxidase mixed with catalase was found to retain the color, flavor, and ascorbic acid content of aseptically packaged papaya puree after 9 months at ambient temperature (Chan and Ramanajaneya 1992).

Papaya puree can be sold as such or it can be utilized as a raw material for other processed products. When it is sold as puree, it is usually canned or frozen. Puree prepared from varieties grown in Hawaii was reported to contain 11.5–13.5% TSS, 50–90 mg/100 g ascorbic acid, 3.5–3.9 mg/100 g carotenoids, and 84–88% moisture content (Brekke et al. 1973). The degradation of carotenoid pigments and visual color varies linearly with the temperature of processing and is therefore suggested to be used for online quality control of papaya puree (Ahmed et al. 2002).

Canned Papaya Products

Canned papaya chunks or slices are some of the popular ingredients employed for the preparation of fruit salads. Although fully ripe, soft papaya fruits are ideal for fresh consumption, but they are not suitable for canning purposes. For canning, only the green mature or semiripe papaya fruits are used. Lynch et al. (1959) have described a canning procedure for papaya slices or chunks. Papaya fruits are washed, peeled, and deseeded manually. The peeled fruits are diced in 2-cm cubes. About 300 g of cubes are filled

into No. 2 cans (307 × 409). Hot 40°Brix syrup containing 0.75% citric acid is poured over these cubes, leaving 0.8-mm headspace. The filled cans are exhausted in steam or hot water at 71°C, and sealed and processed in boiling water for 10 minutes. For ensuring the inactivation of PE enzyme, Nath and Ranganna (1981) recommended thermal processing of 3-cm papaya cubes in $2\frac{1}{2}$ size cans (hot filled with syrup at pH 3.8) at 100°C for 16.2 minutes so as to achieve a F-value of 1.33 or D-value of 2.5 during the canning process. For the establishment of required thermal processing time for canned papaya puree, the use of destruction studies with *Clostridium pasteurianum* conducted at the same temperature used for the inactivation of resistant portion of PE enzyme has been recommended (Dos-Amagalhaes et al. 1996).

Candied Papaya

Fully mature but unripe fruit is hand peeled, deseeded, and cut into 0.5–1.0 cm cubes. These cubes are soaked in 4% brine solution for 2 weeks, after which they are taken out and leached in running tap water to remove the salty taste. The fruit is boiled in 25°Brix syrup for a few minutes and then allowed to stand overnight. The sugar content of syrup is increased by 10% by boiling the mixture of fruit/syrup and allowed to stand overnight. This process is repeated for 5 days until the syrup concentration reaches between 70° and 75°Brix after standing. Other fruit essences such as orange, pineapple, raspberry, and strawberry are added to the syrup and allowed to stand overnight. At this stage, a translucent candied papaya is obtained, which can be rolled in powder sugar to prevent stickiness. The candied papaya finds extensive use in baked products, ice cream, and confectionery formulations. The papaya fruit can also be cut into 7.5-cm cubes and pricked with a fork. These pieces are soaked in 1.5% lime solution for 3–4 hours and then washed in fresh water. The remaining process of boiling in syrup is the same as explained earlier. The finished product pieces are crisp, juicy, and almost transparent. This product is packed in sterilized wide-mouthed containers for long-term storage (Kumar 1952).

Jam and Jelly

Fully mature and ripe, but firm, fruits are used for the preparation of jam and jelly. The fruits are peeled and seeds and inner white rind are removed. The fruit is cut into thin slices and cooked with little water to soften. The cooked slices are mashed, mixed with equal weight of sugar, and the mixture is cooked. Citric acid at the rate of 5 g/kg of pulp is added to improve the sugar–acid ratio and it also helps in the production of inverted sugars, which prevent sugar crystallization in jam during storage. The cooking of fruit pulp/sugar mixture is continued until it attains a thick consistency, which usually corresponds to a TSS of 65°–68°Brix. The jam is filled hot into clean, dry, and sterilized glass jars, sealed airtight and cooled, labeled, and stored. For the preparation of jelly, a clarified fruit extract from papaya pulp is mixed with the sugar, and the mixture is cooked to obtain satisfactory sheeting test or to a temperature of 106.5°C. The product is filled hot in dry, sterilized glass jars, sealed airtight, and cooled (Lal and Das, 1956). Reduced calorie tropical mixed fruit jams using low methoxyl pectin, acesulfame-K, and sorbitol have been made from pineapple, papaya, and carambola mixtures (Abdullah and Cheng 2001). The most acceptable single fruit was pineapple, followed by papaya, but the papaya had the best color among all these jams. Singh et al. (2009) have prepared jams from a combination of papaya with orange, banana, and pineapple and found papaya–pineapple jam to be the best product in terms of overall appearance, color, and flavor.

Juice, Concentrate, and Nectar

Juice and nectar are prepared from papaya puree, either alone or in combination with other fruit juices of different flavors to formulate exotic beverages. A number of formulations have been suggested by various researchers (Benk 1978; Brekke et al. 1973; Rodriguez and de George 1972). Nectar is a RTS beverage, which is prepared from thin pulp with sugar and citric acid. The final product has TSS of 15°–20°Brix and a mild acidic taste. The pulp is mixed with sugar (1.5–2.0 kg/kg pulp) and citric acid (12.5–17.5 g/kg pulp), color and flavor if required. The nectar is filtered and heated to 85–88°C, filled in plain or lacquered cans and cooled in running water to about 38°C. The cans are allowed to dry under ambient conditions to prevent rusting. Storage time and conditions affect the chemical composition and flavor of nectar, juices, and beverages. The type of container and diffused sunlight do not have significant effect on the darkening reactions (Payumo et al. 1968). However, the storage temperature is an important factor in determining the shelf life and quality of these products. After 50 weeks of storage at 38°C, 100 ppm of Fe and 400 ppm of Sn were found in the enamel-lined canned juices. The metal migration can be stopped at storage temperatures of 13–24°C (Brekke et al. 1976). Ascorbic acid decreases the color darkening of juices stored either at room or at refrigeration temperatures. Readings for color density were three times lower in samples that were refrigerated and/or treated with ascorbic acid than those of untreated controls (Payumo et al. 1968).

Squash formulations based on mango–papaya juice blends are prepared using sugar, citric acid, and water. Among the mango–papaya blended squash formulations, the one containing 75 parts of mango and 25 parts of papaya was found to be the most acceptable in terms of color, appearance, flavor, and taste attributes even after 90 days of storage at room temperature (Saravana-Kumar and Manimegalai 2001). Pretreatments given to papaya such as blanching was found to be most effective in affecting the shelf life quality of papaya

squash. Sulfur fumes and citric acid influenced the taste and color of the final product (Sheeja and Prema 1995). RTS beverage from the guava–papaya blends can be prepared using 15% pulp, TSS of 14°Brix, and 0.3% acidity (as citric acid) and processing at 90°C for 20 minutes. After a storage period of 6 months at room temperature, the RTS beverage from pure guava had the highest vitamin C content (28.1 mg/100 g), whereas carotene content was highest (441.6 μg/100 g) in pure papaya beverage (Tiwari 2000). Sensory quality score of guava–papaya (70:30) blend was the highest due to better consistency and flavor, and it also had fair amounts of vitamin C (24.7 mg/100 g) and carotene (303.7 μg/100 g). For the preparation of papaya concentrate, puree is treated with pectolytic enzyme (0.05–0.02%) for about 1–2 hours at a temperature of 50–60°C to reduce its viscosity (Sreenath and Santhanam 1992). The use of hydrolytic enzymes permits preparation of papaya juice free from suspended matter, with a low viscosity and with a flavor similar to that of the fresh fruit (Hermosilla et al. 1991). The depectinized puree is concentrated in a vacuum concentrator up to threefold, packaged, and stored at frozen temperatures. About 5.5% and 14.3% loss of ascorbic acid during pulping and concentrating steps was observed, respectively. About 10–15% losses in carotenoids and 40% in ascorbic acid contents during concentration operations were observed (Chan et al. 1975b; Janser 1997).

Blending of fruit juices could be an economic requisite and blending also helps to improve the appearance, nutrition, and flavor of finished products (Kalra et al. 1991). About 25–33% of papaya pulp (being richer in ascorbic acid than mango) could be incorporated in mango without affecting the quality, nutritive value, and acceptability of the blended beverage. Papaya, being cheaper than mango, could be blended with Dashehari, Chausa, or other varieties of mango in the preparation of economically viable blended beverages. Nectar prepared from papaya alone has an unpleasant aftertaste, whereas adding mango enhances nectar acceptability significantly (Mostafa et al. 1997). A blend of 15% papaya + 15% mango pulp was rated as excellent and was characterized by higher acceptability. In another study, Imungi and Choge (1996) prepared nectar formulations by blending mango and passion fruit purees with papaya puree and pear juice. Based on the cost of ingredients and sensory scores of nectars, blends of passion fruit + papaya (10:90), mango + papaya (10:90), passion fruit + pear (50:50), mango + pear (50:50), and pear + papaya (10:90) were considered as the most acceptable in order of preference. Parker et al. (2010) have prepared papaya pulp nectar using a combination of irradiation and mild heat. Irradiation (5 kGy or 7.5 kGy) in combination with mild heat treatment (80°C for 5 minutes) significantly reduced the PE activity and microbiological viability. This treatment combination further enhanced inhibition of *Listeria innocua* and *Clostridium sporogenes* and the product retained flavor and nutritional value closest to the untreated control.

Dried Papaya Products

A number of low-moisture products such as fruit leather, powder, toffees, chunks, rolls, and slices have been prepared from papaya puree. Siddapa and Lal (1964) patented a process for drying mixtures of papaya juices, previously concentrated, with sugar and other additives. A procedure for the dehydration of ripe papaya slices after steeping in 70°Brix syrup containing 1000 ppm of SO_2 was standardized to give the best quality product (Mehta and Tomar 1980a, 1980b). Slices from peeled and deseeded papaya fruit can be dried at 65.5°C to a moisture content of 8–10%. The dried slices are then ground to pass through 20-mesh screen. This product retained red color and much of the papaya flavor, though 5% of the ascorbic acid was lost, which can be minimized by using a vacuum drier. The pulp can also be dried after adding 5–7.5% sugar, 0.5% citric acid, and 0.3% KMS. This mixture is spread on greased trays in 1 cm thickness layer and dried in cabinet drier at 55–60°C. The dried product develops a leathery consistency, is rolled, and cut into desirable sizes. This fruit leather has a shelf life of about 8 months when stored at 24–30°C (Ponting et al. 1966).

Papaya toffee is a product similar to fruit leather and can be produced from puree. The pulp is first concentrated in a steam-jacketed kettle to a third of its original volume. Then, glucose, skim milk powder, margarine, essence, and color are added. The mixture is cooked to reach a final TSS of 82°Brix. Cooked mass is spread on previously greased hard trays to a thickness of 0.33–0.50 cm. After cooling for 2 hours, the sheet is cut into toffees and dried at 50–55°C to a final moisture content of 5–6%. The toffees are wrapped and packed in airtight jars or tins (Chan and Caveletto 1968). Papaya fruit bars when stored at room temperature for 9 months retained 54%, 46%, and 43% of total carotenes, β-carotene, and vitamin C, respectively, and were judged to have superior texture and aroma with fewer physicochemical changes (Aruna et al. 1999). For cheese product containing fruit blends, optimal ratio of papaya puree to pineapple puree was 2:1 with 2% pectin and processed to 77°–80°Brix (Barbaste and Badrie 2000). Sensory analysis indicated a significant preference for the blended fruit cheese. Shelf life of these products at 4–5°C was around 8 weeks.

Most of the dried products prepared from papaya fruit suffer from undesirable darkening effects. To overcome these defects, less severe treatments have been tried. Freeze-drying is one such method that produced good results to reach a moisture content of as low as 3% in the finished papaya powder. Although ascorbic acid does not significantly affect differences during freezing, 15–20% reduction is observed after freeze-drying. Storage of freeze-dried powder in glass jars did not show significant adverse effects on the quality or composition of finished products after 3 months (Salazar 1968). Carotenoids were found to be most stable in freeze-dried powder at a_w of 0.33 (6–7% moisture content) and were

recommended for the storage of freeze-dried papaya (Arya et al. 1983).

A combination of osmotic dehydration and freezing has been investigated for the preservation of papaya slices (Moyano et al. 2002). When fast freezing with liquid nitrogen (–63°C for 10 minutes) is used, then the osmotic drying conditions should be 65°Brix at 20°C for 60 minutes, and this combination gives a highly acceptable finished product. The ability to predict moisture and sugar contents accurately is useful for producing good-quality papaya products by osmotic dehydration. Two models have been developed by Mendoza and Schmalko (2002) to predict the contents of moisture and sugar during osmotic drying of papaya slices. The osmotic (60°Brix, 60°C) air-drying (60°C) method has been shown to save 8 hours in drying papaya cubes from 6.58 to 0.24 kg water/kg DM as compared with the sample air-dried using the air-drying (60°C) method (Kaleemullah et al. 2002). The removal of moisture from papaya cubes increased with the increase of syrup temperature. Rodrigues et al. (2003) have reported that the use of $CaCl_2$ reinforces papaya tissue structure and improves the texture of papaya slices during osmotic dehydration processing. Processing at 50°C with sodium lactate prevented the softening of papaya slices during processing by osmotic dehydration. The total processing time has been reduced using optimized conditions for osmotic dehydration followed by air-drying of papaya slices (Fernandes et al. 2006). Ultrasound-assisted osmotic dehydration has been reported to increase the water loss and sugar gain during osmotic processing of papaya slices (Rodrigues et al. 2009).

Heat pump dryers are known for their high-energy efficiency and low economic cost when compared with vacuum dryer or freeze dryer. Hawlader et al. (2006) have investigated the effect of using of nitrogen and carbon dioxide on the drying kinetics and quality of dried guava and papaya fruits. They observed less browning, faster dehydration, and more vitamin C retention in the finished products. Chen et al. (2009) optimized processing conditions (such as homogenization pressure and time, blanching time and temperature, and retention of vitamin C) for spray drying of papaya powder. The resulting powder was found to be suitable to prepare an acceptable quality papaya beverage. The dried papaya shreds and spices have been used for the preparation of papaya pickles.

Su and Liu (2006) optimized the process of making papaya pickle using 25 kg of dried papaya shreds, 2 kg of ginger shreds, 3 kg garlic, and 0.4 kg fresh hot peppers. The prepared product packaged in aluminum pouches and sterilized in water at 90°C for 10 minutes had the best quality and longest storage life.

Minimally Processed Products

Minimal processing is based on a combination of mild heat treatment (blanching), a_w reduction, pH reduction, and addition of potassium sorbate and sodium metabisulfite. This process is also known as the hurdle technology and has been used for the preservation of fruit slices. Papaya chunks treated with increasing levels of preservatives up to 680 ppm of metabisulfite and 826 ppm of sodium benzoate exhibited good storage stability up to 90 days at 2°C and ambient temperature (Vijayanand et al. 2001). O'Connor-Shaw et al. (1994) studied the shelf life of minimally processed (peeled, deseeded, and diced) honeydew melon, kiwifruit, papaya, pineapple, and cantaloupe when stored at 4°C. Both shelf life and type of spoilage were related to fruit species. Minimally processed fruits had longer shelf life at 4°C than at temperatures recommended for the whole fruit, if these were greater than 4°C. Spoilage of kiwifruit, papaya, and pineapple pieces stored at 4°C was found to be not due to microbial growth. Lopez-Malo et al. (1994) have produced shelf-stable high-moisture minimally processed papaya slices. The moisture and soluble solids contents, pH, and a_w remained almost constant in treated papaya slices during storage. These slices remained microbiologically stable, due to the sucrose hydrolysis, which reduced a_w in the product. Ascorbic acid decreased during processing and storage at 5°C and 25°C. The total KMS and potassium sorbate concentrations decreased to 62% and 66%, and 40% and 60% of their initial concentrations. No differences were observed in sensory properties of samples stored at 5°C or 25°C. Minimally processed papaya slices had good acceptability even after 5 months of storage at 25°C. The use of vacuum osmotic dehydration (VOD) techniques for the production of high-moisture minimally processed papaya has also been reported (Tapia et al. 1999). It was possible to obtain minimally processed papaya (a_w 0.98, pH 3.5) by applying vacuum osmotic drying for just 10 minutes when sucrose syrup contained 7.5% citric acid, or by applying pulsed VOD treatment (vacuum pulses for less than 15 minutes followed by osmotic drying for less than 45 minutes) when the citric acid concentration in sugar syrup was 2.5% or 5%.

By-Products From Papaya

Papain

Papain is the major by-product from dried latex derived from papaya fruit, which contains a protein-hydrolyzing enzyme. This enzyme has a number of specific technological applications such as in meat tenderization, beverages, and animal feeds; pharmaceutical industry; textile industry and detergents; paper and adhesives; medical applications; sewage and effluent treatment; and research and analytical chemistry (Flynn 1975; Sanchez-Brambila et al. 2002; Kaul et al. 2002). Papain is a hydrolytic enzyme, which digests proteins into amino acids. Papain in solution is easily oxidized by exposure to air, high temperature (above 70°C), or sunlight. Contact with metals such as iron, copper, zinc, and many others also inhibit this enzyme. For improving the stability

of papain enzyme, a number of chemicals such as ascorbic acid, sodium ascorbate, erythorbic acid, sodium erythorbate, sodium metabisulfite, 4-hexylresorcinol, TBHQ, rutin, α-tocopherol, trehalose, and sucrose have been tried (Epsin and Islam 1998). The highest percentage of enzyme activity was retained at 55°C for all chemicals except sucrose and trehalose, which gave best performance at 40°C. Among the food applications, the use of papain in chill haze removal during beer clarification as well as in the tenderization of meat has shown a steady increase over the past years. Based on rat feeding studies, Adebowale et al. (2002) reported that normal consumption of ripe papaya during pregnancy may not pose any significant risk, but unripe or semiripe papaya may be unsafe in pregnancy, as the high concentration of latex produces marked uterine contractions.

Production of papain latex is an economically important alternate product of papaya cultivation. Sun drying of latex is a cause of concern especially in the heavy rainfall areas. Nowadays, vacuum shelf drying is more popular as it yields higher quality product. Papaya cultivars differ in papain yield, Red Panama (Lassoudiere 1969a, 1969b; Foyet 1972), CO6 (Balmohan et al. 1992), CO2 (Wagh et al. 1992), and the line CP1512, CP1513, CP4 (Auxcilia and Sathiamoorthy 1995), and CP5911 (Kanan and Muthuswamy 1992) are shown to produce a high papain yield. Other factors affecting the papain yield from papaya plants are fruit shape (Lassoudiere 1969a, 1969b), stage of maturity (Singh and Tripathi 1957; Bhalekar et al. 1992), season of tapping (Reddy and Kohli 1992), tapping time of the day (Lassoudiere 1969a, 1969b; Foyet 1972), pattern of tapping (Madrigal et al. 1980), and frequency of tapping (Bhutani et al. 1963). Four repeated applications of the plant hormone, Ethephon in coconut oil (at 37 mM), have shown to increase papain yield (Shanmugavelu et al. 1976).

Muthukrishnan and Irulappan (1985) have described the procedure for the collection of latex as well as crude papain manufacturing process using simple equipment. Fruits grown for papain production are thinned on the plant so that each fruit hangs separately for easy collection of latex. Using plastic or stainless steel knives, fruits are lanced and the latex is collected in glass or porcelain containers. Four to five longitudinal cuts made during the morning hours gave the highest yield of latex. Over a period of 2 weeks, this process is repeated three or four times on the untapped portions of the fruits in 3–4 days intervals. The latex, which hardens within 15 minutes, is then precipitated with alcohol, washed with acetone, and dried in a vacuum drier for obtaining good quality crude papain. The addition of KMS (0.05%) in small quantities to the liquid latex before drying acts as a preservative and improves the quality of crude papain powder. The dried papain is powdered and sieved through a 10-mesh sieve and stored in airtight containers. The yield of crude papain powder obtained from raw green papaya is reported to be usually around 0.025% (Nanjundaswamy and Mahadeviah 1993) (Fig. 33.2).

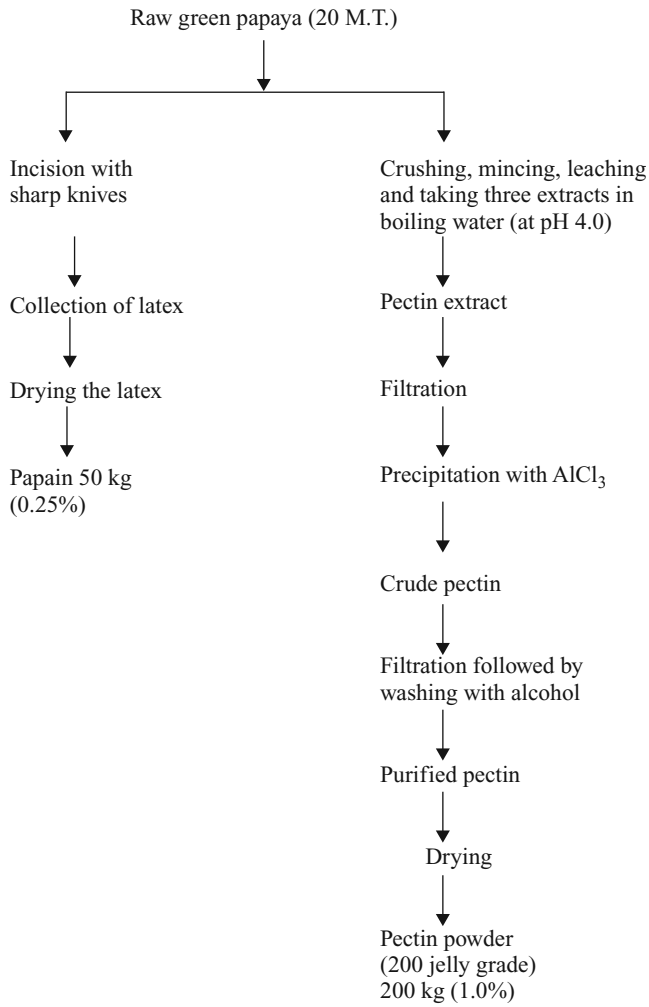

Figure 33.2. Flow sheet of integrated process for the production of papain and pectin. (Adapted from Nanjundaswamy and Mahadeviah 1993.)

Pectin

To make papaya cultivation and papain industry viable, the profitable use of scarred fruit is essential. The quality of such papaya fruits does not appear to be affected adversely but only the fruit appearance seems less attractive to the consumers. The green fruits, whether scarred or not, are rich source of pectin (10% pectin on dry basis), which can be extracted for use in food industry (Das et al. 1954; Varinesingh and Mohammed-Maraj 1989). Peel is shown to be higher in pectin content than the papaya pulp, and pectin content increases at a higher rate with fruit maturity up to a stage (Paul et al. 1998). The integrated processing of papaya fruits for the production of papain and pectin has been found to be economical (Nanjundaswamy and Mahadeviah 1993). This process gives a papain yield of 0.25% and a pectin (jelly

grade 200) yield of 1% on fresh fruit basis. The variety of the fruit, growing conditions, and stage of maturity of fruit are all known to influence the chemical composition of pectin (Lassoudiere 1969a, 1969b).

Miscellaneous Uses of Papaya

Parts of papaya plant (leaves, stem, seeds, roots, and latex) are being investigated for therapeutic value and medicinal properties (Canini et al. 2007; Galindo-Estrella et al. 2009). The pure papain-induced uterine contractions were not sustainable for a longer period; however, the papaya latex (which may be a combination of enzymes, alkaloids, and other substances) produced sustained uterine contractions acting mainly on the alpha androgenic receptor populations of the uterus, thus having abortion-causing properties (Cherian 2000). Dried powder roots of papaya also possess abortion-causing properties (Sarma and Mahanta 2000). Papaya latex has cysteine proteinases that can digest nematode cuticles and can be used for countering gastrointestinal nematode/parasitic infections as these have antihelminetic activity (Stepek et al. 2004; Okeniyi et al. 2007). Papaya leaf extract has shown vasodialtory and antioxidant properties, which could provide health benefits to reduce cardiovascular risks (Runnie et al. (2004). Papaya seeds extract is a good source of antioxidants (Jorge and Malacrida 2009) with a potential as an antifertility drug (Lohiya et al. 2000) or male contraceptive (Goyal et al. 2010); or as a novel nonconventional low-cost adsorbent for the removal of methylene blue (Hameed 2009). Papaya biomass has been used for the sorption of heavy metals (such as mercury) as environmental pollutants (Basha et al. 2009). The application of papaya lipase as an emerging and versatile biocatalyst for producing modified fats for various applications has been reported (Maria et al. 2006; Wiermann et al. 2008).

Due to the activity of proteolytic enzymes as well as the antimicrobial activity, papaya fruit has been used for the treatment of pediatric burns in Africa (Starley et al. 1999; Gurung and Skalko-Basnet 2009). Recombinant chitinase produced by gene cloning from papaya with antifungal and antibacterial properties has been produced by Chen et al. (2007). The recombinant chitinase enzyme was able to inhibit 100% spore germination of *Alternaria brassicicola* and 50% inhibition of the *E. coli*. Extracts from both green papaya (GPE) and ripe papaya (RPE) have been investigated for the wound healing and fetal toxicity properties in mice (Anuar et al. 2008). GPE treatment was found to be more effective than RPE as it induced complete wound healing in a shorter time (13 days) compared with 17 days in RPE. Hiramoto et al. (2008) studied the effect of oral administration of fermented papaya preparation (FPP) for the prevention of hypersensitive immune-response. Their results indicate that the FPP has a therapeutic potential against dermal and allergic inflammations. FPP has also been reported to attenuate β-amyloid precursor protein, which is related to the pathogenesis of Alzheimer's disease (Zhang et al. 2006). FPP has shown high free-radical scavenging ability both *in vitro* and *in vivo*. Their results showed that FPP prevents the cell apoptosis through Bax/Bcl-2 sensitive pathway. The aqueous and methanol extracts of whole unripe papaya contain terpenoids, alkaloids, flavonoids, carbohydrates, glycosides, saponins, and steroids, which may have cytoprotective and antimotility properties (Ezike et al. 2009). Oral administration of these extracts significantly reduced the ulcer index on the ethanol- and indomethacin-induced gastric ulcers in rats.

FUTURE RESEARCH NEEDS

Papaya fruit is of considerable economic importance, as it enjoys domestic markets in many tropical countries and export markets in the temperate countries. Limited shelf life of papaya fruit under ambient tropical conditions, susceptibility to mechanical injury during handling and transportation, pest attack, and fungal diseases are some of the constraints that need to be overcome to prevent considerable fruit wastage. Recommended refrigerated storage temperature varies with the variety that need to be optimized to avoid chilling injury and to maintain desirable flavor of papaya fruit. Limited research has so far been reported on the use of modified and controlled atmospheres for papaya fruit storage. Improved methods of postharvest handling, storage, and packaging are necessary to alleviate the chilling injury in papaya fruits. Various parts of papaya plants, which are rich in health-promoting phytochemicals with a potential to act as free-radical scavengers, need to be further investigated for possible medicinal uses.

More research is necessary in tissue culture propagation of papaya rather than depending on the production of plants from seeds. This newer technology raises the prospects for rapid dissemination of high-yielding, disease-resistant cultivars, developed for specific conditions, or localities to encourage the production of excellent quality fruits for fresh consumption as well as for processing industry. Antioxidant properties of papaya leaves, stems, roots, and fruits need to be further investigated for health-promoting properties.

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34
Production and Processing of Date Fruits

Jiwan S. Sidhu

Abstract: Date fruit has always occupied an important place in the dietary habit of people in the Arab world. In spite of the enormous socioeconomic transformation that has taken place in this part of the world, date fruit continues to form an essential component of the daily diet of most people. To provide comprehensive coverage at one place, this chapter covers date palm cultivation, date production and marketing, date cultivars, physiochemical characteristics of date fruits, postharvest handling and treatments, storage problems, value-added products (such as jam, jelly, pickles, chutney, date bars), by-products of date processing, nutritive value and other health benefits, standards, and regulations.

INTRODUCTION

In the Arab world, there are few cultivated plant species that have so well integrated with human sustenance as the date palm (*Phoenix dactylifera* L.). In spite of the enormous socioeconomic transformation that has taken place in this part of the world, date fruit continues to form an essential component of the daily diet. In the Arabian countries, the date palm tree (Figs. 34.1A, B) and its fruits have immense importance. Every household feels proud to grow at least one tree in their backyard for fruit production. Date tree is mentioned and honored in the Holy Quran, and recommended by the Prophet—"Peace Be Upon Him." Date fruit is known to be a rich source of carbohydrates (mainly glucose and fructose sugars) and certain vitamins, minerals, and dietary fiber (Al-Hooti et al. 1997f).

Date fruit development is differentiated into four maturity stages, that is, *kimri, khalal, rutab,* and *tamer* (Hussein 1970). *Kimri* stage fruit is young, green in color with hard texture, thus can be used for the preparation of pickles and chutney. Depending on the cultivar, the date fruit changes its green color during the next stage. The *khalal* (*or bisr*) stage date fruit attains maximum size and weight; develops a typical yellow, purplish-pink, red, or yellow-scarlet color but retains a firm texture and is largely consumed raw as fresh fruit or can be used for jam, butter, or dates-in-syrup (Al-Hooti et al. 1995b). During the *rutab* stage, half of the fruit becomes soft, less astringent, and sweeter but darkens in color and can be used for jam, butter, date bars, and date paste. *Rutab* stage fruits of a few cultivars are being popularly consumed as fresh. During the final or ripe stage, *tamer*, the whole fruit attains maximum total solids, highest sweetness, and lowest astringency with a dark brown color, a soft texture, and a wrinkled appearance.

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(**A**) (**B**)

Figure 34.1. (**A**) Fruit-bearing date tree. (**B**) Date fruit trees in an orchard.

The physical appearance of a few date cultivars at various stages of maturity is shown in Figures 34.2A–G. For prolonged shelf life and storage, *tamer* stage fruits can be sun dried. A major portion of the date produce enters world trade as *tamer* fruit for human consumption (Mikki et al. 1986).

Date fruit is cherished for its flavor and nutritive value all over the Arab world, as this plant is well suited to grow in arid regions where there are hot and dry climates with limited rainfall. Date trees are usually propagated vegetatively by offshoots. The trees grown from seeds show high genetic heterozygosity that result in not true-to-type male and female plants (Toutain 1967). To overcome these drawbacks of longer generation times and genetic heterozygosity, newly emerging tissue culture techniques are now being employed for the propagation of date palm trees (Zaid 1986; Sudhersan et al. 1993a, 1993b).

This chapter reviews production, preharvest and postharvest handling, storage, physicochemical characteristics, nutritive value and health benefits, processing and marketing aspects of date fruit.

HISTORY OF DATE CULTIVATION

The date palm belongs to the Arecaceae (or Palmae) family and has been cultivated for a long time in the semiarid and desert areas of Middle East, Pakistan, India, the United States (California), in the Canary Islands, and in the northern African countries for fuel, shade, fiber, food, and as building material (Nixon 1951). In addition to date palm, this family also includes other kinds of palm trees such as oil palms, coconut palms, and Washington palms. Although it is not known exactly where the date palms originated, it is suggested that they first originated in Babel, Iraq or in Dareen or Hofuf, Saudi Arabia, or Harqan, an island in Bahrain, from where it spread to other places (Marei 1971). Date palms were first introduced to Andalus by the Arabs, during the seventh and eighth centuries and later spread throughout the deserts of the Middle East and North Africa by the Bedouin tribes of the Arab countries. It is also believed that date palm trees were introduced in India by Alexander, the Great, around 327 BC. In around 1769, date seeds were introduced to the arid areas in the United States, namely the states of New Mexico, California, and Arizona (Al-Tayeb 1982). The Middle East and North African countries are the major date-fruit producing countries in the world; the United States and Spain also produces sizable quantities of date fruits.

DATE PALM CULTIVATION

Being a tree of the desert, date fruit is well established in the Middle Eastern region. Date trees grow to about 23 m tall; the stems are strongly marked with the pruned stubs of old

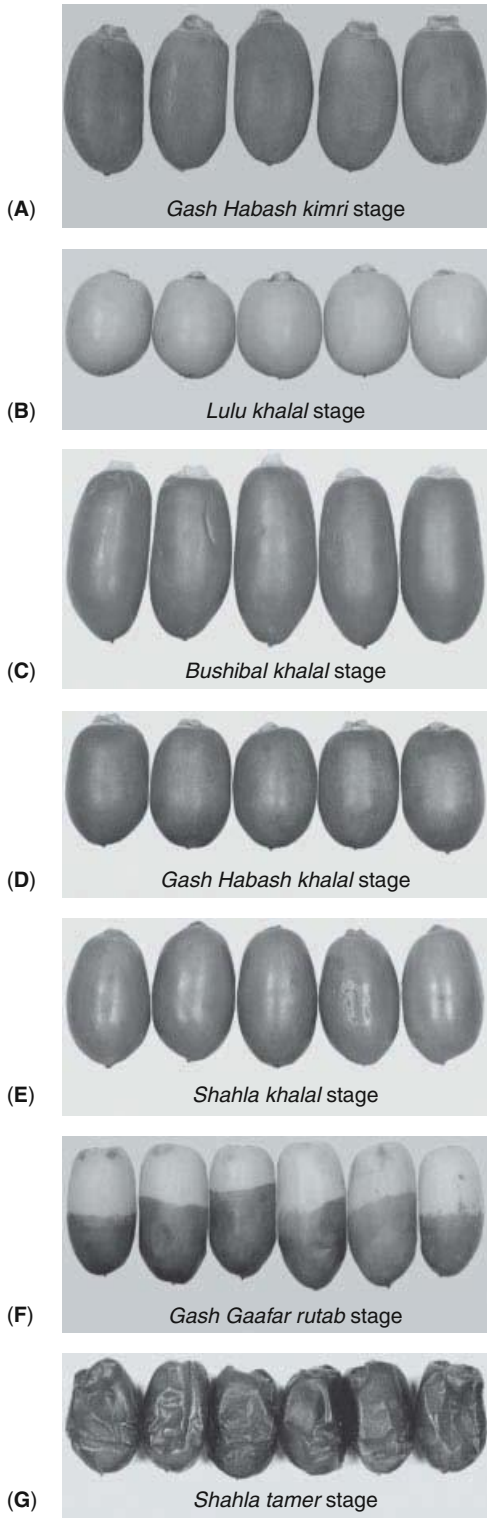

Figure 34.2. (**A**) *Gash Habash* cultivar—*kimri* stage of maturity. (**B**) *Lulu* cultivar—*khalal* stage of maturity. (**C**) *Bushibal* cultivar—*khalal* stage of maturity. (**D**) *Gash Habash* cultivar—*khalal* stage of maturity. (**E**) *Shahla cultivar—khalal* stage of maturity. (**F**) *Gash Gaafar* cultivar—*rutab* stage of maturity. (**G**) *Shahla* cultivar—*tamer* stage of maturity. (*Photo source*: Prof. Jiwan S. Sidhu.)

leaves. The plant has a crown of graceful, shining, pinnate leaves, measuring about 5 m long. Depending on the cultivar and other agricultural practices, 1000 dates may appear in a single bunch and weigh 8 kg or more. Date trees start bearing fruit in 4–5 years and reach their full potential in 10–15 years, producing 40–80 kg of fruit per tree. Although date trees can live as long as 150 years, due to declining fruit production, commercial cultivators replace them at an earlier age. Propagation of date palm trees through seeds is not successful because of the high genetic variation (not true-to-type) in male and female seedlings. Thus, date palms are mainly propagated by offshoots produced by younger palm trees, and these offshoots maintain true-to-type makeup of the cultivars (Nixon and Farr 1965). With the recent developments in tissue culture techniques, date palm breeding has been given a boost. Now, this technique is being used extensively to clone a wide range of economically important palms such as coconut palms (Eeuwens and Blake 1977), oil palms (Rabechault and Martin 1976), and date palms (Tisserat 1979).

Date cultivation is not mechanized in the Middle Eastern and North African countries; most operations such as pollination, pruning, and harvesting are carried out manually. However, attempts are being made to mechanize date production due to the rising cost of production and shortage of skilled labor (Shabana and Mohammad 1982). The number of palm trees per hectare is an important parameter that determines the yield and quality of date fruits. The number of trees per hectare varies from 100 to 250 depending on the cultivars. For most cultivars, palm trees are usually planted in square patterns with about 9 m gap between the rows. For the initial few years, intercropping of fodder or vegetable crops can be carried out. In the United States, most operations, such as pollination, bunch thinning, pruning, bagging, and harvesting, are carried out with the help of machines (Perkins and Brown 1966; Brown 1982). Harvesting is a very expensive operation as it consists of handpicking of individual, mature fruits from each bunch. Pollination is the next expensive operation. To ensure good yields of quality fruits, pollination must be performed according to the opening of the flowers. One part of pollen is usually mixed with 6–10 parts of wheat flour a day or so before the application to the female flowers (Brown et al. 1969). Thinning is carried out at that time, bunches are tied down so that optimal amounts of fruits are retained in these bunches to attain an acceptable fruit size.

With regard to the irrigation requirements of date trees, an old Arab saying, "The date palm, queen of trees, must have her feet in running water and her head in the burning sky," has been quoted by Hussein and Hussein (1982a), who recommended moderate irrigation of 12 applications per year with 300 m^3/*Feddah* each time at intervals of about 4 weeks. Prolonged periods of severe water restriction during the growing period have been reported to affect the growth of leaves, and the size, grade, and yield of fruits (Aldrich 1942; Furr 1956). Unsuitable irrigation practices result in small-sized early ripening fruit of poor quality (Hilgman et al. 1957).

Deep irrigation at long intervals is more beneficial in maintaining higher moisture levels in the root zones compared with shallow irrigation at short intervals (Hilal 1986). Although the date tree can tolerate the hot, dry conditions of desert climates, sufficient quantities of irrigation water must be provided during the fruiting season to obtain the maximum yield of higher quality fruits.

The amount of nitrogen fertilizers used affects the vegetative growth and yield of fruit (Furr and Armstrong 1959). The addition of nitrogen to palm trees increases the fruit yield but the dry matter, total soluble solids, total sugars, and sucrose remain lower (Hussein and Hussein 1982b). When the fruits have higher moisture content, the fruit maturity is delayed. About 750 g of nitrogen per palm tree is recommended to obtain the highest fruit yield and quality. The Saudi date palm growers are generally satisfied with the use of organic manure only. Bacha and Abo-Hassan (1982) investigated the effect of seven fertilizer treatments comprising nitrogen, phosphate, potassium, and organic manure on the yield and fruit quality of the *Khudari* date variety grown in Saudi Arabia, and showed that chemical fertilizers increased the fruit yield and size but did not affect the mineral contents of the fruits. In addition to organic manure, they recommended 1500 g of nitrogen per tree.

Pruning is one of the important cultural practices in palm cultivation, and it affects the fruit-bearing capacity of the date tree. The number of green leaves present on a date tree depends on the cultivar and determines its photosynthetic potential and ultimately its fruit-bearing capacity (Nixon 1943). Too many leaves may affect the fruit quality adversely by shading and may increase disease incidence. The presence of an adequate number of leaves on palm trees is important; the most suitable leaf–bunch ratio has been suggested as being 5.4–9.0 by a number of researchers (Nixon and Wedding 1956; Nixon 1957; Miremadi 1970; Miremadi 1971; Abdulla et al. 1982) who reported that leaf–bunch ratio affected the fruit yield and other properties except the titratable acidity, tannins, and crude fiber of *Hayany* dates grown in the Kalubia Province of Egypt. In Saudi Arabia, 12 leaves are usually left in each bunch, to obtain the best yield and fruit quality (Hussein et al. 1977), but farmers in the western province cut off only dry leaves after harvest (Khalifa et al. 1983). During pruning, the spikes (thorns) are also removed to facilitate pollination and fruit picking during the harvesting operation.

Date trees bear flowers that can be bisexual or unisexual and monoecious or dioecious. The occurrence of hermaphroditism in male date palm has been reported (Sudhersan and Abo El-Nil 1999). Although the date tree normally produces only unisexual flowers, the occurrence of bisexual flowers has also been reported in this species (De Mason and Tisserat 1980). Because of the unisexual nature of this plant, the female flowers, within a few days of opening, are pollinated manually (a tedious and expensive operation) by sprinkling pollen from male flowers on them. The production, storage, and handling of pollen, therefore, are very important operations for the success of date cultivation. In the United States, pollination is done mechanically from the ground, thus minimizing the drudgery (Nixon and Carpenter 1978). To economize on the use of pollen, it is mixed with diluents such as talcum powder or wheat flour. The time of pollination, type of male flowers, and storage history of the pollen are known to affect the fruit set as well as its quality. Use of 20–40% pollen in talcum powder gives satisfactory yield and fruit quality for *Zegloul* date trees. Use of 20% pollen results in lower bunch weight but the fruit quality is improved (El-Kassas and Mahmoud 1986). Better fruit set and quality are obtained if pollination is carried out just before sunset rather than in the morning (Moustafa et al. 1986). Pollen stored either at room temperature or at chilling temperature in a refrigerator produces higher fruit set compared with the pollen stored in a deep freezer (Shaheen et al. 1986). Male palms having greater (spathe) weight, greater length, and number of strands and more than 15 g of pollen per spathe should be selected for pollination to obtain the best fruit set and quality (Nasr et al. 1986). Mixing one part pollen with nine parts wheat flour or in 10% sucrose solution has been reported to be more effective than the use of pure pollen in smaller amounts (Khalil and Al-Shawaan 1986). Wheat flour and sugar solution media are good carriers of date palm pollen grains.

Due to overbearing of fruits, alternate bearing is common among many cultivars of date palm, resulting in smaller fruits of inferior quality. Fruit and bunch thinning usually overcomes this problem and improves fruit quality (El-Hamady et al. 1982). Commercially, thinning operations could be accomplished mechanically by reducing the number of fruits per bunch or the number of bunches per tree. To reduce alternate bearing and to improve fruit quality, certain chemicals such as 2,4-D (2,4-dichlorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), and ethephon are used as thinner for many fruit crops including the date palm (Ketchie 1968; El-Zeftawi 1976; Weinbaum and Muraoka 1978). Use of 400 ppm of ethephon significantly reduces the biennial bearing behavior in date trees (El-Hamady et al. 1982). Compared with controls, significantly higher fruit weight and total soluble solids but lower tannin contents were obtained in fruits treated with ethephon. Thinning treatments improve the fruit quality but result in an overall lower yield of fruit per tree. To expose the date fruits to sunlight and to prevent fruit-bearing stalks from breaking, bunches are pulled downward and tied to a nearby leaf stalk at the *kimri* stage. This practice is particularly important for those cultivars having long fruit stalks.

DATE PRODUCTION AND MARKETING

The annual world production of date fruits was reported to be 7048 metric tons (MT) during the 2009 crop year, and is

Table 34.1. Major Date Fruit Producing Countries of the World (MT)

Country	Production	Country	Production
World	7048	Iraq	440
Algeria	500	Israel	30
Egypt	1326	Kuwait	14
Libya	175	Qatar	21
Sudan	336	Oman	256
Tunisia	127	Spain	5
United States	165	Saudi Arabia	983
Bahrain	13	Morocco	73
China	135	UAE	755
Iran	1000	Yemen	55
Mauritania	22	Pakistan	680
Chad	18	Turkey	9

Source: FAOSTAT (2010).

expected to increase further due to the efforts taken by various countries to encourage and popularize date palm cultivation through modern tissue culture techniques (FAOSTAT 2010). Egypt leads the world in date fruits with a total production of 1326 MT in 2008 (Table 34.1). The other major producers are Iran, Saudi Arabia, United Arab Emirates (UAE), Pakistan, Algeria, Iraq, Sudan, and the Sultanate of Oman.

For marketing purposes, most of the fresh dates at the *khalal* and *rutab* stages of maturity are packaged in wooden or plastic crates (2–3 kg/crate) and offered for sale in the fruit and vegetable markets in these countries. However, dates at the *tamer* stage of maturity are packaged in tin cans, plastic bags, or straw baskets, either in a pressed or in an unpressed form. These date fruits are bought by the consumers from the date markets usually located in a central place in the town (Sabbri et al. 1982). Although the major portion of dates is consumed at the *tamer* stage, a significant amount of *khalal* date fruit is also being consumed. Thus, the marketing prospects for fresh dates at the *khalal* stage have opened up interesting opportunities to extend their shelf life and consumer acceptability (Al-Hooti et al. 1995a). Asia is the largest importer and consumer of date fruits in the world. Within Asia, China and India are the major importers of date fruits. In the European Union, France is the leading importer followed by Germany. In North America, the United States is the main importer of date fruits, followed by Canada.

DATE CULTIVARS

Hussain and El-Zeid (1975) reported the existence of 400 cultivars, but Nixon (1954) had indicated the probability of only about 250 named varieties. Among these cultivars, only a few dozen have attained economic and commercial importance. Of the four imported cultivars grown commercially in the United States, three-fourths of the cultivated area is under *Deglet Noor* cultivation and 10% under, *Zahidi, Khadrawy,* and *Halawy*. Knight (1980) reviewed important cultivars grown commercially all over the world. The cultivar *Deglet Noor* (which literally means the date of the light or translucent seedling) is popular because of its large size, light color, delicate flavor, and outstanding shelf life during storage. This cultivar is also known for prolific bearing, and ripens in October–November. Like most other date cultivars, it also requires high temperature and low humidity for proper ripening. Another high-yielding *Yahidi* cultivar is being commercially grown in Iraq. This cultivar is hardy and drought resistant, and exhibits vigorous growth. *Hallawi* (which means sweet) cultivar bears a light-colored fruit and is one of the leading cultivars grown in Iraq and exported from Basra. Another cultivar *Sayer* (meaning widespread) known for its very sweet fruit is a hardy plant capable of tolerating adverse climatic conditions. It has shown the highest production and is quite important in commercial trade. *Medjool* is an important commercial cultivar from Morocco known for its sweetness.

Asif et al. (1986) described the characteristics of 15 commercially important cultivars, *Burhi, Gur, Hilali, Khalas, Khasab, Majnaz, Ruzeiz, Sahal, Shashi, Tanjeeb, Tayyar, Um Rahim,* and *Zamil* that are being grown in the Al-Hassa area of Saudi Arabia. Some of the cultivars like *Khudari, Nabbut-Al-Seif, Sullaj, Sukai, Maktumi, Sultana, Shagra, Nabtat Ali, Shbibi, Barni, Rabiaa, Safawi, Shalabi*, and *Sifri* are the major cultivars of commercial importance in Saudi Arabia (Anon 1984). Some of the other important cultivars being grown commercially are *Zaghloul, Duwiki,* and *Hayani* in Egypt; *Kabkabe* and *Khustawai* in Iran; and *Barhee, Maktoom, Shalabi, Sukkari,* and *Khustawai* in Iraq (Popenoe 1973; El-Kassas 1986).

PHYSICOCHEMICAL CHARACTERISTICS

Morphology of Date Fruits

Depending on the cultivars as well as the stage of maturity, date fruit varies its shape, size, and color. Besides changes in physical characteristics, date fruit varies greatly in chemical composition. As the fruit matures, it undergoes major morphological and chemical changes that subsequently determine the overall quality and acceptability of this fruit. A lot of information on the physicochemical changes occurring in date fruits during different stages of maturity is now available from all the major date-fruit growing countries of the world (Salem and Hegazi 1971; Shabana et al. 1981; Mohammed et al. 1983; Al-Hooti et al. 1997f).

Date fruits may have round, oval, oblong, or cylindrical shapes depending on the cultivar. Al-Hooti et al. (1997f) reported physical measurements and colors of five major date-fruit cultivars grown in the UAE. All the cultivars were green in color at the *kimri* stage but at the *khalal* stage, the color varied among the cultivars. At the *khalal* stage, *Shahla*

and *Bushibal* were red, *Gash Gafaar* and *Lulu* were yellow, whereas *Gash Habash* fruits were yellow-scarlet (Figs. 34.2A–G). At the last stage of maturity (i.e., *tamer*), the fruits of all the cultivars turned dark brown and shriveled considerably. The fruit weight, pulp–seed ratio, and physical measurements at the various stages of maturity of these five cultivars have been described in detail elsewhere (Sidhu and Al-Hooti 2005). At the *kimri* stage, the *Bushibal* and *Gash Gafaar* fruits are cylindrical in shape, whereas the *Lulu* fruits are nearly round. These shapes are more or less retained by all cultivars throughout the various stages of fruit development. The lengths of *Bushibal, Gash Gafaar, Gash Habash,* and *Shahla* are 26.5, 24.8, 23.7, and 27.7 mm, respectively, with the corresponding values for width being 15.4, 15.5, 17.7, and 18.6 mm. In contrast, the *Lulu* cultivar has a length and width of 19.3 and 18.6 mm, respectively, indicating its nearly round appearance. Fruit weights are generally the highest at the *khalal* stage (6.1–10.0 g) and decrease subsequently toward the *tamer* stage (4.9 g). The pulp percentage varies from 83% to 90%, and the seed percentage varies from 10% to 17% among these five cultivars.

The physicochemical characteristics of 55 Saudi cultivars at *khalal* and *tamer* stages of maturity are quite similar to those of the UAE cultivars reported by Al-Hooti et al. (1997f). Some of Saudi cultivars had a bigger fruit size (25.6–26.8 g) at the *khalal* stage, but it was reduced to 13.7–14.1 g at the *tamer* stage. The fruit weights ranged from 5.8 to 26.8 g (with an average of 13.5 g) at the *khalal* stage and from 4.8 to 18.3 g (with an average of 9.8 g) at the *tamer* stage. The weight of seeds ranged from 0.7 to 1.8 g at *khalal* stage and 0.6–1.3 g at the *tamer* stage of maturity of these cultivars. The pulp percentage of these cultivars was reported to be in the range of 86–96% and was slightly higher than that reported by Al-Hooti et al. (1997f), although some of the smaller fruit cultivars studied by them had similar fruit size and pulp percentages. Sourial et al. (1986) evaluated four local cultivars, namely, *Sofr-Eldomain, Kabooshy, Sergy,* and *Homr-Baker*, in relation to their control cultivar, *Hayany*, grown in Egypt for their physicochemical characteristics. The fruit lengths for these five cultivars ranged from 4.9 to 5.6 cm and fruit weights ranged from 15.79 to 25.30 g, seed weights ranged from 1.87 to 2.38 g, and pulp percentage ranged from 88.15% to 90.70%. In another study, Nour et al. (1986) reported the physical characteristics of nine dry palm cultivars (i.e., *Balady, Bartamuda, Degna, Garguda, Gondalia, Kolma, Malkabi, Sakkoti,* and *Shamia*) grown in Aswan, Egypt. The fruit weights, fruit lengths, fruit widths, and seed weights ranged from 6.5 to 16.9 g, from 3.89 to 5.40 cm, from 1.75 to 3.32 cm, and from 1.0 to 1.63 g, respectively. The cultivar *Malkabi* had the highest fruit weight (16.9 g), *Shamia* was the longest (5.4 cm), and *Bartmuda* had the smallest seed (1.0 g only). Physicochemical characteristics and sensory quality of two date varieties have been investigated under commercial and industrial storage conditions by Ismail et al. (2008). Khalas variety maintained the best quality for only 2 months at -3°C, whereas Barhee variety was good for 1 year at this temperature.

Carbohydrates

The major chemical constituents of date fruit are carbohydrates, mainly reducing sugars, such as glucose and fructose, and also a nonreducing sugar, sucrose. Carbohydrates (i.e., sugars) are, therefore, the most widely studied constituents of date fruits. The chemical composition of five major cultivars grown in the UAE at various stages of maturity has been described by Al-Hooti et al. (1997f). In a majority of the cultivars, the sucrose content increased rapidly as the date fruit matured, reaching the highest level at the *khalal* stage (42.58%) but subsequently decreased to a nondetectable level at the *tamer* stage of maturity. As the date fruits matured, the glucose and fructose sugars increased rapidly to reach a level of 38.47–40.04%. When the date fruit matured from the *kimri* to the *tamer* stage, the fructose content increased approximately threefold, which accounts for the characteristic sweet taste of *tamer* date fruits? The total sugar contents, which were 32.99–38.20% at the *kimri* stage, reached nearly 80% by the *tamer* stage of maturity. The presence of equal amounts of glucose and fructose in soft-type cultivars is responsible for their enhanced levels of sweetness. On the other hand, some of the semidry and dry cultivars are reported to retain higher levels of glucose than fructose or the unhydrolyzed sucrose. One of the earliest studies also reported that the total sugars and invert sugars increased with ripening, reaching a maximum level by the later stages of development (Vinson 1924).

The total reducing sugar contents are related to the cultivar as well as to the stage of maturity. In the semidry varieties of Egyptian *tamer* dates, both the sucrose and reducing sugars are about 35–40% each. The total sugar concentration at this stage reaches between 80% and 90% of the dry weight. During the curing stage, the sucrose content of soft varieties disappears completely (Ragab et al. 1956). The total sugar contents of 39 Saudi Arabian cultivars varied from 61% to 80% (Hussein et al. 1976). The sucrose content is usually the highest (10–30%) at the *khalal* stage in most of the cultivars, but it declines to 0–2% at the *tamer* stage. In contrast, the reducing sugars generally increase with fruit development, reaching 29–85% at the *tamer* stage of maturity. Reducing sugars are mainly the predominant sugars at *tamer* stage in most of the cultivars, with the exception of two cultivars, namely, *Sukkari* and *Sukkarat Al-Shark,* which contain more sucrose at the *tamer* than at the *khalal* stage of maturity. In a given cultivar, the sucrose and reducing sugar contents are related to the quality and texture of the date fruit (Coggins and Knapp 1969). The majority of Saudi Arabian cultivars (Hussein et al. 1976) having higher concentrations of reducing sugars at the *tamer* stage, are the soft-type date fruits. The five cultivars from the UAE reported by Al-Hooti et al. (1997f) with nondetectable sucrose contents at the *tamer*

stage also belonged to the soft-type date fruits. The declining moisture content coupled with the rapid increase in glucose and fructose contents render the *tamer* date fruits extreme resistance to fungal spoilage during storage.

As the texture and color of dates are the important attributes affecting fruit quality and acceptability, most of the biochemical and enzyme studies have been limited to these aspects of date-fruit physiology. The higher activity of the sucrose-hydrolyzing enzyme invertase present in soft-type date-fruit cultivars is the most important enzyme influencing the date-fruit quality and is considered to be mainly responsible for the highest levels of reducing sugars present at the *tamer* stage of maturity (Vinson 1911; Vandercook et al. 1980). The changes in invertase activity in *Deglet Noor* date fruits during maturation and ripening have been studied by Hasegawa and Smolensky (1970). Soluble invertase increases dramatically when the date fruit matures from the green stage to the early red stage. The insoluble form of this enzyme is present in substantial amounts during the green stage, when it decreases to 50% of its original activity and then remains fairly constant later on. Both the insoluble and soluble invertase hydrolyzes sucrose, raffinose, and melezitose in a similar manner. Among the four grades of dates evaluated in their study, soft, good quality dates had a higher activity of this enzyme than the tougher dates of inferior quality. Invertase can be used to improve the quality and market value of date cultivars, which have crystalline sucrose present in their tissues (Smolensky et al. 1975). The enzyme concentration, temperature, and the time of treatment are important to bring the ratio of sucrose–reducing sugars to a level low enough to prevent sucrose crystallization later on during storage. Soluble invertase and insoluble invertase have been isolated from date fruits (*Zehdi* var.), and for both enzymes 45°C is an optimum temperature for activity (Marouf and Zeki 1982). The optimum pH ranges for soluble and insoluble invertase are 3.6–4.8 and 3.6–4.2, with K_m values of 3.12×10^{-3} and 4.35×10^{-3} mM, respectively. The specific activity of soluble invertase is 40.2 μM/mg protein per minute, while the specific activity of insoluble invertase is 1.1 μM/mg protein per minute. Sodium dodecyl sulfate inhibits both the enzymes.

Proteins

In addition to the major constituent carbohydrates, date fruits contain significant amounts of protein, crude fiber, pectin, tannins, minerals, and vitamins. Al-Hooti et al. (1997f) analyzed five important date cultivars from the UAE at different stages of maturity. The crude protein content in these cultivars is highest at the *kimri* stage (5.5–6.4%) and gradually decreases to 2.0–2.5% as the fruit reaches the *tamer* stage of maturity. Although the protein content is not high in *tamer* date fruits, the essential amino acid content of these proteins is quite good. Similar protein content in other cultivars has been reported by various other workers (Hussein et al. 1976).

Fat

The date fruit is low in crude fat, which usually ranges from 0.5% at the *kimri* stage to 0.1% at the *tamer* stage of maturity (Ragab et al. 1956; Al-Hooti et al. 1997f).

Crude Fiber

The crude fiber content of date fruits at the *kimri* stage is substantially higher (6.2–13.2%) than that at the *tamer* stage (2.1–3.0%) of maturity (El-Kassas 1986). The crude fiber content of date fruits is not a good indication of their dietary fiber content (Yousif et al. 1982). The total dietary fiber content (comprised of pectin, hemicellulose, cellulose, gums, mucilages, resistant starch, and lignin) depends on the stage of maturity of the date fruits (El-Zoghbi 1994). Xylan has been identified as one of the components of date-fruit fiber (Hag and Gomes 1977). Alcohol-extractable material from date fruit, when further treated with water, dilute acid, and aqueous alkali yields polysaccharide, which contains varying proportions of D-galactose, D-glucose, L-arabinose, D-galacturonic acid, and L-rhamnose. Glucomannan is another polysaccharide found in date fruits. The structure of glucomannan isolated from the seeds of Libyan dates has been elucidated (Ishrud et al. 2001). This polysaccharide is extracted with 80% hot ethanol (Fraction-I) and 0.1 M phosphate solution (Fraction-II), fractionated and purified by ion exchange and gel filtration chromatography. According to methylation and hydrolysis analysis, the main chains of FI and FII consist of 1–4, linked glucomannan with only traces of branched sugar residues.

The total fiber decreases as the date fruits lose their firm texture and become soft at the *tamer* stage. A large variation in the total dietary fiber content of date fruits comes from the type of method employed in its determination. The Southgate method does not determine resistant starch, whereas the Fibertec and Englyst methods do (Kirk and Sawyer 1991). So, to obtain comparable results, internationally accepted methods of analysis for dietary fiber must be employed. The total dietary fiber content measured by the enzymatic method (Lund et al. 1983) has been reported to be 9.2% (6.9% as insoluble and 2.3% as soluble fiber). The total fiber content in some of the dates from Saudi Arabian, Egyptian, Iraqi, and Irani cultivars, determined by the Fibertec system, ranged from 8.1% to 12.7% (Al-Shahib and Marshall 2002). Research conducted during the past three decades has shown that an adequate intake of dietary fiber (20–25 g daily) lowers the incidence of colon cancer, heart diseases, diabetes, and other diseases. Obviously, the consumption of 100 g of date fruit (six to seven dates) would provide us with about 50% of the recommended daily amount of dietary fiber. The total dietary fiber of dates decreases from 13.7% at the *kimri* stage to 3.6% at the *tamer* stage of maturity (Ishrud et al. 2001). The decrease in the pectin, hemicellulose, cellulose, and lignin contents during date-fruit ripening range from 1.6 to 0.5, from 5.3 to 1.3, from 3.4 to 1.4, and from 3.5% to 0.3%, respectively. This

shows that maximum benefit can be obtained by consuming fresh dates (i.e., those at the *kimri, khalal,* and *rutab* stages) rather than by consuming the fully mature *tamer* fruits. The presence of resistant starch in the fresh dates will provide an additional advantage as it may be prebiotic, promoting conducive conditions for the growth of desirable bifidobacteria in the lower gastrointestinal tract (Topping and Clifton 2001). Chemical composition and characteristics of the dietary fiber obtained from two date palm cultivars grown in Tunisia have been reported by Elleuch et al. (2008). They obtained a concentrate from date fruits that contained a total dietary fiber content ranging from 88% to 92.4% and that exhibited a water-holding capacity of approximately 15.5 g water/g sample.

Pectins

The pectic substances (considered a part of the soluble dietary fiber) are a complex mixture of polysaccharides that are important constituents of plant cell wall structures. The pectin contributes to the adhesion between cells and also plays an important role in some of the processed fruit products such as jams, jellies, and preserves (Jarvis 1984). As the date fruit ripens, protopectin is converted into water-soluble pectin through the combined action of two pectolytic enzymes, polygalacturonase, and pectin methyl esterase (Coggins et al. 1968; Al-Jasim and Al-Delaimy 1972). There is a close relationship between polygalacturonase activity and fruit softening during ripening (Hasegawa et al. 1969). Like invertase, polygalacturonase activity is relatively higher in soft dates than in the tough dates. Unlike cellulase and polygalacturonase, the activity of pectin esterase increases as the fruit grows reaching a maximum during the *khalal* and *rutab* stages of maturity (Al-Jasim and Al-Delaimy 1972). Cellulase activity, which is absent in *kimri*-stage fruit, increases as the fruit develops, reaching its peak at the late *rutab* stage and remains constant during the *tamer* stage (Hasegawa and Smolensky 1971). As the date fruit ripens, the pectin content increases, reaching a maximum level at the *khalal* stage (7.0–14.3%), and then decreases at the *tamer* stage (1.3–1.9%) of maturity. Graces-Medina (1968) estimated the pectin contents of banana, mango, pineapple, and mountain apple to be 0.62%, 0.38%, 0.13%, and 0.47%, respectively. The date fruit, therefore, can be a better source of soluble dietary fiber in our diet than some of the more common fruits such as banana, mango, pineapple, and apple.

Minerals

Dates are known to be a reasonably good source of many minerals. The mineral composition of date fruit is largely affected by the level of soil fertility as well as by the amount of chemical fertilizers and manures applied to the trees (Hussein et al. 1976). The ash content of date fruits decreases from the *kimri* stage (3.5–3.9%) to the *tamer* stage (1.3–1.8%) of maturity (Al-Hooti et al. 1997f). The ash content of some common fruits like grapes, apples, plums, and oranges is also similar (1.9–3.1%) to that of date fruits (FAO 1982). Obviously, date fruits are an equally good source of important minerals. Although the mineral content decreases at the *tamer* stage of maturity, the change is small when compared with changes in other constituents such as sugars. The composition of date fruits from five major cultivars being grown in the UAE, in terms of important mineral contents, has been reported in detail by Al-Hooti et al. (1997f). These date cultivars are rich in most macroelements but are poor in microelements. Like most other fruits, these cultivars are low in sodium (1.5–9.4 mg) but high in potassium (402.8–1668.6 mg). Minerals, particularly potassium, accumulate in date fruits during ripening (Ragab et al. 1956). This low sodium, high potassium makes this fruit a desirable option for persons suffering from hypertension.

Date fruits are considered a rich source of iron (Anwar-Shinwari 1987). Different varieties generally contain significantly varied amounts of iron per unit weight or per fruit, the variation is attributed to genetic differences. Boron is another important mineral present in date fruits. The formation of a red complex between boron and the quinalizarin reagent can be used to determine the boron content in date fruits through a simple and sensitive spectrophotometric method. At 620 nm, the absorbance is linear ($r = 0.999$) over the 0.25–2.5 μg/mL concentration range (Al-Warthan et al. 1993). This method can detect the prevailing wide variation in the mineral contents of Saudi Arabian date cultivars.

Tannins

The tannins in date fruit play an important role not only in flavor perception but also in development of color during ripening and storage. The color of dates is primarily due to the pigments produced by browning reactions during ripening, processing, and storage. These brown pigments could be produced by three possible mechanisms: browning of sugars, enzymatic oxidation of polyphenols, and oxidative browning of tannins (Coggins and Knapp 1969). Generally, the oxidative browning reactions occur more rapidly at elevated temperatures than at low-refrigerated temperatures. Even at room temperature, the enzymatic browning of polyphenols and tannins is much faster than sugar browning reactions. However, at temperatures above 38°C, sugar-browning predominates. As the date fruit matures, tannins decrease rapidly from the highest value of 1.8–2.5% at the *kimri* stage to about 0.4% at the *tamer* stage of maturity (Al-Hooti et al. 1997f). This trend of reduction in tannins with ripening was also observed earlier in other date cultivars (Hussein et al. 1976).

Kimri fruit is quite astringent and unpalatable but this decreases drastically at *tamer* stage when the level of tannins reaches a very low level, indicating some probable contribution of tannins in the flavor of date fruits. The *Lulu* cultivar had the lowest tannin content at the *khalal, rutab,* and *tamer*

stages of maturity, when compared with other cultivars. The major enzyme involved in the metabolism of tannins in date fruits, polyphenol oxidase (PPO), has been studied at different stages of ripening (Benjamin et al. 1979). Using catechol as a substrate, the optimum pH and temperature for its activity are 6.4 and 37°C, respectively. This enzyme has no monophenol oxidase activity and varies in specific activity toward several diphenols. Its heat inactivation follows first-order reaction conditions. During the ripening of date fruit, the PPO activity is the highest at the *kimri*, followed by *khalal* and *tamer* stages. The PPO activity can be completely inhibited by 0.01 M of ascorbic acid, cysteine, sodium sulfite, and sodium dithiocarbamate.

VITAMINS

Compared with other fruits, the *tamer* date fruit is not considered a good source of vitamins, but *khalal*-stage fruits contain appreciable amounts of ascorbic acid and β-carotene (Watt and Merrill 1963). *Khalal* dates are reported to contain 1.8–14.3 mg and *tamer* dates 1.1–6.1 mg of ascorbic acid per 100 g of fresh fruit pulp. Similarly, the β-carotene content (Pro-vitamin A), expressed as IU of vitamin A, ranged between 20 and 1416 IU in *khalal* and 0–259 IU/100 g fresh fruit pulp in *tamer* date fruits (Hussein et al. 1976). Date fruit is also a reasonably good source of thiamin, riboflavin, and niacin (Watt and Merrill 1963). Carotenoid composition of Algerian date varieties at different stages of maturity has also been reported by Boudries et al. (2007). Date fruits at the *khalal* stage of maturity had the highest provitamin A content, whereas the *tamer* had the lowest content.

PREHARVEST TREATMENTS FOR DATE FRUITS

Preharvest application of naphthalene acetic acid (NAA) at 10, 20, 30, 40, and 60 ppm to immature date fruits of the *Zahdi* date palm 15–16 weeks after pollination (i.e., late in the *kimri* stage) influences fruit size, fruit weight, and volume, pulp–seed ratio, and moisture content (Mohammed and Shabana 1980). The highest increase in fruit weight (39%) can be obtained with the 60-ppm application of NAA. Total solids are not changed with the 40- to 60-ppm application of NAA but fruit ripening is delayed by about a month. Ethrel significantly increased the length, diameter, fresh weight, volume, and pulp–seed ratio of 2,4,5-trichlorophenoxy-propionic-acid-treated fruits but failed to show such effects in NAA-treated fruits (Mohammed et al. 1980). Ethrel increases the moisture content of NAA-treated date fruits and reduces the total soluble solid contents of both types of auxin-treated fruits. Gibberellic acid (GA) can be applied to unpollinated date flowers to produce seedless fruits, but the fruit yield decreases and fruit ripening is retarded. Additional application of 200 ppm of ethephon improves the fruit quality in terms of color, total soluble solids, and titratable acidity (Maximos et al. 1980). However, higher dosages of ethephon (0, 125, 250, 500, 1000, or 2000 ppm) applied to *Shahani* cultivar date fruits, from Iran, during harvest showed minor increases in the dry weight percentage of the pulp–seed ratio, titratable acidity, soluble solids, and respiration rates; and a minor decrease in pH, firmness, and astringency (Rouhani and Bassiri 1977).

The effect of GA treatment of date fruits on date palm trees depends on the level and rate of application. Mohammed et al. (1986) sprayed the date bunches of three *Zahdi* and three *Sayer* cultivars with 0, 50, 100, or 150 ppm GA during the slow period of growth (i.e., 12–14 weeks after full bloom and pollination). About 18 weeks after the treatment, fruit bunches were harvested and the fruits were analyzed for physical parameters and chemical composition. GA had no pronounced effect on total soluble solids, except at the highest level applied to *Zahdi* cultivar, in which the sucrose content was higher. Total and reducing sugars increased with GA application but varied with the cultivar and the rate of GA application. The natural plant hormone, indole-3-acetic acid (IAA) is suggested as being involved in the control of date-fruit development (Abbas et al. 2000). The female flowers of the date tree are very rich in IAA, and if not pollinated, this leads to the setting of parthenocarpic fruit (i.e., fruit which fails to ripen fully, due to the absence of a climacteric rise in respiration). The concentration of IAA declines 2 weeks after pollination (at fruit set) probably because it is used in cell division. The IAA concentration rises again in 2 weeks, possibly due to the embryo development but remains high up to 8 weeks after pollination, before it declines to a minimum in fully ripe fruits, that is, around 18 weeks after pollination. The fall in IAA is accompanied by a marked increase in gibberellins in date plants.

The application of plant growth regulators, alone or in combinations, is known to produce varied results in date-fruit characteristics and in the productivity of the date palm tree (Al-Juburi et al. 2001). Application of 150 ppm of GA or 1000 ppm of ethephon on flower clusters of the *Barhee* date palm tree showed no consistent effect on fruit characteristics or productivity. However, 100 ppm of 2-(1-naphthyl) acetic acid (NAPA) or the above growth regulator mixtures reduced fruit dry matter and fruit ripening percentage, but increased the fruit weight per bunch per tree. NAPA, when applied to *Barhee* date palm flowers 20 days after pollination, resulted in the increase of the fruit flesh percentage and the date palm yield.

POSTHARVEST HANDLING OF DATE FRUITS

At the *tamer* stage of maturity, date fruit has good storage stability mainly because of low moisture and high sugar contents. Due to its good shelf life during storage, date fruit

is also known as a self-preserving fruit. As discussed earlier, most of date fruits are consumed at the *tamer* stage of maturity but because of higher nutritional value, substantial amounts are also consumed in the perishable, immature *khalal* and *rutab* stages. Date fruits at these immature stages are rich in dietary fiber, ascorbic acid, and β-carotene; hence, they are traditionally quite popular in date-growing regions (Al-Hooti et al. 1997a). Date fruits of some cultivars at the *khalal* and *rutab* stages of maturity are preferred by consumers (Al-Mulhim and Osman 1986). *Khalas*, *Shahl*, and *Khenaizi* in Saudi Arabia have been the preferred fresh dates among consumers there. Over 84% of the consumers of fresh dates are reported to prefer *Khalas* dates and 73% of the consumers purchase fresh dates packaged in baskets. But unfortunately, date fruits at these immature stages of maturity not only have higher moisture contents and are susceptible to microbial spoilage but are also available only for a very limited period during the season.

Among the potential pathogenic bacteria, *Escherichia coli, Staphylococcus aureus,* and *Bacillus cereus* have been identified in date fruits together with lactic acid bacteria, yeasts, *Aspergillus flavus*, and *A. parasiticus*. Date fruits at the *khalal* and *rutab* stages being high in moisture are the most heavily contaminated (Aidoo et al. 1996). Development of any postharvest techniques to extend the shelf life of date fruits at the *khalal* and *rutab* stages would enhance the commercial and economic value of this crop, on the one hand, and would also provide consumers with a greater choice of delicious products with desirable nutritional contributions to their diet over an extended period of time.

One approach to achieving shelf-life extension is the use of antifungal agents such as potassium sorbate (Al-Hooti et al. 1997a). Compared with the control, the shelf life of *khalal* stage fruits of *Bushibal* and *Lulu* cultivars treated with 0.05% potassium sorbate when stored at 4°C, remained acceptable for an additional 8 and 10 weeks, respectively. The microbial load on these date fruits stayed within the acceptable limits. When these treated fruits are stored at –2°C and –20°C, no coliforms or enterobacteriaceae were detected, while the aerobes and mold counts stayed within the acceptable limits. These subzero temperatures retard the growth of naturally occurring microflora present on these fruits. The fruits of both the cultivars matured from the *khalal* stage to the *rutab* stage during the storage period, thus making the fruits more acceptable to consumers.

The frozen storage of date fruits at the *rutab* stage also leads to changes in various physicochemical characteristics. During 6 months of storage at –18 ± 2°C, *rutab* date fruits increased in moisture content, reducing sugars, and pH but decreased in tannins (Mikki and Al-Taisan 1993). The fruits developed an acceptable sweet taste with the disappearance of astringency. At the end of storage, the thawed product became soft in texture and darker in color. Similar findings on the chemical composition of Egyptian dates during frozen storage have been reported (Goneum et al. 1993). Some of the Saudi cultivars at the *rutab* stage of maturity are suitable for preservation by refrigeration and frozen storage (Al-Mashadi et al. 1993; Yousif and Abou-Ali 1993). The *Haynai* var. of date fruits, when picked at the red stage, can be stored in frozen conditions at –18°C. On thawing, it has a relatively short shelf life when stored at varying temperatures (6°C, 15°C, 20°C, or 26 ± 0.2°C).

Date cultivation poses another unique problem in countries like India and Pakistan, where the crop ripening period coincides with the rainy season (Chatha et al. 1986), which leads to extensive spoilage of the date crop. However, to avoid these conditions, date fruits are harvested at the *khalal* stage and then cured using various techniques such as the use of sodium chloride, sodium hydroxide, acetic acid, 2,4-dichlorophenoxy acetic acid, etc. Even using these methods, the shelf life of *khalal*-stage fruits cannot be extended beyond 2 months, after which the fruits turn black in color. Date fruits may suffer losses due to rains or insects/birds during ripening. To accelerate the ripening process by about 2 weeks, use of 2% sodium chloride solution immersion has been suggested by Saleem et al. (2005). This treatment does not require the date fruits to reach *rutab* stage of maturity and can be treated at the *Dhoka* (*khalal*) stage itself. Baloch et al. (2006) have studied the impact of controlled atmosphere and water activity (a_w) on the color, pH and titratable acidity during 4 months of storage at 40°C. Among all the conditions of storage investigated, the samples with the lowest water activity stored under nitrogen atmosphere exhibited the greatest stability.

Antimicrobial agents and refrigeration are used for the preservation of high-moisture dates (43–56%) (Hassan et al. 1979). Date fruits can be immersed for 1 minute in 0.25%, 0.5%, 1%, 2%, 5%, and 10% solutions of calcium propionate, sodium benzoate, potassium metabisulfite ($K_2S_2O_5$), potassium sorbate, dehydroacetic acid, and combinations of sodium benzoate with calcium propionate or with SO_2, inoculated with molds and yeast spores, and stored at 18–25°C or 2–5°C. Treatment with 10% calcium propionate or 5% potassium metabisulfite did not provide adequate protection during 13 weeks of storage at any of these temperatures. Potassium sorbate provided 2 weeks protection at 0.5%, 7 weeks at 2%, and 14 weeks at 5% at low temperatures. At low temperatures, 5% benzoate-treated dates stayed acceptable for 4 weeks. Use of 1% sodium benzoate with 2% potassium metabisulfite or calcium propionate protected these date fruits against microbial spoilage for 9 months with refrigerated storage.

The *khalal* stage fruit can also be used for the preparation of *Chhuhara (khalal matbukh*) by cooking for 10, 15, 20, or 25 minutes and then drying in a solar drier (Gupta and Siddiqui 1986). *Chhuhara* (dried dates) prepared from *Khadrawi* cultivar yields better quality in terms of pulp content, sugars, proteins, and sensory characteristics, than those prepared from *Shamran* cv. The quality of the *chhuhara* from

Khadrawi dates improved with prolonged boiling, whereas the quality deteriorated with prolonged boiling for *Shamran* cultivar. The ripening of date fruits shows a small peak in ethylene production initially, which increases as the fruit matures, thus suggesting that dates could be considered a climacteric fruit, and the plant hormone ethylene is responsible for changes in its color, fruit texture, soluble solids, and acidity. Fruit firmness decreases during various stages of ripening. The greatest loss of fruit firmness correlates with the greatest increases in both the polygalacturonase and the β-galactosidase activity (Serrano et al. 2001).

OTHER STORAGE PROBLEMS

All varieties of date fruits are commonly attacked by a number of insect pests and fungi during storage. Most of the insects belong to the Lepidoptera and Coleoptera orders. Some species belonging to the order Acarina can also cause considerable damage to date fruits. The commonly reported insects found in stored date fruits are *Oryzaephilus surinamensis, O. mercator, Tribolium confusum, Plodia interpunctella, Cadra cautella, C. calidella*, and *C. figulilella* (Carpenter and Elmer 1978; Abdelmonem et al. 1986b). The commonly isolated fungi from date fruits are *Aspergillus* sp., *Alternaria* sp., *Fusarium* sp., *Penicillium* sp., *Rhizopus* sp., and *Saccharomyces* sp. (Carpenter and Klotz 1966; Chohan 1972). Most important is the fact that any insect (at any stage of their growth) and/or insect fragments, sharply reduce the market value of such fruits. Moreover, the presence of these insects in date-fruit products creates serious quarantine problems in the international trade (Abdelmonem et al. 1986a).

Besides insects, mycotoxins can be produced by many common filamentous fungi found on various food and feed products. Aflatoxins are among the most potent carcinogenic, mutagenic, and teratogenic chemicals that can be produced by *A. flavus* and *A. parasiticus*, under conditions suitable for growth. Four major aflatoxins, namely, B_1, B_2, G_1, and G_2, are commonly found in foods in tropical and subtropical climates. Date fruit under conditions of high humidity and moderate temperature can be contaminated with aflatoxins. Some varieties of date fruit stored under simulated conditions of 98% relative humidity and 30°C were found to contain significant levels of aflatoxin B_1 or B_2 ranging from 35 to 11,610 μg/kg (Shenasi et al. 2002).

The presence of *A. flavus* and *A. parasiticus* on date fruits has been reported from a number of countries (Ahmed et al. 1997; Ahmed and Robinson 1997; Salik et al. 1979; Abu-Zinada and Ali 1982; Emam et al. 1994; Ahmed and Robinson 1999). Two of the isolates from the date fruits treated with methyl bromide (MB) and stored in polyethylene bags for 8 months at 60–75% relative humidity and 20–25°C, produced aflatoxins B_1, G_1, and G_2 in synthetic medium and on date fruits (Emam et al. 1994). The presence of *A. flavus* and *A. parasticus* in some of the date fruits imported to the United Kingdom has been observed (Ahmed et al. 1997). The mold *A. parasiticus* is able to penetrate the intact date-fruit tissue and can produce aflatoxin in 10 days at 28°C in all stages of maturity except at the *tamer* stage, which do not support mold growth (Ahmed and Robinson 1999), but the extracts from all four stages of date fruit were able to support growth of this mold for aflatoxin production (Ahmed and Robinson 1997), and the amounts of aflatoxin produced increased with ripeness. Generally, the pattern of aflatoxin production appears to be broadly in line with the changes in the sugar content and chemical composition of maturing date fruits. Therefore, maximum care should be taken during the processing and handling of date fruits to avoid aflatoxigenesis.

Detection of aflatoxins in date fruits requires an accurate method for extraction and derivatization. The Romer minicolumn method is able to detect aflatoxins in contaminated date fruits. However, using high-performance liquid chromatography and postcolumn derivatization, the contaminants branch (CB) method gave average recoveries of 75.7% and 83.5% for the *Lulu* and *Naghal* date varieties, respectively (Ahmed and Robinson 1998). The recovery of total aflatoxins by the best food (extraction and purification procedure) is about 35% less than that with the CB method. The available Association of Official Analytical Chemists methods, with slight modifications, give better recoveries of aflatoxins from date fruits.

Besides insect infestation, it is not known whether or not the dates available in the market are contaminated with aflatoxins. Consequently, a number of control measures have been suggested to overcome these problems of insect infestation and the growth of undesirable mycotoxin-producing microorganisms on date fruits during marketing and storage. The commercially packed *Zahdi* cultivar treated with ionizing radiation or with MB fumigation can provide an insect-free product for about 25 days (Ahmed et al. 1982) but with longer storage, re-infestation takes place. The major fungi, *Botrytis cinerea* and *Penicillium expansum*, causing postharvest decay of soft-type date fruits of the *Zagloul* var. can be drastically reduced without causing any shrinkage of the fruits when irradiated with up to 200 krad gamma ray dosages (El-Sayed 1978). Additionally, the reduction of the tannin content with irradiation leads to reduced astringency and improved sensory quality. Fortunately, irradiation does not produce any changes in the amino acids, sugars, and protein contents of these treated date fruits during their extended storage life.

Irradiation of date fruits can be used to control the growth of undesirable microorganisms without adversely affecting the sensory quality of the fruit. To reach a decimal reduction value (D_{10} value), a dosage of 1.4 kGy is sufficient for total plate counts, 1.2 kGy for yeasts, and 0.9 kGy for bacterial spores present in some of the date-fruit varieties being grown in Saudi Arabia. A dosage of 4–5 kGy is required to

reduce the microorganisms to an undetectable level without adversely affecting the sensory quality of date fruit (Grecz et al. 1986). Emam et al. (1994) found that irradiation (1.5 and 3.0 kGy) is more effective in preventing insect infestation than fumigation with methyl bromide (MB) of Egyptian semidried date fruits of the *El-Seidi* cultivar during storage for 8 months at room temperature. Neither irradiation nor MB caused any significant changes in moisture content, pH, or titratable acidity, but both produced significant changes in browning, total, reducing, and nonreducing sugars; and in the sugar–acid ratio. An irradiation dosage of 3.0 kGy was more effective than MB fumigation in inhibiting fungal growth and aflatoxin production, which is recommended for maintaining date-fruit quality during long-term storage. Fumigation and aeration of mature, dry date fruits of the *Zahdi* cultivar with phosphine gas at various levels from 0 to 56.7 mg/L for 72 hours did not produce significant differences in the sugar and protein contents, but the threonine and methionine contents decreased significantly (Al-Hakkak et al. 1986). Jaddou et al. (1990) have reported that a γ-irradiation dosage up to 150 krad did not reduce significantly the ascorbic acid contents of Iraqi dates. Najafi and Khodaparast (2009) have recently used ozone gas fumigation to reduce microbial population in date fruits.

A method exists to determine if a date fruit has been irradiated or not. An unirradiated date stone contains a radical with a single line $g = 2.0045$, feature A. Irradiation up to a dosage of 2.0 kGy (the recommended dosage for irradiation of fruits in the United Kingdom) induces the formation of additional radicals with signals $g = 1.9895$ and 2.0159, feature C. The single line having $g = 2.0045$ decays both in the irradiated and control date-fruit samples, whereas the additional signals $g = 1.9895$ and 2.0159 remain almost unaltered for 15 months of storage at room temperature and at 4°C (Ghelawi et al. 1996).

Three fumigants, namely, phostoxin, MB, and hydrogen cyanide; dry heat treatment (55 ± 2°C); and cold storage (at –15°C and 5°C) have been tested against the most common insects present in stored date fruits (Abdelmonem et al. 1986a). The three fumigants caused 100% mortality of all insect species (*Cadera cautella*, *Oryzaephilus surinamensis*, and *Tribolium confusum*) after 24 hours of exposure. Dry heat treatment also produced similar results after 1.5 hours of exposure against all insects. Chilling temperature could achieve only up to a maximum of 84% mortality in 30 hours, whereas –15°C, treatment produced 100% mortality in just 6 hours. These fumigants are also effective in reducing the fungi commonly present on date fruits, with MB being the most effective (Hegazi et al. 1986a). The use of a 100% carbon dioxide environment to control the insects and fungi commonly present in stored date fruits has been tried, but the success rate is variable against these organisms (Mohammed et al. 1980). Carbon dioxide gas in saturated chambers produced 100% mortality of all insects after 48 hours but the fungi and bacteria survived in the stored date fruits.

VALUE-ADDED FOODS FROM DATE FRUITS

Most of the date fruits at *khalal, rutab*, and *tamer* stages of maturity are consumed directly with little or no processing. However, a number of value-added date products are now available in the local market throughout the year. For a more detailed description of value-added functional foods prepared from date fruits, the reader should refer to Sidhu and Al-Hooti (2005). A brief discussion about some of the important value-added food products prepared from date fruits is presented here.

Commercially Packed Dates

Besides, sizeable quantities of dates being consumed at perishable immature stages (*khalal* and *rutab*), the majority of date fruits are consumed in the dry *tamer* stage with moisture content of less than 20% (Sabbri et al. 1982). These *tamer* date fruits are bulk packed in bags, metal tins, or baskets without fumigation or even without normal washing and are offered for marketing. To maintain the high quality expected by the consumers, the date producing and exporting countries have established a number of bulk-packing houses with modern facilities. The Government of Saudi Arabia has initiated an ambitious project to modernize the date-processing industry and to establish modern date-packing plants. To conform to the Saudi date standards for quality, the dates are fumigated with MB to kill all insects, if present (Anon 1983). MB is used at a concentration of 1.0 lb/1000 ft^3 for an exposure time of 24 hours. Chloropicrin may also be added to the MB at a rate of 2%. After fumigation, the dates are transferred to a shaker for preliminary washing with water sprayers to remove dust or other coarse foreign materials. The washed dates are then graded and sorted to remove the defective and inferior dates. The dates are finally washed using fresh water containing a food-grade detergent superchlore (sodium salt of dodecylbenzene sulfonic acid) and dubois 317 (sodium mono- and dimethyl naphthalene sulfonate) as a disinfectant. Excess water is removed from the dates by blowing hot air before packing in 20-kg corrugated cartons, which are then pressed, sealed, and wrapped (Mikki et al. 1986). If they are not sent for immediate shipping and marketing, the packed dates are transferred to cold storage (5 ± 2°C) to maintain shelf life of up to 6 months with minimal changes in their original texture and flavor (Hegazi et al. 1986b).

Preserved Products

A number of preserved products such as pickles, chutney, jam, date butter, dates-in-syrup, paste, candy, and confectionery items have been prepared from date fruits (USDA 1973). For preparing pickles and chutney, date fruits at the *kimri* and *khalal* stages of maturity are suitable. Pickles-in-oil and chutney prepared from *kimri* date fruits (Al-Hooti

et al. 1997b, 1997c) can substitute the popular products commercially prepared from raw mango fruit (Das-Thakur et al. 1976). Typical hard texture and the ample amounts of sugars present at *kimri* stage are conducive for producing good-quality pickles and chutney. The shape, size, and green color of *kimri* stage date fruits make them look similar to olives. Except for their lower acidity values, the sweetness and textural characteristics of *kimri*-stage date fruits are similar to raw mango fruit, thus suitable for preparing pickles-in-oil and sweet chutney for local consumption and export purposes. Brine and salt-stock pickles are other popular products that could be prepared from *kimri* date fruits (Hamad and Yousif 1986). These pickles are microbiologically safe as coliforms were absent, and the products had acceptable sensory quality even after 3 months of storage. The duration of the pickling process varies from prolonged fermentation for brine pickles to very limited fermentation for fresh-pack pickles or no fermentation as for mango and other fruit pickles (Das-Thakur et al. 1976). Detailed information on the most important factors for pickling, such as brine concentration, use of antimold additives like sorbic acid and acetic acid, thermal processing, etc. is reported by several researchers (Al-Ogaidi et al. 1982; Yousif et al. 1985; Khatchadourian et al. 1986). Some of the processed products prepared from date fruits are presented in Figure 34.3.

Traditionally, jam is defined as a self-preserved, cooked mixture of fruit and sugar (honey is often qualified as a sugar), with a total soluble solid content of 68.5% or higher (Al-Hooti et al. 1997d). For preparing a good jam, 65% of sugar, 1% of pectin, and a pH of about 3.0–3.2 are required. If the fruit is low in acidity, citric acid is often added. The basis of jam preservation is related to the water activity of the product. Mainly the sugar and pectin present in jam are responsible for attaining the desired water activity. Usually, a sugar–date pulp ratio of 55:45 is used for jam making. Date fruits, having high sugar contents, are suitable for jam manufacture (Khatchadourian et al. 1986; Besbes et al. 2009). The *rutab* stage date fruits have a reasonable quantity of sugar as well as the pectin required for jam preparation. Certain date-fruit cultivars, such as *Khalas*, *Sukkary*, and *Ruzeiz*, have been shown to possess the desirable sugar and pectin contents and are highly suitable for jam making (Yousif et al. 1993a). For making date butter (similar to peanut butter), *tamer* fruits having the highest sugar content are used. All the steps are similar to jam making, except the pH of the pulp and sugar mixture is adjusted to 4.5–4.7, and the total soluble solid content at finishing stage is 74°–75°Brix. Usually, a sugar–date pulp ratio of 40:60 is used in date butter making. For the preparation of dates-in-syrup, peeled, pitted whole date fruits at the *khalal* stage of maturity are used (Al-Hooti et al. 1997e). After adjusting the pH of sugar syrup (50°Brix) to 2.8–3.0, it is boiled to reach a concentration of about 75°–80°Brix. The hot syrup is poured into glass jars containing peeled, pitted date fruits, and the jars are capped immediately. The minimum drained weight of processed fruit should be kept at 55%. To achieve microbial sterility, the capped jars are processed in hot water (95°C) for 30 minutes, then cooled to room temperature and labeled.

Date syrup (dibs) is another useful product that can be prepared from *tamer* stage fruits. Sidhu et al. (2002) used pectinase and cellulase enzymes to obtain almost double the recovery of soluble solids than were obtained with the conventional hot water and autoclaving extraction methods. The date syrup extracted with pectinase and cellulase can be used as a good substitute for sucrose in bakery products (Sidhu et al. 2003). Compared with the traditional heating methods, the use of microwave heating is another alternative to obtain better uniformity in product temperature, in a comparatively shorter time period that leads to better quality and yield of syrup (Ali et al. 1993). Sonication of date fruit/water mixture has been used for the extraction of date syrup in higher yield and with better microbial quality (Entezari et al. 2004). Date syrup produced by these methods is used in a variety of food products, such as cakes (El-Samahi et al. 1993), carbonated beverages (Hamad and Al-Beshr 1993), soft frozen yogurt (Hamad et al. 1993), milk-based drinks (Yousif et al. 1996; Yousif et al. 1986a; Alhamdan 2002), nutritious creamy foods (Alemzadeh et al. 1997), and ready-to-serve date juice beverages (Godara and Pareek 1985; Yousif et al. 1993b). Based on date syrup, butter, hazelnuts, dried skim milk, cocoa, starch, lecithin, and baking powder, a food can be formulated to have 6.13% protein, 19.86% fat, 47.8% total sugars, and a good amount of minerals (Alemzadeh et al. 1997). The hot weather prevailing in this part of the world for most of the year offers a very good potential for the commercial production of these date juice or syrup-based drinks.

Traditionally, a number of fruits, such as apple, apricot, mango, raisin, and strawberry, are converted into paste on a commercial scale for use in baby foods, baked goods, and confectionery (Ziemke 1977; Anon 1981), but so far date fruit has not been exploited to its full potential. Date fruit is not only the richest source of sugars but also contains various vitamins, minerals, and phytochemicals. The production of date paste is, therefore, of particular interest to the food industry as it also results in reduced transportation and storage costs, since the stones (10–20% of the whole fruit weight) are removed in the process. This will also ensure the availability of date-fruit paste for the food industry throughout the year. For the preparation of date paste, pitted *tamer* date fruits are either soaked in hot water at 95°C for 5–15 seconds or steamed at 10 psig for about 3 minutes. To maintain the desirable color and good shelf life, citric acid or ascorbic acid (0.2% on a fruit basis) is added to lower the pH of date paste. The water activity (a_w) and pH of date paste prepared by this method are kept within the safe limits of 0.57 and 5.4, respectively (Yousif et al. 1986b, 1986c). Date paste offers an opportunity to convert even the lower grade date fruits into an intermediate value-added product by the date processing industry (Mikki et al. 1983). Date paste and date-fruit chunks can also be added to a number of food products such as baked

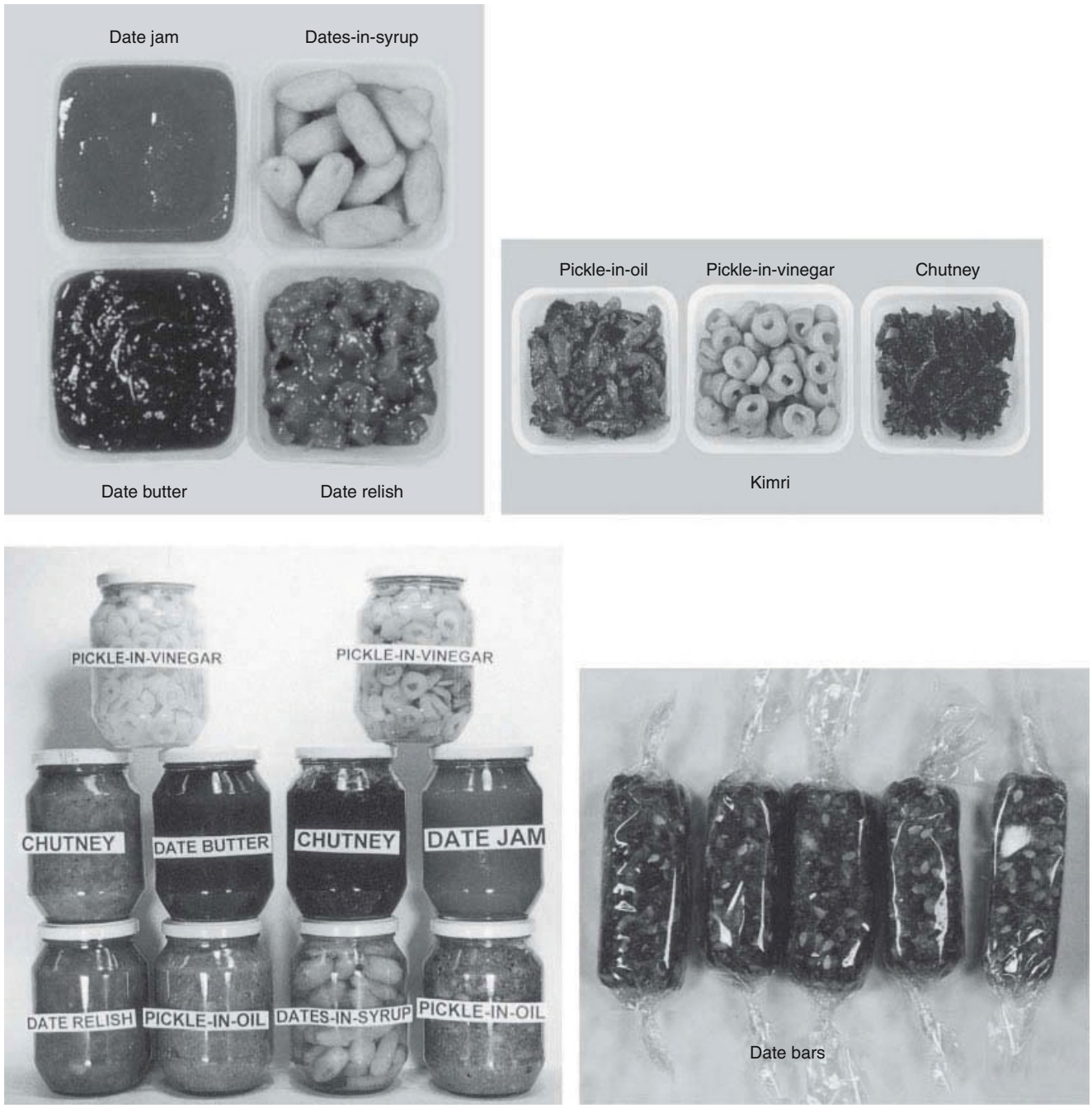

Figure 34.3. Selected processed date fruit products. (*Photo source*: Prof. Jiwan S. Sidhu.)

goods and ice cream. Up to 50% of the sucrose in ice cream can easily be replaced with date paste without adversely affecting its quality (Hamad et al. 1986). Addition of date pieces (10%) to ice cream reduces the overrun slightly. Use of 4–8% date paste in bread formulation results in marked improvements in the dough rheological properties, delays gelatinization, improves gas production and retention, prolongs the shelf life, retards staling, and improves the crumb and crust characteristics (Yousif et al. 1991). Ahmed and Ramaswamy (2006) investigated various physicochemical properties (total solids, color, rheology, texture, melting point, and glass transition) of commercial date pastes made from three cultivars (*Khalas, Bumaan, Lulu*). Paste made from Bumaan exhibited elastic and viscous modulus compared to other cultivars.

Texture Profile Analysis data on *Lulu* date paste exhibited the least hardness, gumminess, chewiness, and springiness but moderate cohesiveness when compared with date paste made from other cultivars. Sablani et al. (2008) have developed a technique to produce non sticky and free flowing powder granules from date paste and measured its water activity, bulk density, color, hygroscopicity, and glass transition temperature.

Date fruits serve mainly as a source of calories as these are rich in carbohydrates (about 78%) but low in proteins (2–3%) and fat (1%). To convert date fruits into nearly a complete food would, therefore, require supplementation with proteins, dietary fiber, and fats. Recently, the trend is shifting toward the use of blends of vegetable and dairy proteins to formulate a variety of candies, energy bars, and confectionery, which are becoming popular among children and adolescents. One similar product made with *tamer* date pulp, sesame seeds, almonds, and oat flakes has been found to be quite acceptable to consumers (Al-Hooti et al. 1997e). The average ash, fat, and protein contents of 1.78%, 6.09%, and 7.83% in the control date bars (containing date paste and almonds) changed to 2.60%, 3.90%, and 9.56% in these date bars fortified with sesame seeds, almonds, skim milk powder, and rolled oats, respectively. In another type of date bars fortified with soy protein isolate, single-cell proteins, almonds, and skim milk powder, the protein content was increased from 4.9% to 5.3% in the control to about 10.7–12.1% (dry basis) in samples containing the high-protein ingredients. Such formulated bars not only supply calories but can also provide a reasonable amount of fat, fiber, and minerals. These supplemented date bars not only have increased protein content but also possess significantly higher chemical scores of essential amino acids (Khalil 1986).

A variety of candied or glace fruits are being prepared from a number of fruits for use in new food product development by the dairy and bakery industries. To enhance the penetration of sugars, the fruit is pierced and is also dipped in dilute calcium chloride solution to toughen the texture. Use of citric acid and ascorbic acid is also commonly used in the preparation of invert sugar syrup (about 30°–45°Brix) required for cooking such fruit. During the preparation of candied fruit, the cooking of fruit with sugar syrup is repeated for short intervals over a period of many days until the soluble solids content of the cooked fruit reaches 70°Brix or higher. This higher sugar content enhances the shelf life of candied fruit even when stored for many months at room temperature.

Khalal stage fruits can be used for the preparation of glace dates (Sawaya et al. 1986). *Khalal* fruits from two varieties, *Hallaw* (red) and *Khuwaildi* (yellow), were washed, air-dried, and pricked to facilitate sugar penetration. Sugar syrup of 35°Brix was prepared from 4.25 kg each of sucrose and glucose in 20 L of water. To the syrup, 10 g each of calcium chloride and potassium sorbate are added, and the pH is adjusted to 2.8 with a solution made from a 4:1 mixture of citric acid and ascorbic acid. The fruit and syrup are cooked slowly over a period of time (with intermittent overnight rests) till the fruit gets to 75°Brix. The glace fruit can be flavored or coated with milk chocolate for improved acceptability. Dehydrated dates from immature date fruits have been prepared by Kulkarni et al. (2008). These dried dates when packaged in 75 low-density polyethylene maintained an acceptable quality for 6 months at room temperature.

BY-PRODUCTS FROM DATE PROCESSING

Waste date pulp, low-grade rejected date fruits, and the date seeds (pits, stones) are the three major by-products coming out of the date-fruit processing plants. Azaza et al. (2008) have substituted soybean meal with waste date fruits for growing Nile tilapia fish. Wasted dates have also been used in animal feeds for growing sheep (Rekik et al. 2008). As the waste date pulp and rejected date fruits are rich in many components such as soluble sugars, proteins, vitamins, and minerals, these can be used as a fermentation substrate for oxytetracycline production by some suitable mutants of *Streptomyces rimosus* (Baeshin and Abou-zeid, 1993). At the end of 96 hours of fermentation period, the cell biomass is harvested and the antibiotic is recovered. The presence of naturally occurring glucose, fructose, sucrose, proteins, amino acids, certain B-complex vitamins, and minerals in date-fruit pulp is conducive for the synthesis of oxytetracycline by the chosen strain, *S. rimosus*. In addition to waste date-fruit pulp, low-grade date fruits, immature fruits, and other wastes coming out of date-fruit processing plants can also be used for the production of many pharmaceuticals, enzymes, xanthan gum, citric acid, and ethanol (Bari et al. 2010; Saleh et al. 2010).

Date pit is another major by-product, constituting about 10% by weight of the whole fruit. As the date seeds are rich in oil, proteins, minerals, and fiber, these could serve as valuable raw materials for animal feeds. After extracting edible oil, date seed meal can be used for animal feeds (Rygg 1977). The reported values for date seeds are 6–7% protein, 9–10% fat, 1–2% minerals, 20–24% fiber, and 48.64–193.83 mg/100 g total phenolics (Al-Hooti et al. 1998; Rahman et al. 2007; Al-Farsi and lee 2008). The fats from date seeds are rich in many unsaturated fatty acids such as oleic acid (58.8%) and linoleic acid (12.8%). Considering the nutritional importance of the fatty acid profile, date seeds have the potential for the production of edible oil for human consumption (Besbes et al. 2005). The major minerals present in date seeds are potassium, phosphorus, calcium, and magnesium. The essential amino acid profile of date seed proteins is quite comparable with those of other comparatively expensive oilseeds such as soybean, groundnut, cottonseed, and sesame. To improve their nutritional value as animal feeds, the higher content of cell wall materials present in date seeds needs to be solubilized by treating them with 4.8–9.6% solution of sodium

hydroxide (Al-Yousef et al. 1986). The ligninase enzyme has been shown to be useful in solubilizing date seeds and thus improving their nutritional value for use in animal feeds. For the production of this enzyme, date seeds rich in carbohydrates, proteins, lipids, and minerals can be utilized as a substrate to grow *Phanerochaete chrysosporium*. Slurry of 10% crushed seeds in water is inoculated with *P. chrysosporium* and incubated at 30°C for 7 days. The pH of the substrate is adjusted to 4.0 for achieving the highest yield of ligninase enzyme (El-Nawawy et al. 1993). After increasing the supply of carbon and nitrogen in the fermentation medium, the date seeds can also be used for the production of oxytetracycline by *Streptomyces rimosus* as the date seeds, as such, cannot produce appreciable amounts of this antibiotic (Abou-zeid and Baeshin 1993). Activated carbon from date stones has been used to adsorb various hazardous materials and pollutants such as pesticides, phenol, heavy metals, and dyes from the wastewater as well as from the environment (Alhamed 2009; Hameed et al. 2009; Al-Ghouti et al. 2010; Al-Mutairi 2010).

NUTRITIVE VALUE AND HEALTH BENEFITS

Long before recorded history, date fruits were so important in Arabian diets that they were called the "Fruit of Life." Date crops in the desert regions of the Middle Eastern countries have been the bases for survival for its residents. During the Holy Month of Ramadan, at the time of breaking fast in the evening, a few date fruits are eaten. Dates are consumed in many forms such as fresh, preserved, candied, and as a constituent of the processed food products. The largest amount of date fruit is eaten as a fully ripe fruit (*tamer*). Many advances have recently taken place in date processing. Now, a number of companies are producing cleaned, washed, and pressed *tamer* dates in a variety of attractive packaging. Small amounts are also pitted, stuffed with nuts (almonds) and/or mixed with anise or fennel seeds and offered for retail sale (El-Shaarawy 1986).

Date fruits are mainly considered a source of readily available carbohydrates. At the *tamer* stage of maturity, dates are a rich source of readily available carbohydrates in our diet, as dates (without pits) contain more than 80% of total monosugars (Myhara et al. 1999). The sucrose present at the *khalal* and *rutab* stages of maturity in most of the cultivars is almost completely converted to glucose and fructose through the action of the invertase enzyme. *Tamer* dates are also a rich source of total dietary fiber (about 12.97–13.32%, on a dry basis), both water-soluble and water-insoluble fractions, both having proven health benefits. Dietary fiber from date fruits when fed to white albino rats for 8 weeks has been shown to significantly lower the total cholesterol, triglycerides, and phospholipids in rat livers (Jwanny et al. 1996). Apart from lowering the total serum lipids and low-density lipoprotein cholesterol by 32–48%, even the serum triglycerides and total cholesterol are decreased by 23–35%. The practice of eating date fruits at *khalal* and *rutab* stages of maturity would also supply reasonable amounts of soluble dietary fiber such as pectins (4–5% dry basis), thus making significant nutritional contributions to the dietary fiber intake among humans.

An average person in Saudi Arabia consumes daily about 100 g of dates (El-Shaarawy 1986), which would meet 13% of their daily requirement for total energy, more than 11% of their daily requirement for iron, about 7% of their daily requirement for ascorbic acid, and 6% of their daily requirement for proteins. Some "date lovers," are known to consume even higher amounts of dates at the *tamer, Khalal,* and *rutab* stages; thus, the intake of these valuable nutrients will be much higher in their diets. Traditionally, the date fruits are consumed with milk, especially during the fasting month of Ramadan, which has a strong scientific logic. In addition to providing calories, the vitamin C and fructose present in date fruits are known to enhance the absorption of iron. This makes the date fruit and milk a good nutritional combination in terms of iron, vitamin C, and proteins. There are a number of chemical constituents that are known to enhance the absorption of iron. Ascorbic acid is one such enhancer that improves the absorption of the iron present in the date fruits (Fleming et al. 1998).

Dates, at all stages of maturity, are extremely low in fat (about 1%), but rich in minerals, certain B-complex vitamins, and polyphenolic compounds. Among the minerals, dates are especially rich in potassium, but at the same time, are low in sodium, thus serve as an excellent food source for persons suffering from hypertension. Among the other minerals, dates are reasonably good sources of iron, copper, sulfur, and manganese; and fair sources of calcium, chloride, and magnesium. Dates also contain moderate amounts of a few B-complex vitamins in relation to the calories they contain, especially thiamin, riboflavin, and folic acid. In terms of recommended levels of thiamin, riboflavin, and nicotinic acid of 0.4, 0.6, and 6.6 mg/1000 calories, the date fruits are known to provide 0.32, 0.35, and 8.0 mg/1000 calories, respectively (Vandercook et al. 1980).

Dates are now known to be a rich source of many phytochemicals such as phenolic compounds, and flavonoids (Mansouri et al. 2005). The astringency of *kimri* stage date fruit is due to the presence of phenolic substances, generally known as tannins. The antioxidants concentrations in date has been reported to vary among different cultivars as well as the stage of maturity (Amoros et al. 2009; Biglari et al. 2009) Many types of tannins are found in date fruits but two main groups, phenolic acids and condensed tannins, are thought to be important mainly in producing astringency. These phenolic acids comprise cinnamic acid derivatives originating from the amino acid, phenylalanine, while

condensed tannins, or proanthocyanidins, are polyphenolics (Myhara et al. 2000). *Kimri* stage date fruit is known to contain maximum amount of tannins, which decrease as the fruit matures to the *tamer* stage (Al-Hooti et al. 1997f). Date fruits have been shown to exert protective and proliferative effects against H_2O_2-induced cytotoxicity (Asadi-Shekaari et al. 2008). The aqueous extract of date fruits has been reported to provide neuroprotective effect against the oxidative injury to rat neurons (Panahi et al. (2009).

STANDARDS AND REGULATIONS

A novel and robust color space conversion and color index distribution analysis technique for automated date maturity evaluation has been suggested for commercial grading and marketing (Lee et al. 2008a). A machine vision system using digital reflective near-infrared imaging for automatic date grading and packing facility has been tested under commercial conditions (Lee et al. 2008b). Compared to manual grading, this grading system results in improved accuracy and substantial reduction in operating costs. Except for packed dates, food grades or standards for all the processed date-fruit products need to be developed by these countries. Food standards for the packed dates have been developed by the State of Kuwait, and similar standards exist for the other Gulf Cooperation Council countries (Anon 1998). These standards are only for the packed dates and cover labeling, contamination with sand or grit, good manufacturing practices to be followed, expected shelf life, limits for microorganisms, and the suggested methods of analysis required for testing of these products. Some of the packaging requirements for *tamer* date fruits are described in Tables 34.2 and 34.3.

As per the Kuwaiti Standards, besides the weight and number of fruit pieces, the packed dates should conform to the identity of declared cultivar on the package as well as its stage of maturity. It should be free from insects, their fragments or excreta, and should possess the characteristic flavor of the cultivar. All fruits in the package should be of the same color and size. The packed date fruits (without seeds) should not contain more than two whole seeds or four parts of broken seeds/100 date fruits. However, other nuts (such as almonds, coconut) and condiments (e.g., fennel) of suitable quality (fit for human consumption) may also be added to these packed dates. The other specifications for the packed dates are <7% blemished dates; <6% damaged, unripe, and unpollinated dates; <7% dirty, insect infested dates; and <1% souring, moldy, and decayed dates. The packaging material used should be clean, dry, impermeable to moisture, and capable of preventing contamination of dates from dirt, etc. The packed dates should be stored in a cool dry place, free from humidity, away from direct sunlight, and rodents.

Table 34.2. Kuwaiti Standards for Quantity Requirements for Packed *Tamer* Date Fruits

	Number of Date Fruits (per 500 g)	
Fruit Size	Without Seeds	With Seeds
Small fruits	>110	>90
Medium fruits	90–110	80–90
Large fruits	<90	<80

Source: Anon (1998).

FUTURE RESEARCH NEEDS

At present, a complete chemical composition, especially of micronutrients and various phytochemicals in different varieties of dates from various regions is not available (Vayalil 2002). Like other fruits, research efforts can be directed to determine potential antioxidants, their bioavailability and stability during date-fruit processing, storage, and distribution.

Besides emphasis on fruit size, bearing capacity, uniformity of fruit maturity, and total yield per hectare, recent advances in biotechnology and tissue culture techniques can include investigations into improvements fruit traits related to nutritional quality. There is scope to identify and quantify chemical constituents responsible for distinct flavors of date fruits from different cultivars. Currently, there is a standard for the packed *tamer* date fruits, suitable standards and regulations are required for processed date-fruit products.

Table 34.3. Kuwaiti Standards for Microbiological Quality of Packed *Tamer* Date Fruits

Type of Microorganism	No. of Positive Samples Observed	Maximum No. of Samples to Exceed Permissible Limits	Maximum Permissible Microbial Load (CFU/g)	Maximum Microbial Load in Any of the Sample Tested (CFU/g)
Yeasts	5	2	10	10^2
Molds	5	2	10^2	10^3
E. coli	5	2	0	10

Source: Anon (1998).

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35
Super Fruits: Pomegranate, Wolfberry, Aronia (Chokeberry), Acai, Noni, and Amla

Jiwan S. Sidhu and Tasleem A. Zafar

Abstract: The name super fruit was initially coined as a marketing and promotional tool to highlight the exceptional nutritional quality and unique health-promoting phytochemicals present in certain fruits. As these super fruits are gaining a lot of attention from the health-professionals and the consumers, their popularity is going to increase significantly during the coming years. This chapter deals with production, fruit quality, including chemical, nutritional, and phytochemical characteristics, postharvest storage, processing into value-added products, and medicinal value of the six important super fruits: pomegranate, wolfberry, chokeberry, acai, noni, and amla.

INTRODUCTION

The name super fruit was coined as a marketing and promotional tool to highlight nutrient richness and unique bioactive compounds present in certain fruits. The current group of super fruits includes wild blueberries (*Vaccinium angustifolium*), wolfberry (*Lycium barbarum* L.), chokeberry (*Aronia melanocarpa),* cranberry (*Vaccinium macrocarpon*), acai (*Euterpe oleracea*), noni (*Morinda citrifolia*),

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mango (*Mangifera indica*), pomegranate (*Punica granatum*), Indian gooseberry (*Phyllanthus emblica*), mangosteen (*Garcinia mangostana*), sea-buckthorn (*Hippophae rhamnoides*), and red grapes (*Vitis vinifera*). Fruits such as, apple (*Malus domestica*), tomato (*Solanum lycopersicum*), orange (*Citrus sinensis*), raspberry (*Rubus idaeus*), blackberry (*Rubus ursinus*), and strawberry (*Fragaria vesca*), which although have many of the properties of super fruits, are not included. However, some exotic fruits, such as, abiu (*Pouteria caimito*), breadfruit (*Artocarpus altilis*), Burmese grape (*Baccaurea ramiflora*), chupa-chupa (*Matisia cordata*), cupuaçu (*Theobrama grandiflorum*), jackfruit (*Artocarpus heterophyllus*), langsat (*Lansium domesticum*), maqui (*Aristotelia chilensis*), miracle berry (*Synsepalum dulcificum*), rambutan (*Nephelium lappaceum*), yumberry (*Myrica rubra*), and souari nut (*Caryocar nuciferum*), are likely to be considered as super fruits. This chapter deals with production, quality, including nutritional and phytochemical characteristics, and processing aspects of six important super fruits: pomegranate, wolfberry, chokeberry, acai, noni, and amla.

Figure 35.1. Pomegranate fruit. (Adapted from Wikipedia.org [http://en.wikipedia.org/wiki/Pomegranate].)

SECTION 1: POMEGRANATE

INTRODUCTION

Pomegranate fruit (*Punica granatum* L.) belongs to Punicaceae family. The name pomegranate is derived from Latin word *pomum* (apple) and *granatus* (seeded); however, the fruit is considered a large berry. It is called *Granatapfel* in German (seeded apple), *Melograno* in Italian, and *granatus* in Spanish (Anon 2010a). This fruit features prominently in all major religions. It is the symbol and Heraldic device of the ancient city of Granada in Spain—from which the city gets its name (Jurenka 2008). Pomegranate tree ranging in size from a large shrub to a small tree grows 5–8 m tall. A native to Persia and Himalayas, pomegranate is cultivated throughout the Mediterranean region, Asia, Africa, and Europe. In the United States, it was introduced in 1769 by Spanish and is grown mainly in California and Arizona (Anon 2010b).

Pomegranate grows well in semiarid, mild temperate to subtropical climates and is naturally adapted to regions with cool winters and hot summers. The fruit season is September to February in the Northern Hemisphere, and March to May in the Southern Hemisphere. The pomegranate tree is extremely long-lived; some specimens in Europe are known to have survived over two centuries (Anon 2010b).

The fruit is nearly round ranging from 2.5" to 5" in diameter with a tough leathery skin or rind of yellowish to red color (Fig. 35.1). The interior of the fruit is separated by whitish spongy membranous walls into compartments packed with juicy corn-sized arils, which are pink red in appearance with sweet–tart taste. Each aril contains a soft to hard white or red angular seed. Seeds represent about 52% of the weight of the whole fruit (Morton 1987).

CULTIVARS

In Iran, about 760 different pomegranate varieties are recognized (Pirseyedi et al. 2010). Some of the famous Iranian varieties are: Rabob, Aghaei, Shisheh cap, Shirin Shahvor, Ardestony, Malas e Daneh Siah, Farouq, Rahab, Khafar e Shiraz, Touq Gardan, Ferdous e Khorasan, Bidaneh Sangan, etc. Important pomegranate varieties in other countries are, Iraq: Ahmar, Aswad, and Halwa; Saudi Arabia: Magulati; Israel: Wonderful and Red Loufani; India, Pakistan, and Afganistan: Bedana and Kandahari. Bedana pomegranates are soft seeded (also called seedless) and are medium to large, whitish to brownish rind and pinkish white pulp, juicy and sweet. Kandahari fruits are large, deep-red with blood-red arils (juice), hard seeded, and sweet tangy flavor. Other important pomegranate varieties are: Alandi, Kabul, Muskat Red, Muscat White, Poona, Paper shell, Dholka, and Vellodu (Morton 1987).

Pomegranate varieties in the United States include Wonderful, Balegal, Cloud, Crab, Fleshman, Grenanda, Sweet, Utah Sweet, and Spanish Ruby; Mexican varieties are Tehuacan, Pueblua, Grenada de China, and Grenada Agria (Anon 2010b).

PHYSIOLOGY, RIPENING, AND CHEMICAL COMPOSITION

Pomegranate fruit ripens 6–7 months after bloom and is picked when fully mature. It does not ripen off the trees even

with ethylene treatment. In California, maturity is deemed with titratable acidity of 1.8% and soluble solids of 17% or more (Morton 1987). In general, the fruit is considered mature if it makes a metallic sound when tapped, and when it achieves a distinct color. The fruit is picked before it is overripe as it has a tendency to crack (Anon 2010b). Besides genetic differences, factors affecting the size of the fruit, amount of arils, juice content and taste, include environmental conditions such as climate, temperature, humidity and time of harvest (Schwartz et al. 2009).

The color of pomegranate juice changes as the fruit matures from unripe to fully ripe due to increase in pigmentation. The moisture content of juice and seeds are reported to be 85% and 79%, respectively (Gil et al. 1995). Total soluble solids (TSS) vary among cultivars grown in different regions and are an important determinant of the taste of pomegranate juice. The TSS values reported for different accessions in Israel were 13.7–17.8 g/100 g (Dafny-Yalin et al. 2010), in Macedonia between 8.2 and 13.2 g/100 g (Veres 1976), and in Russia 15.2–20.5 g/100 g (Poyrazolua et al. 2002). Soluble sugars are the major constituents of TSS. Among sugars, amount of glucose increases in the juice as the fruit ripens whereas the amount of fructose does not change between ripe and unripe fruit juice. The higher content of glucose compared to fructose was independent of climatic conditions as observed in the same cultivars either grown in Mediterranean or desert environment (Schwartz et al. 2009). The juice pH of the fully mature ripe pomegranate was 3.57 and Brix, 16.90° (Al-Maiman and Ahmed 2002).

The desired pomegranate taste varies in different countries and regions, for example, in North Africa, almost all commercial varieties are sweet tasting, sour species are popular in Russia and other northern countries (Al-Kahtani 1992). A study (Dafny-Yalin et al. 2010) of 29 accessions of pomegranate aril juices and peels showed that the TSS and soluble sugars in pomegranate aril juices differ only slightly but the titratable acidity and citric acid differ significantly and are the major contributors to the taste. Peel homogenates were low in titratable acid, TSS, soluble sugars, and organic acids than the aril juices.

Pomegranate juice is rich in vitamin C, potassium, pantothenic acid, and polyphenols. It provides about 10% of an adult's daily vitamin C requirements per 100 mL serving. As most of its fiber is in seeds, whole fruit arils are better source of fiber than the refined juice. Seeds also contain unsaturated fatty acids. The most abundant and valuable antioxidants in pomegranate are the soluble tannins, the polyphenols called punicalagins and ellagitannins; and the phytochemicals such as catechins, gallocatechins, and anthocyanins—delphinidins, prodelphinidins, cyanidins, and pelargonidins (Table 35.1). These compounds are not only found in the fruit juice but also in other parts of the fruit such as the seed, rind, leaf, bark, root, or flower. Table 35.2 lists some of the polyphenols contained in various parts of the pomegranate (Jurenka 2008).

Table 35.1. Chemical Composition of Pomegranate Juice from Arils only

Chemical Constituent	Per 100 g Juice (3.5 oz)[a]
Energy (kcal)	68
Total carbohydrates (g)	17.17
Sugars (g)	16.57
Dietary fiber (g)	0.6
Proteins (g)	0.95
Fat (g)	0.3
Thiamin (vitamin B12) (mg)	0.03(2%)
Riboflavin (vitamin B2) (mg)	0.063(4%)
Niacin (vitamin B3) (mg)	0.300(2%)
Vitamin B6 (mg)	0.105(8%)
Pantothenic acid (B5)	0.596(12%)
Folate (vitamin B9) (μg)	0.300(2%)
Vitamin C (mg)	6.1(10%)
Iron (mg)	0.30(2%)
Potassium (mg)	259 (6%)
Calcium (mg)	3 (0%)
Magnesium (mg)	3 (1%)
Phosphorus (mg)	8 (1%)
Zinc (mg)	0.12 (1%)

Source: USDA nutrient database.
[a]Percentages are relative to US recommendations for adults.

POSTHARVEST HANDLING AND STORAGE

The fruit is clipped close to the base leaving no stem to prevent damage during postharvest handling and shipping. Shipping for local markets is done with the fruit cushioned

Table 35.2. Pomegranate Fruit Parts and Constituents

Plant Component	Constituents
Pomegranate Juice	Anthocyanins, glucose, ascorbic acid, ellagic acid, gallic acid, caffeic acid, catechin, EGCG, quercetin, rutin, numerous minerals particularly iron, amino acids.
Pomegranate seed oil	95% punicic acid, ellagic acid, other fatty acids, sterols, etc.
Pomegranate pericarp (peel, rind)	Phenilic punicalagins, gallic acid and other fatty acids, catechin, EGCG, quercetin, rutin, other flavonols, flavones, flavonones, anthocyanidins
Pomegranate leaves	Tannins (ounicalin and punicafolin), flavone glycosides including luteolin and apigenin
Pomegranate flower	Gallic acid, ursolic acid, triterpenoic acid including maslenic acid and asiatic acid, other unidentified constituents
Pomegranate roots and bark	Ellagitannins including punicalin and punicalagin, numerous piperidine alkaloids

Source: Jurenka (2008).

in wooden crates or baskets with paper or straw. For long distance and international markets, the fruit is graded, packed in layers, unwrapped but topped with shredded plastic in wooden boxes. The fruit is precooled rapidly and shipped in refrigerated trucks.

Pomegranate fruit has a long storage life. For shelf life of up to 7 months without shrinkage and spoilage, storage temperatures of 32–41°F (0–5°C), and relative humidities of 80–85% are helpful. Storage makes the fruit juicier and more flavorful. However, prolonged storage causes internal breakage, pulp streaking, and flat flavor (Morton 1987).

Minimally processed ready-to-eat pomegranate seeds held at 1°C, 4°C, and 8°C for up to 7 days in unperforated oriental polypropylene (OPP) bags were shown to maintain quality better than those packed in perforated bags and held at 1°C for 7 days (Gil et al. 1996).

ANTIOXIDANT COMPOUNDS IN POMEGRANATE AND THEIR HEALTH BENEFITS

Research shows positive associations between inflammation and oxidative stress. Biomarkers of inflammation include C-reactive protein (CRP), tumor necrosis factor-α (TNF-α), interleukin-1 (IL-1), interleukin-18 (IL-18), vascular cell adhesion molecule-1 (VCAM-1), soluble CD40 ligand (sCD40L), and monocyte matrix metalloproteinase-9 (MMP-9) (Basu and Penugonda 2008).

Pomegranate has been recognized as a medicinal fruit from ancient times. Compared to other fruits such as cranberry, grape, grapefruit or orange juice, or green tea and red wine, the pomegranate fruit juice contains about three times higher antioxidant activity, as evaluated on the basis of scavenging free-radicals and iron-reducing capacity (Gil et al. 2000).

In a series of experiments using atherosclerotic apolipoprotein-E deficient (E^o) mice, pomegranate extracts were shown to inhibit atherogenesis. When E^o mice with advanced atherosclerosis were supplemented with pomegranate juice for 2 months, compared to the placebo control, their peritoneal macrophage (MPM) lipid peroxide content was reduced by 42%. In the experimental mice, rate of cholesterol esterification was 80% lower and the size of atherosclerotic lesion in the aorta was 17% smaller than the control mice. It was also demonstrated that the antioxidants from pomegranate ease the progression of atherosclerosis in early stages by reducing the influx of cholesterol in the MPM, and increase HDL mediated cholesterol efflux from the MPM in advanced stages (Rosenblat et al. 2006a; Aviram et al. 2000; Kaplan et al. 2001).

Among extracts from different parts of pomegranate tested in E^o mice, flower extract (PFLE) was more effective on atherosclerotic lesion size, lipid profile, and blood sugar level than pomegranate fruit liquid extract, polyphenol powder extract, juice, grounded arils, and seeds. The reduction in the lesion size was analyzed as 70%, 38%, 39%, 44%, and 6%, respectively, compared to placebo (Aviram et al. 2008). The 70% reduction by PFLE was attributed to a synergistic effect of polyphenols with dietary fiber (30.2%) and other carbohydrates (Vasdev et al. 2006). In Zucker hyperlipidemic diabetic rats, PFLE was effective in decreasing circulation of lipids thus cardiac triglyceride content and decreased plasma nonesterified fatty acids and total cholesterol. PFLE was also noted to improve insulin sensitivity and improved postprandial glycemic response in rat (Huang et al. 2005a, 2005b). Khalil (2004) reported effect of pomegranate fruit extract (PFE) on improved insulin response by decreasing blood glucose levels through possible effect on pancreatic beta cells regeneration.

Anti-inflammatory role of pomegranate was demonstrated in obese Zucker rats on atherogenic diet supplemented with pomegranate juice and fruit extract for 5 weeks (de Nigris et al. 2007). Rats with liver damage induced by carbon tetrachloride (CCl_4) were protected from lipid peroxidation by 54% after feeding pomegranate peel extract that enhanced or maintained the free-radical scavenging activity of the hepatic enzymes catalase, superoxide dismutase (SOD), and peroxidase (Chidambara Murthy et al. 2002).

Malik et al. (2005) and Malik and Mukhtar (2006) in experiments using highly aggressive prostate carcinoma cells, (PC-3 cancer cell line) implanted in mice showed that PFE inhibited cell growth and induced apoptosis. A few workers have also demonstrated a synergistic effect on inhibition of the cancer cells by combining any two of the aforementioned extracts than either of them alone (Albrecht et al. 2004; Lansky et al. 2005; Adams et al. 2006a). Similarly, breast cancer cell lines MCF-7 and MB-MDA-231 when treated with pomegranate juice and fruit extract suppressed tumor growth, invasiveness, and proliferation (Mehta and Lansky 2004; Kim et al. 2002).

Pomegranate juice consumption (50 mL/day) for 2 weeks inhibited serum angiotensin converting enzyme (ACE) activity and reduces systolic blood pressure in ten hypertensive patients (Aviram and Dornfeld 2001). In a 3-month study on type 2 diabetics, consuming 50 mL/day pomegranate juice significantly decreased lipid peroxidation by 56%, thiobarbituric acid reactive substance (TBARS) by 28% and cellular uptake of oxidized low-density lipoproteins (LDL) by monocyte-derived macrophages by 39% compared to the baseline values, suggesting gradual attenuation in the progression of atherosclerosis (Rosenblat et al. 2006b). In individuals suffering with diabetes consumption of 40 g concentrated pomegranate juice for 8 weeks resulted in a significant reduction in total cholesterol, LDL cholesterol, ratio of total/HDL and LDL/HDL compared to baseline (Esmailzadeh et al. 2006). Consumption of 50 mL/day of pomegranate juice by ten patients with severe carotid artery stenosis (70–90% stenosis of internal carotid arteries) for a year reduced mean intima-media thickness (IMT), systolic blood pressure, and serum lipid oxidation values compared to baseline.

The pomegranate juice had an additive synergistic effect on heart health parameters (Aviram et al. 2004). In a 3-month randomized double-blinded study, 45 patients of mayocardiac ischemia who consumed 240 mL pomegranate juice daily showed a significant reduction in stress-induced ischemia (Sumner et al. 2005). Pomegranate juice was tested on 46 patients with recurrent prostate cancer. Daily consumption of 8-oz pomegranate juice containing 570 mg total polyphenol as gallic acid decreased prostrate specific antigen (PSA) levels by 27% in 35% patients. There was a 40% reduction in oxidative state and 23% average increase in nitric oxide production compared to the control (Pantuck et al. 2006).

BIOAVAILABILITY OF ANTIOXIDANTS

The potential health benefits of pomegranate juice and extracts from its various parts make it crucial to understand its metabolism and pharmacokinetics. Most of the research to date has been conducted in *in vitro*, animal model or on human subjects. The information learnt from the few clinical studies point to ellagitannins as a major polyphenol accounting for 92% of the antioxidant activity in the pomegranate juice. Ellagitannins are concentrated in aril juice, peel, membrane, and piths of the fruit (Basu and Penugonda 2008).

Commercial juice prepared by pressing the fruit as a whole is high in ellagitannins and total polyphenols content. Punicalagin is the most abundant ellagitannins, which hydrolyzes to ellagic acid and smaller phenols after ingestion, and are measured in plasma and urine as a biomarker for the availability of the pomegranate polyphenols. In a pilot study, 180 mL of pomegranate juice containing 25 mg of ellagic acid resulted in 32 ng/mL ellagic acid in plasma post 1-hour consumption by a single healthy human subject. It was rapidly eliminated from the body in 4 hours, with no other ellagitannin metabolites detected (Seeram et al. 2004). The same amount of pomegranate juice given to 18 volunteers led to the detection of ellagic acid 1 hour postconsumption in blood together with other metabolites such as dimethylellagic acid glucuronide (DMEAG) and urolithins in plasma and urine in most of the subjects (Seeram et al. 2006). In 11 volunteers, consuming 800 mg of pomegranate extract containing 330 mg punicalagins and 22 mg ellagic acid, 34 ng/mL of ellagic acid was measured after 1 hour of ingestion. Other ellagitannin metabolites including urolithin A, hydroxy-urolithin A, urolithin B, urolithin A-glucoronide, and DMEAG were measured in blood samples taken 2–24 hours postingestion. In addition to high variability of these metabolites, the study also measured postingestion antioxidant capacity of plasma which increased significantly by 32% after 30 minutes, and the values increased 1.62 and 1.43 folds at 1 and 2 hours, respectively (Mertens-Talcott et al. 2006). In another study, six healthy volunteers consumed 1 L of pomegranate juice for 5 days. Three metabolites were found in plasma, while six were detected in urine 24 hours later. Maximum excretion rate of these metabolites was observed for 3–4 days after juice consumption (Cerda et al. 2004).

PROCESSED PRODUCTS

Pomegranate juice is the most commonly consumed processed product. Commercially, either the whole fruit intact or quartered is pressed to squeeze the juice. This results in high tannin content from the rind, which is precipitated out by a gelatin process. Depending on the processing of the fruit extract, soluble tannins and polyphenols vary in the juice within the range of 0.2–1.0% (Gil et al. 2000). Hydraulic extraction of juice at a pressure less than 100 psi prevents undue tannin release. The juice is then filtered and pasteurized before packaging.

Pomegranate juice can be converted into jelly. It is also made into sauce (to serve with fish, kebab, etc.) used as a salad dressing or to marinate meats. Pomegranate syrup or molasses is a popular dip in Syria and Turkey, in Armenia it is used to make wine. In Saudi Arabia, pomegranate arils may be frozen intact or the extracted juice is concentrated and frozen for future use. Anardana, a common spice used in India, Pakistan, Bangladesh, Afghanistan, and Iran, is prepared by drying pomegranate seeds. Special pomegranate that is sour with hard seeds is used for making "anardana." The arils are removed from the rind and sun dried for 10–15 days, which are then sold as a spice whole or powdered (Anon 2010a).

BY-PRODUCTS FROM POMEGRANATE PROCESSING

Almost all parts of the pomegranate tree are utilized for making different products. The rind and flowers are used to make dyes for the textile industry. Ink is made from steeping its leaves in vinegar. Tannin is a valuable by-product that is obtained from its trunk bark, root bark, fruit rind, or leaves and is important ingredient for tanning leather (Morton 1987).

Pomegranate has been used for pharmaceutical purposes from ancient times. In Ayurvedic medicine, it is considered "a pharmacy unto itself" and is used as a remedy for dyspepsia, diarrhea, dysentery, parasites, ulcers, hemorrhages, and as a blood tonic. Dried pulverized flower buds are considered effective in treating bronchitis and throat inflammation. Pomegranate seeds, leaves, roots, and barks have been used for hypertension as well as for leprosy (Lansky and Newman 2007).

SECTION 2: WOLFBERRY (GOJI BERRY)

INTRODUCTION

Wolfberry, commercially known as goji berry, is the common name for the two closely related species namely *Lycium*

Figure 35.2. Wolfberry (goji berry). (Adapted from Wikipedia.org [http://en.wikipedia.org/wiki/Wolfberry].)

barbarum L. and *L. chinense* Mill., belonging to Solanaceae family. Both species are used for food and medicinal purposes in China and Tibet. Other common names for wolfberry are Chinese wolfberry, matrimony vine, Duke of Argyll's tea tree, Murali, Red medlar, Tibetan, or Himalayan goji (USDA 2010). In Japan, it is called kuku and in Korea, gugija. Goji is derived from Chinese gouqi; however, the origin of the common name "wolfberry" is not known (Potterat 2010). It might be that the genus name "lycium" is confused with "lycos," the Greek word for wolf (Zhang et al. 2001).

Wolfberry species are deciduous, perennial woody plants that grow 1–3 m high. Its original habitat is not definitely known, but is found mostly in the warm regions of the world particularly the Mediterranean Basin, Central Asia, and Southwest. It is planted as a hedge plant in Australia and North America. China is the biggest exporter of wolfberry and its products. Most of the commercially produced fruits come from Xinjiang Uyghur autonomous region of western China and the Ningxia Hui autonomous region of north-central China. Ningxia wolfberries are of premium quality and are described as "red diamonds" (China Daily Reporter 2010). As of 2001, 42% of the total nation's wolfberry production came from Ningxia (People's Daily 2010). The fruit is a bright orange–red color berry, 1–2 cm in length with bitter–sweet taste. The number of seeds per berry ranges from 10 to 60 depending on the cultivar and fruit size. The fruit (Fig. 35.2) ripens from July to October in the Northern Hemisphere.

CHEMICAL COMPOSITION

Mainly fruits from the *L. barbarum* species and roots and leaves of *L. Chinese* have been analyzed (Potterat 2010). Polysaccharides are the most abundant group of substances found in the berry comprising about 23% by dry weight (Yin and Dang 2008) and are referred to as *Lycium barbarum* polysaccharides (LBP). The molecular weight of the LBP has a range of 24–241 kDa and several wolfberry polysaccharides (LbGp1 to LbGp5) have been isolated and purified. LBP consists of a complex mixture of highly branched, water soluble, and well-researched glycol-conjugates, recognized as active compounds with various health benefits. Its glycosidic part (90–95%) comprises glucose, galactose, mannose, arabinose, xylose, and galacturonic acid (Peng and Tian 2001; Huang et al. 1999).

Wolfberries contain significant amount of various phytochemicals. Its bright orange–red color is derived from a group of carotenoids. The predominant carotenoid is zeaxanthin, which comprises about one-third to one-half of the total carotenoids and exists mainly as dipalmitate. This dipalmitate zeaxanthin constitutes 56% of the fruit (Peng et al. 2005), and 83% of root total carotenoids (Qian et al. 2004). Zeaxanthin contents reported in the literature show a considerable variation such as 2.4 mg/100 g, 82.4 mg/ 100 g, or 200 mg/100 g (Lam and But 1999; Weller and Breithaupt 2003; Peng et al. 2005). Another important class of compounds in wolfberry is flavonoids that include aglycones myricetin, quercetin, and kaempferol (Le et al. 2007).

ANTIOXIDANT COMPOUNDS AND THEIR HEALTH BENEFITS

Wolfberry has been used in traditional Chinese medicine for nearly 1700 years. It is described as a tonic in the first recorded herbal medicine book, *Shennong's Chinese Materia Medica*, in three Kingdoms (230–280 AD) in China (Rich Nature Natural Products 2010). The health benefits of goji berries are especially due to their antioxidant properties, mainly attributed to the polysaccharides (LBP) and flavonoids. The potential health benefits of the wolfberries include protection from cardiovascular and inflammatory diseases, neurological disorders, various cancers, vision related diseases, and immunomodulatory disorders. The *in vivo* antioxidant markers to assess lipid peroxidation consist of serum level of SOD, glutathione peroxidase (GSH-Px), and level of malondialdehyde (MDA) (Amagase et al. 2009).

The antioxidant effect of LBP was demonstrated in various *in vitro* studies, for example, mitochondrial lipid peroxidation was inhibited (Wu et al. 2004); goji LBP protected mouse testicular cells from H_2O_2-induced oxidative damage (Luo et al. 2006); and murine seminiferous epithelium from the oxidative damage by the oxygen radicals (Wang et al. 2002a). In laboratory-created diabetes induced by streptozotocin, DNA damage was protected against oxidative stress in rats orally administered with LBP compared to the placebo-controlled rats (Li 2007). Feeding both crude as well as purified LBP fractions resulted in lowered hyperglycemia and hyperlipidemia in alloxan-induced diabetic and hyperlipidemic rabbits (Luo et al. 2004). Similarly, oral infusion of LBP in mice fed with high-fat diet reduced total cholesterol, LDL cholesterol, and triglycerides while increased activities of antioxidant enzymes (Ming et al. 2009). *L. barbarum* polysaccharides significantly decreased oxidative stress

induced by the exhaustive exercise in rats as measured by the increased glycogen level and antioxidant enzymes activities and decreased MDA level and creatine kinase activities (Niu et al. 2008).

Wolfberries' anticancerous effect was extrapolated from *in vitro* studies that showed the apoptosis of a human hepatoma cell line. The study observed arrest of the cell cycle in S phase and thus inhibition of cell proliferation (Zhang et al. 2005; Chao et al. 2006). In another study, the antitumor stimulatory properties of the LBP were correlated with the inhibition of the growth of S-180 sarcoma tumors in mice (Gan et al. 2004). Wolfberries are also associated with neuroprotection. In an *in vitro* study, when rat cortical neurons were pretreated with an aqueous extract of *L. barbarum*, they were protected from the Aβ-induced toxicity, which appears to involve inhibition of the Aβ-triggered c-Jun N-terminal kinase (JNK) signaling pathway (Yu et al. 2005).

In a double-blinded, placebo-controlled randomized design study on humans consumption of goji berries juice for 14 days, showed subjective general well-being, improved neurological performance and gastrointestinal functions. However, the study was criticized as it was conducted on a small number of subjects ($n = 34$) (Amagase and Nance 2008). A follow-up double-blinded study investigated the effect of goji berries juice on serum antioxidant markers in healthy Chinese subjects, aged 55–72 ($n = 30$). The antioxidant capacity of the subjects was significantly increased as shown by increased level of glutathione peroxidase (GHS-Px) and SOD while decreased level of MDA in serum after 30 days (Amagase et al. 2009).

High zeaxanthin and other carotenoids content of wolfberries suggest a favorable effect on protection against age-related eye disorders. In a study where 12 volunteers were given carotenoid extracts from goji berries suspended in yogurt indicated enhanced absorption of zeaxanthin dipalmitate (Breithaupt et al. 2004). Another human study tested a commercial product (*Fructus barbarum* L.), "Rich Nature" brand wolfberry, results showed an increase of 250% in plasma zeaxanthin after consuming 15 g/day for 28 days (Cheng et al. 2005).

SAFETY CONCERNS

There have been some controversies over the atropine alkaloid content in the wolfberries, a product that is toxic and is found in other members of the Solanaceae family. It was reported at a level of 0.95% in India (Harsh 1989)). However, an analysis of wolfberries revealed traces (19 ppb; w/w), atropine, which is below the toxic levels (Adams et al. 2006b). The LD_{50} of a water extract of goji berries subcutaneously applied in mice is reported to be 8.32 g/kg, which confirms the absence of toxicity and safety of the fruit for consumption (Potterat 2010). However, some caution is still advised for the samples of wolfberries of unknown origin. Allergic reactions can occur in some sensitive individuals. Therefore, people suffering from diarrhea, fever, arthritis, and strong inflammation conditions should avoid goji berries or its products (Potterat 2010).

Another caution is to individuals who take specific drugs such as warfarin. Warfarin is an effective drug but has a narrow therapeutic index and is subjected to significant drug–drug or drug–nutrient interaction. A potential interaction of warfarin and *L. barbarum* in a 61-year-old Chinese woman was observed based on her elevated international normalized ratio (INR), which was raised to 4.1 from 2.0 to 3.0, when she started drinking a concentrated goji berry tea, with no other change in her medication or lifestyle, which returned to normal after discontinuing the tea. The dissociation constant of $K_i = 3.4$ mg/mL suggested that other mechanisms account for the drug interaction *in vivo* (Lam et al. 2001). However, it is advised that combining *L. barbarum* L. with warfarin or other drugs of narrow therapeutic indices should be avoided.

OTHER USES

Wolfberries are eaten mostly as dried fruit. As a food, they are traditionally cooked before consumption. Wolfberry is added as an ingredient to Chinese tonic soups. It is added to snacks like granola bars and mixed nuts. Some herbal teas and wines contain wolfberries. China is the biggest producer and exporter of wolfberry as dried berries, juice, and pulp. Its juice is mostly available as a cocktail, in combination with other fruits. Goji is found in cookies, chocolate, muesli, sausages, and soups. In the West, wolfberry is typically sold as "Tibetan goji berry" in health food stores, drug stores, or organic food shops (Potterat 2010).

Goji products are sold legally in the Europe and the United States without being promoted as drugs. Any therapeutic claim is prohibited by law unless it is proven by sufficient research and approved by FDA. In 2006, FDA sent warning letters to goji juice distributors about the marketing claims, which violated the Food and Drug Cosmetic Act (FDA 2006a, 2006b). However, in Europe, in 2007, UK Food Standard Agency established after evaluation that the fruit does not fall under the Novel Food legislation as there was sufficient records of the alimentary use of the goji products in the United Kingdom. In the United States, goji is still not listed on the GRAS (generally regarded as safe) list of the FDA (Potterat 2010).

SECTION 3: CHOKEBERRY (ARONIA)

INTRODUCTION

Chokeberry is a deciduous shrub native to eastern part of North America and Canada. The plant introduced around 1900 in Russia and Germany was established as a cultivar in Soviet Union in 1946 (Kulling and Rawel 2008). The berries

are high in antioxidants, especially anthocyanins. The name "chokeberry" comes from the astringency of the berries, which are inedible when raw, but just before harvest they sweeten. Chokeberries are often confused with chokecherries, which are also related to the Rosaceae family, and are high in anthocyanins (Anon 2010c).

CULTIVARS

Chokeberry (*Aronia*) belongs to the Rosaceae family. The two species are red chokeberry (*Aronia arbutifolia*) and black chokeberry (*Aronia melanocarpa*). A third species is a purple chokeberry (*Aronia prunifolia*), which is a hybrid of the two, although some botanists are considering it as a full species rather than a hybrid (Weakley 2008). The plant grows 2–3 m tall. White flowers appear in spring, producing deep purple, almost black berries (Figs. 35.3A, B). The fruit is a small pome and is named after its color "black chokeberry," "red chokeberry," and "purple chokeberry." The fruit is produced from May to June and is harvested between August and September (Anon 2010c).

The important cultivars of *Aronia melanocarpa* include Viking (Finland), Nero (Czechia), Aron (Denmark), Kurkumacki (Finland), Hugin (Sweden), Fertodi (Hungary), and Rubina (cross between Russian and Finish plants) (Kulling and Rawel 2008).

CHEMICAL COMPOSITION

Factors such as cultivar, fertilization, location, fruit maturity, harvest date, etc., affect chemical composition of the fruit (Skupien and Oszmianski 2007). Dry matter content of the berries varies from 17% to 29%. Sugars analyzed in chokeberries were mostly glucose and fructose varying from 13 to 18 g/100 g fresh weight (FW). Sucrose was not detected. The glucose, fructose, and sorbitol contents of freshly pressed juice averaged 40 g/L, 38 g/L, and 80 g/L, respectively. Its dietary fiber (cellulose, hemicellulose, and lignin, with relatively low pectin (0.3–0.6%)) content was 5.62 g/100 g FW. In freshly pressed juice from different cultivars, the acidity varied from 1% to 1.5% FW (Tanaka and Tanaka 2001). The pH of the juice ranged from 3.3 to 3.9; L-malic acid being the predominant acid (Kulling and Rawel 2008).

Fresh fruits have low-fat content. The oils in seeds are mainly linoleic acid, and phospholipids such as phosphotidylcholine, phosphotidylinositol, and phosphotidylethanolamine. The sterols included β-sitosterol, stigmasterol, and avenasterol. Fresh chokeberries are a good source of vitamins and minerals. The seed oil was found to be fairly high (5.6 mg/100 g) in tocopherol (vitamin E), α-tocopherol being more dominant then β-tocopherol (Zlatanov 1999). β-carotene and β-cryptoxanthin were also found in high amounts. Freshly pressed juice is reported to contain a range of water soluble vitamins such as thiamin, 25–90 μg/100 mL; riboflavin, 25–220 μg/100 mL; niacin, 100–550 μg/100 mL; pantothenic acid, 50–380 μg/100 mL; vitamin B6, 30–85 μg/100 mL; and vitamin C, 5–100 mg/100 mL. Mineral content was in the range of 440 mg/100 g to 580 mg/100 g. Amount of zinc and potassium is shown relatively high (Kulling and Rawel 2008).

Figure 35.3. (**A**) Chokeberry flower. (Adapted from Wikipedia.org [http://en.wikipedia.org/wiki/File:Aronia-melanocarpa-Aron.JPG].). (**B**) Red chokeberry fruit. (Adapted from http://en.wikipedia.org/wiki/File:Choke-Berries-IMG_2431_051013_121714.jpg [accessed December 31, 2011].)

Polyphenols are the most important constituents of chokeberries. The total phenolic content (procyanidins predominating) is reported to vary widely from 3440 mg/100 g dry weight (DW) (Hudec et al. 2006) to as high as 7849 mg/100 g DW (Oszmianski and Wojdylo 2005). The total phenolic content (TPC) varies among whole fruit, pomace, or juice fractions. Kulling and Rawel (2008) have reported the TPC to range from 664 mg/100 g FW to 5182 mg/100 g DW in the fruit, from 5611 mg/100 g DW to 8192 mg/100 g DW in pomace, while from 1579 mg/100 g DW to 3652 mg/100 g DW in juice.

Anthocyanins are the major flavonoids and are responsible for the red, black, and purple colors of the berries and their juices. The anthocyanins content vary enormously depending on the cultivar, growing and harvesting conditions and extraction methods, storage temperature, etc. Oszmianski and Wojdylo (2005) determined the anthocyanins content of the common cultivars such as Aron, Viking, and Nero in two consecutive years and found that the value of 880–1400 mg/L in the first year went up to 1290–1970 mg/L in the second year. This suggests the increase in anthocyanins content with maturation of the chokeberries. The anthocyanins analyzed are: cyanidin 3-O-galactoside, cyanidin 3-O-arabinoside, cyanidin 3-O-oxyloside, cyanidin 3-O-glucoside, epicatechin, caffeic acid, quercetin, delphinidin, petunidin, peonidin, and malvidin (Oszmianski and Wojdylo 2005).

ANTIOXIDANT COMPOUNDS AND HEALTH BENEFITS

Anthocyanins comprise 25% of the total phenolic compounds in chokeberries (Oszmianski and Wojdylo 2005; Benvenuti et al. 2004). Procyanidins and anthocyanins are excellent chelators of iron and copper in their free states, thus inhibiting their pro-oxidative and catalytic potential (Hider et al. 2001). The antioxidant activities of chokeberries have been mostly studied in *in vitro* assays, namely oxygen radical absorbance capacity (ORAC) assay (Wu et al. 2004; Zheng and Wang 2003), ferric ion reducing antioxidants power (FRAP) (Pool-Zobel et al. 1999), methyl linoleate oxidation (Kahkonen et al. 2001), Trolox equivalent antioxidant capacity (TEAC), and antiradical capacity using DPPH (Oszmianski and Wojdylo 2005; Benvenuti et al. 2004). According to the comparative studies by ORAC measurement, fresh chokeberries ranked highest in the antioxidant capacity (Wu et al. 2004; Zheng and Wang 2003). The polyphenol content of the chokeberries was about four times higher than blueberries, cranberries, and red wine (Seeram et al. 2008; Gil et al. 2000).

The free radicals via cytochrom p450 generate chain reactions of lipid peroxidation, specifically in liver, causing cellular injury that may become cancerous (Kulling and Rawel 2008). In an *in vitro* experiment, chokeberries extract was effective in decreasing reactive oxygen species (ROS) generation in human vein endothelial cells and protected against seven beta-hydroxycholesterol induced apoptosis (Zapolska-Downar et al. 2009). In a study to investigate the effects of commercial anthocyanin-rich fruit extracts on colonic cancer cells, Zhao et al. (2004) reported that chokeberry extract stimulated apoptosis of human HT-29 colon cancer cells more than the anthocyanins extract from grapes or bilberries. Gene expression of tumor suppressor carcinoembryonic antigen-related cell adhesion molecule 1 (CEACAM1) was upregulated in human colon cancer cell line (Caco-2 cells) after repetitive exposure to Aronia juice (Bermudez-Soto et al. 2007).

In laboratory experiments, rats consuming chokeberry juice for 28 days when injected intraperitoneally with a dose each of *N*-nitrosodiethylamine (NDEA) and carbon tetra chloride (CCl_4) showed a respective decrease of 53% and 92% in microsomal lipid peroxidation compared with the control group (Kujawska et al. 2011). Aronia juice pretreatment also prevented CCl_4 induced hepatotoxicity in rats measured by nitrosamine activity and plasma and liver MDA levels (Valcheva-Kuzmanova et al. 2006). In an *in vivo* study, rats were treated with azoxymethane, a colon carcinogen, to produce colon cancer. When rats were treated with anthocyanins extract from chokeberries, Lala et al. (2006) demonstrated inhibition of colonic cellular proliferation. In other *in vivo* experiments, Borissova et al. (1994) showed chokeberries juice to have antiinflammatory effects. Chrubasik et al. (2010) induced inflammation by histamine and serotonin that resulted in paw swelling in rats. According to them, feeding chokeberries was more effective in suppressing paw inflammation than rutin.

In clinical trials, Naruszewicz et al. (2003, 2007) treated patients of blood pressure and myocardial infraction with chokeberries. In combination with statin therapy, extract from chokeberries resulted in reduced systolic blood pressure, decreased LDL oxidation, and inhibition of factors that mediated inflammation. In another study, men with mild hypercholesterolemia, who consumed a cup (250 mL) of Aronia juice daily for 6 weeks showed a significant decrease of total cholesterol, LDL cholesterol, and triglycerides, but increase in HDL cholesterol. Skoczynska (2007) reported significant (from initial 138.6 and 89.0 to 125.1 and 82.0 mmHg, respectively) reduction in diastolic and systolic blood pressures after consumption of aronia juice for 18 weeks.

When fed with *Aronia melanocarpa* juice, streptozotocin-induced diabetic rats showed attenuation of hyperglycemia and hypertriglyeridemia (Valcheva-Kuzmanova et al. 2007). In an intervention study on human subjects, consumption of 200 mL *Aronia melanocarpa* juice regularly for 3 months lowered fasting plasma glucose and glycated hemoglobin HbA1c concentration as well as improved blood lipid profile (Simeonov et al. 2002). Aronia products are reported to help with urinary tract infections, memory, and digestion (Chrubasik et al. 2010).

PROCESSED PRODUCTS

Chokeberry is processed into juice, concentrate, jam, jelly, and tea. Fresh berries are pressed and used as natural food colorant (McKay 2004). The chokeberry juice has a unique flavor, similar tartness as cranberry, and a slightly more astringency and a little less sweetness than blackberry. However, pure Aronia juice has less consumer appeal due to its tart and astringent flavor and is popular as a blend with black current juice, apple juice, etc. Aronia berries are used for liqueur and fruit wine production (Chrubasik et al. 2010).

OTHER USES

Chokeberry plant is highly resistant to industrial pollution and pests and can be cultivated with a minimal use of herbicides. It is an excellent plant in absorbing swampy water, thus is used in habitat preservation (Anon 2010c).

SAFETY ISSUES

Aronia berries contain amygdalin, a cyanogenic compound that not only gives bitter-almond taste and smell to the fresh fruit but also gives rise to hydrogen cyanide from its prussic acid. Hydrogen cyanide is highly volatile compound that boils at slightly above room temperature and is very poisonous (lowest observed level of <1 mg/kg for adults). The amount of amygdalin is 20.1 mg/100 g in fresh berry, 5.7 mg/100 mL in juice, and 52.3 mg/100 g in fresh pomace (Kulling and Rawel 2008). Its high sorbitol content may have laxative effect. Consumption of high polyphenolic compounds can decrease absorption of minerals such as zinc, copper (Frejnagel and Wroblewska 2010), and iron, and thus can cause mineral deficiency and anemia (Chrubasik et al. 2010).

SECTION 4: ACAI

INTRODUCTION

Acai (*Euterpe oleracea*) is a kind of palm tree, which grows in many regions of Latin America, especially, the Northern Amazon area of Brazil. The acai berries are known to be rich in many health-promoting antioxidant phytochemicals (Alexander 2007). The acai tree can reach a height of 25–30 m and bears fruits from July to December. The fruit size ranges from 1 to 1.5 cm in diameter. Each plant can produce 3–4 bunches of fruit, and each bunch carries between 3 and 6 kg of fruit. The round immature fruit appears as a green cluster, which turns to purple and finally black when fully mature (Anon 2007). Acai fruit has become popular in the form of energy drinks, juice cocktails, sorbets, ice cream, semifrozen fruit puree, and probiotic yogurt (Anon 2010d).

Acai is processed into flakes, puree, and powder for use in other food products (Brombacher 2005). Many health claims, including, heart disease, weight loss, aging, cancer, improved digestion, better sleep, protection against arthritis, as well as improved general health, are being made for the acai fruit (Marcason 2009). Acai has gained popularity in the United States and is now gaining ground in Europe as well.

CHEMICAL COMPOSITION

The acai fruit pulp contains about 4% protein and 12% lipids. The acai juice is viscous and contains about 2.4% protein and 5.9% lipids. Other nutrients present in acai include vitamins A, C, and E, calcium, phosphorus, iron, thiamine, polyphenols, and anthocyanins (Marcason 2009). Acai and its pigments rich in acylated anthocyanins displayed low stability in presence of hydrogen peroxide (Pozo-Insfran et al. 2004). The total polyunsaturated fatty acids (PUFA), total monounsaturated fatty acids (MUFA), and total saturated fatty acids (SFA) contents were 11.1, 60.2, and 28.7%, respectively. Oleic acid (53.9%) and palmitic acid (26.7%) were the two predominant fatty acids (Schauss et al. 2006). General composition of freeze-dried acai pulp is presented in Table 35.3.

Table 35.3. Chemical Composition of Acai Fruit Pulp

Chemical Constituent	Per 100 g Freeze-Dried Acai Pulp Powder
Energy (kcal)	533.9
Total carbohydrates (g) (Including dietary fiber)	52.2
Dietary fiber (g)	44.2
Total protein (g)	8.1
Total fat (g)	32.5
Oleic acid (as % of total fat)	56.2
Palmitic acid (as % of total fat)	24.1
Linoleic acid (as % of total fat)	12.5
Calcium (mg)	260
Iron (mg)	4.4
Vitamin A (IU)	1002

Source: Anon (2010d).

de Rosso et al. (2008) reported a total anthocyanin content of 282–303 mg/100 g in frozen acai pulp, with cyanidin 3-glucoside and cyanidin 3-rutinoside, in the ratio of 13:87, respectively.

Pacheco-Palencia and Talcott (2010) investigated the influence of different classes of naturally occurring and externally added polyphenolic cofactors on the phytochemical and color stability of anthocyanins in acai fruit. According to their findings, cyanidin glycosides-rich acai fruits offer potential for use as color enhancers and stabilizing agents in various food products, juice blends, and beverages.

ANTIOXIDANT PROPERTIES

Acai fruit pulp contains health-promoting phytochemicals such as polyphenols and anthocyanins. Lichtenthaler et al. (2005) showed that contributions of anthocyanins to the overall oxidant capacity of the acai fruit was about 10%, therefore, other, unidentified, compounds may be responsible for the remaining 90% of the antioxidant capacity of acai fruit.

West (2009a) evaluated two commercially available acai juice blends in the US market. The total antioxidant

activity determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay varied from 52.9% to 74.5%. The sample with higher radical scavenging activity had more ascorbic acid. Kang et al. (2010) isolated seven major flavonoids from freeze-dried acai pulp. Using NMR and MS, they elucidated their structures as orientin, homoorientin, vitexin, luteolin, chrysoeriol, quercetin, and dihydrokaemferol. The oxygen radical absorbance capacity (ORAC) values of these compounds ranged from 1420 to 14,800 μM TE/g.

Pacheco-Palencia et al. (2008a) investigated the absorption and antiproliferative effects of phytochemical extracts from acai fruit pulp and polyphenols-enriched acai oil. Mixtures of polyphenols (0–12 μg gallic acid equivalent (GAE)/mL) from acai fruit pulp and acai oil extracts inhibited cell proliferation by 90.7%. These polyphenols were readily absorbed in the intestines and transported to other organs. Mertens-Talcott et al. (2008) evaluated the pharmacokinetics of anthocyanins and antioxidant effects of consumption of anthocyanin-rich acai juice and pulp by healthy human volunteers. In a 4-way crossover clinical trial with acai pulp and clarified acai juice, they compared these samples to the apple sauce and a nonantioxidant beverage. They reported an increase in blood antioxidant capacity up to 2.3 and threefold in acai pulp and apple sauce, respectively.

MEDICINAL PROPERTIES

The effects of acai fruit polyphenols on the antiproliferation activity and the induction of apoptosis in HL-60 human leukemia cells was investigated by Pozo-Insfran et al. (2006). The glycosidic forms of phenolic acids and flavonoids showed higher level of antiproliferative and apoptosis activities than their respective aglycone forms, while anthocyanin aglycones had the opposite effect.

Spada et al. (2009) reported a negative correlation between the polyphenol content of acai and damage to lipids and proteins in hippocampus of rats. Carvalho-Ribeiro et al. (2010) reported that acai pulp showed no genotoxic effects in Swiss albino mice.

The antiproliferative activity of monomeric and polymeric fractions of anthocyanins present in acai fruit has been investigated by Pacheco-Palencia et al. (2010). Their results showed that the polymeric anthocyanins significantly influence the absorption of monomeric anthocyanins present in the acai fruit. Hogan et al. (2010) reported antioxidant and antiproliferative properties of anthocyanin-rich extract from acai fruit (AEA) against the C-6 rat brain glioma and MDA-468 human breast cancer cells. They also compared the AEA with the anthocyanin-rich extracts from a number of other berries, such as, strawberry, raspberry, blackberry, and wolfberry, for their antiproliferative activity. Unlike acai extract, the aforementioned berries did not show suppressing effects on cancer cells.

FUNCTIONAL FOODS

Acai fruit juice being rich in anthocyanins and antioxidant has been studied by Coisson et al. (2005) for use as a natural colorant in yogurt. Addition of 10% acai juice in yogurt gave a product similar to that of commercial yogurt containing bilberry juice.

Almeida et al. (2009) added 5–7% acai fruit pulp to produce yogurt with desirable flavor, color, and consistency. Espirito Santo et al. (2010) have studied the effect of adding acai fruit pulp on the prebiotic bacteria and the acid profile of stirred yogurt. According to their results, addition of acai pulp increased the monounsaturated and polyunsaturated fatty acid contents, with higher levels of α-linolenic acid and conjugated linoleic acids during fermentation in the prebiotic yogurt produced with *Bifidobacterium animalis* ssp. *lactis* B104 and B94 strains. Alves Toaiari et al. (2005) reported that bioavailability of iron from acai fruits was lower (12.1 ± 5.5%) than manioc flour (44.6 ± 3.6%).

JUICE, PULP, AND POWDER

de Rosso and Mercadante (2007) evaluated the stability of added anthocyanins from acerola and acai to an isotonic beverage system stored under supermarket-like conditions. A gradual reduction in red color, accompanied by decreased color intensity of drink beverage was observed.

Phytochemical, antioxidant, and pigment stability of semiclarified and clarified acai juice as affected by ascorbic acid fortification and storage conditions (4°C and 20°C) have been studies by Pacheco-Palencia et al. (2007a). About 27% loss in total polyphenolics, 20% loss both in total anthocyanins and total antioxidant activity was observed in clarified acai pulp. Fortification of clarified juice with ascorbic acid resulted in higher degradation of anthocyanins (Pacheco-Palencia et al. 2007b).

Marya de Silva Menezes et al. (2008) investigated the use of high hydrostatic pressure (HHP) processing of acai pulp as an alternative to conventional thermal processing techniques. According to their report, polyphenoloxidase (PPO) enzyme was completely inactivated at a pressure of 500 MPa, but peroxidase (POD) enzyme was only partially inactivated. Investigation of rheological properties of acai pulp indicated that it forms weak gel (Tonon et al. 2009a).

Tenon et al. (2008) standardized process for acai fruit juice powder. Increasing the level of maltodextrin in the feed, decreased air inlet temperature, increased feed flow rate, and produced powder with lower hygroscopicity. Due to heat sensitivity, anthocyanins retention was adversely affected by the increase in air inlet temperature. Higher spray-drying temperature produced acai powder of larger particle size and smooth surface, lower moisture, greater hygroscopicity, and lower anthocyanin retention. Acai juice powder prepared with maltodextrins and gum Arabic, showed higher polyphenolic

retention and antioxidant activity than powder prepared using tapioca starch (Tenon et al. 2009b, 2009c). Water adsorption was highest in acai juice powder produced with 20DE maltodextrin and gum Arabic, followed by powder made with 10DE maltodextrin and tapioca starch (Tenon et al. 2009d). Gordon-Taylor model was found to be suitable to predict the strong plasticizing effect of water on the glass transition temperature properties. Anthocyanin stability and antioxidant activity of acai juice powder produced by spray drying using four different carrier agents and stored under different temperature and water activity conditions (temperature of 25°C and 35°C, a_w of 0.328 and 0.529) have recently been reported (Tenon et al. 2010). For all experimental conditions studied, 10DE maltodextrin showed the highest anthocyanin retention and antioxidant activity.

MISCALLENEOUS PRODUCTS

The methanol and ethanol extracts of acai seeds exhibited antioxidant capacity against peroxyl radicals similar to that of acai fruit pulp (Rodrigues et al. 2006).

Chemical composition, antioxidant properties, and thermal stability of phytochemical rich oil extracted from acai seeds were analyzed at 20°C, 30°C, 40°C by Pacheco-Palencia et al. (2008b). The phenolic acids composition of acai seed oil was found to be quite similar to acai fruit pulp. After 10 weeks, phenolic acids declined by about 16% when stored at 20°C and 30°C, and by 33% at 40°C. In low- and high-phenolic acai oils, the procyanidin oligomers degradation was much higher (23% at 20°C, 39% at 30°C, and 74% at 40°C). Because of its higher phenolic acids content, the phytochemical-rich acai seed oil can be a potential alternative to traditional tropical oils for use in foods, supplements, and cosmetics.

SECTION 5: NONI

INTRODUCTION

Noni (*Morinda citrifolia* L.) is known by many names, such as, Indian mulberry, great morinda, *nunaakai* (Tamil language, India), dog dumpling (Barbados), *mengkudu* (Malaysia), noni (in Hawaii), beach mulberry, or cheese fruit. This tree from the coffee family, Rubiaceae, grows up to 10 m high. Although a native to Southeast Asia and Australia, it is now distributed throughout the tropics (Anon 2009).

Noni tree bears flower and fruits throughout the year. The fruit is a multiple fruit, which gives a pungent odor during ripening, hence also called cheese fruit. Noni fruit has been used for food and medicinal purposes for more than 200 years in Polynesia. Health foods and beverages made from noni fruit have entered markets in the United States, Europe, and Asia (Starling 2003).

PLANT AND FRUIT CHARACTERISTICS

Noni plant belongs to family Rubiaceae, genus *Morinda*, which has nearly 80 species. Noni is a small tree that grows up to 3–10 m high. The noni fruit is oval, fleshy and reaches 3–10 cm in length and 3–6 cm in width when fully grown. The ripe fruit has strong butyric acid-like rancid smell and bitter taste but eaten in some areas as staple food, either raw or cooked (Morton 1992). The fruit starts as green, then turns yellow and finally almost white when fully mature and ready to pick. It is covered with small reddish-brown buds (pits) that contain four seeds. The ripe fruit pulp is juicy and bitter, of yellow-whitish color and gelatinous consistency (Dittmar 1993).

In Hawaii, the tree bears fruit almost throughout the year, but elsewhere there are seasonal variations in flowering and fruit bearing. Fruits are harvested manually in Hawaii two or three times a month. With good soil fertility and proper agronomic practices, about 600 trees can be planted per hectare. In Hawaii, an average annual yield of 50 tons/hectare per year is attained. Noni fruit gives a juice yield of nearly 50% (w/w) (Nelson 2001; 2003a).

Depending upon the postharvest practices, noni fruit may be harvested at different stages of maturity. However, for juice production, most processors prefer fruits harvested at the "hard white" stage as the fruits become soft within a few hours. Before processing, fruits are ripened at room temperature for a day or more depending upon the final product (tea, juice, pulp, and dietetic product) produced (Nelson 2003).

The effect of ripening and aging of noni fruits on the microbial population and antioxidants compounds has been studied by Chan-Blanco et al. (2007). The fungi, mesophilic, and lactic acid bacteria (LAB) grew exponentially for 2 weeks and then stabilized except for LAB, which were undetectable after 5 weeks. The pH, lactic acid, ethanol, and soluble solids also stabilized toward the end of 5 weeks. Total phenolics, (50 ± 20 mg/100 g GAE), vitamin C (300 ± 60 mg/100 g), and the antioxidant activity (6.8–9.5 μM TE/g) in the pulp remained constantly high during aging.

CHEMICAL COMPOSITION AND FLAVOR

A complete physicochemical composition of noni fruit has not been reported and only partial information is available on noni juice. Chemical composition of the Hawaiian pure noni fruit juice as well as noni fruit powder is presented in Tables 35.4 and 35.5, respectively. Among the sugars, dextrose was predominant, followed by fructose, lactose, and sucrose. Small amounts (<5 IU) each of β-carotene and retinol were also reported. Noni fruit powder (per 100 g) had 36 g total dietary fiber, 5.8 g protein, and 1.2 g fat (Nelson 2006). Vitamin C in noni fruit has been reported to range from 24 to 158 mg/100 g dry matter (Morton 1992). Noni fruit contains about 90% water and the major components

Table 35.4. Chemical Composition of Hawaiian Pure Noni Fruit Juice

Chemical Constituent	Per 100 g Juice
Moisture (g)	95.67
Calories	15.3
Total carbohydrates (g)	3.4
Sugars (g)	1.49
Ash (g)	0.54
Proteins (g)	0.43
Total dietary fiber (g)	<0.2
Total fats (g)	<0.1
β-carotene (IU)	<5
Potassium (mg)	66.6
Sodium (mg)	10.5
Calcium (mg)	10.1

Source: Nelson (2006).

of the dry fruit are soluble sugars, dietary fiber, and proteins. Chunhieng (2003) reported higher protein and lower ash contents in noni juice. The minerals were mainly potassium, sulfur, calcium, and phosphorus with traces of selenium. Potassium was the major mineral reported by West et al. (2006a) and West (2006). West (2009b) measured the mineral contents and pH of ash residues in noni fruit juice and noni leaves. According to his findings, minerals from both foods were predominately potassium, calcium, sodium, and magnesium.

Sang et al. (2002) reported presence of nearly 51 volatile compounds in ripe noni fruit. These compounds included organic acids (mainly octanoic and hexanoic acids), alcohols (3-methyl-3-buten-1-ol), esters (methyl octanoate, methyl decanoate), ketones, (2-heptanone), and lactones [(E)-6-dodeceno-γ-lactone]. Pino et al. (2009) reported 34 volatile compounds in noni fruit harvested at the soft white stage of maturity using conventional extraction procedures and the gas chromatography-flame ionization detector (GC-FID) and gas chromatography-mass spectroscopy (GC-MS) analysis. The main volatile acids identified were, octanoic acid (3.06 g/kg) followed by hexanoic acid (0.33 g/kg). They identified 26 nonvolatiles in noni fruit, in which malonic acid (1.46 g/kg) and fumaric acid (1.03 g/kg) predominated. Farine et al. (1996) studied the influence of volatiles on *Drosophila*. Octanoic acid was found to be responsible for general toxicity to most *Drosophila* species.

Table 35.5. Chemical Composition of Hawaiian Noni Fruit Powder (Per 100 g Powder)

Chemical Constituent	Amount (%)
Moisture	9.3
Total dietary fiber	36
Carbohydrate	71
Ash	10.3
Protein	5.8
Fat	1.2

Source: Nelson (2006).

Wang et al. (2000) have reported the presence of three novel glycosides in noni, a MS and NMR analyses, determined their structures to be 6-O-(β-D-glucopyranosyl)-1-O-octanoyl-β-D-glucopyranose; 6-O-(β-D-glucopyranosyl)-1-O-hexanoyl-β-D-glucopyranose; and 3-methylbut-3-enyl 6-O-β-D-glucopyranosyl-β-D-glucopyranose. In another study, the polysaccharide composition of the noni fruit juice has been reported to be predominately the pectic substances (Bui et al. 2006). Three new constituents (Samoylenko et al. 2006) and new trisaccharide fatty acid esters (Dalsgaard et al. 2006) that can be used as markers for the identification of noni fruit juice have been reported.

A number of phenolics (e.g., acubin, L-asperuloside, alizarin, scopoletin, and other anthraquinones) present in the noni fruit have been shown to possess antibacterial properties against a number of microorganisms, such as, *Pseudomonas aeruginosa, Escherichia coli, Helicobacter pylori, Streptococcus pyogenes, Bacillus subtilis, Mycobacterium tuberculosis, Salmonella,* and *Shigella* (Atkinson 1956; Dittmar 1993; Locher et al. 1995; Saludes et al. 2002). They observed that the antibacterial effect was related to the degree of ripeness and processing, and was greater with the fresh ripe fruit. The noni fruit extract has shown antifungal effect on *Candida albicans,* the inhibitory effect varied with concentration as well as contact time (Jainkittivong et al. 2009).

ANTIOXIDANT COMPOUNDS

Different parts of the noni plant (stem, leaves, fruit, flowers, and roots) have been used in folk medicine in Asia, Hawaii and Tahitian islands for many centuries (Deng 2010). Use of noni juice is reported to combat fatigue, improve endurance, balance, and flexibility and increase overall physical performance in mice (Ma et al. 2007). An epidemiological evaluation of the benefits of noni juice consumption in European population has been reported (Westendorf and Mettlich 2009). Using HPLC method, phytochemical fingerprints of the characteristic components in 7 noni fruits and 13 commercial fruit juices from Caribbean, Central America, the Central and South Pacific, and Asia have been reported by Deng et al. (2010). Their results showed that scopoletin, rutin, quercetin, and 5,15-dimethylmorindol were present in all samples but their content was affected by the geographical environment and the postharvest conditions. Therefore, the scientific data on the toxicological and pharmacological profiles from one noni fruit or juice may not be applicable to all noni fruits and products, even from the same region.

Although noni is considered a medicinal plant having antitumor activity (Furusawa et al. 2003; Hirazumi and Furusawa 1999), little scientific information is available on

the biologically active components present in the fruit. The bioactive extracts from noni, comprising polysaccharides, anthraquinones, and alkaloids, have been shown to be a potential immunostimulant herbal drug (Nayak and Mengi 2009). The methanol extracts of noni fruit containing iridoid-, hemiterpene-, and fatty acid-glycosides exhibited marked inhibitory effects on the melanogenesis (Akihisa et al. 2010).

Phenolics, such as, damnacanthal, scopoletin, morindone, alizarin, aucubin, nordamnacanthal, rubiadin, rubiandin-1-methyl ether, and anthraquinone glycosides have been identified in the noni juice (Morton 1992; Dittmar 1993). Heinocke (1986) patented an alkaloid, xeronine, in noni juice. He attributed most of the health-improving effects of noni to xeronine. However, this compound has not yet been characterized chemically or its content in noni assessed.

The free-radical scavenging activity (RSA) of noni juice and powder has been estimated by Yang et al. (2007). Fermented noni juice lost 90% of the RSA within 3 months, whereas dehydration at 50°C showed only 20% RSA loss. Storage of noni juice or powder at –18°C and 4°C for 3 months reduced RSA by 10–55%. Loss of RSA in noni juice, puree, or powder was greater than the total phenolics. Three phenolic compounds, namely, isoscopoletin, aesculetin, and 3,3′,4′,5,7-pentahydroxyflavone (quercetin) having antioxidative properties have been isolated from fermented noni juice by Liu et al. (2007). In a study, coumarin derivatives such as scopoletin, 7-hydroxycoumarin, and 4-hydroxycoumarin from noni fruit juice have been reported to have a dose-dependent effect in quenching various ROS such superoxide, singlet oxygen, hydroxyl radical, and peroxynitrile (Ikeda et al. 2009).

Juice from ripe noni fruit has been reported to contain high total phenolics, condensed tannins, flavonoids, and scopoletin. It exhibited free radicals scavenging capacity as well as higher angiotensin-converting enzyme (ACE) inhibitor activity (Yang et al. 2008). Deng et al. (2009) developed a selective and validated method for the analysis of anthraquinones in noni fruits and leaves. This method would be useful to identify presence of potentially genotoxic lucidin and rubiadin and major nongenotoxic anthraquinones, alizarin, and 5-15-dimethylmorindol in noni juice and other products.

Total phenolics, ascorbic acid, and antioxidant capacity of noni juice and powder as affected by illumination during storage at 24°C have been studied by Yang et al. (2010). After 2 weeks of storage, illuminating noni juice caused loss of 32% total phenolics, 89% ascorbic acid, and 46–65% antioxidant capacity, these losses were more than 8%, 22%, and 9–15%, respectively than the control juice.

MEDICINAL PROPERTIES

Noni plant has been used by the Polynesians for medicinal purposes for more than 2000 years to prevent and cure several diseases. It is now gaining worldwide popularity as a dietary supplement with versatile health benefits. Tahitian noni juice (TNJ) has been studied to inhibit the calpain-1 enzymes that might be useful in calpain-related diseases, such as to improve memory functions (Palu 2009). TNJ has been shown to provide hepatic protection against carbon tetrachloride-induced chronic liver damage in female Sprague Dawley (SD) rats (Wang et al. 2008). Such protective mechanisms provide evidence for the use of noni juice for curing liver ailments.

Psychological distress, characterized by anxiety, depression, and certain symptoms of aggressive behavior is a serious health concern in modern society. Deng et al. (2007a) studied the effect of noni fruit on the anxiety symptoms *in vitro* using a gamma-aminobutyric acid A (GABAa) receptor-binding assay. Their results indicated the presence of competitive ligands that may bind to the GABAa receptors as an agonist and induce its anxiolytic and sedative effects, thus providing a rationale for traditional medicinal uses. Palu et al. (2008) investigated the mechanism involved in the immunomodulatory effects of noni fruit *in vitro* and *in vivo* in mice. According to their findings, noni fruit juice modulates immune system by activating the cannabinoid 2 (CB_2) receptors, suppressing the production of IL-4, and increasing the production of IFN-γ cytokines.

Consumption of 1–4 oz of TNJ for a month has been reported to significantly reduce the aromatic DNA adduct levels in smokers (Wang et al. 2009). Anthraquinones present in noni root have been isolated and studied for their anticancer properties against colon cancer in humans (Kamiya et al. 2009). Consumption of noni juice was shown to have analgesic and sedative effects (Wang et al. 2002b).

The noni root extract, which contains anthraquinones has been shown to have several beneficial effects such as: Inhibition of overreactive aromatase enzymes for treatment of breast cancer (Palu et al. 2009); inhibition of lipoxygenase enzyme (Deng et al. 2007b); inhibition of angiotensin I converting enzyme (ACE) for reducing blood pressure (Yamaguchi et al. 2002); prevention of low-density lipoprotein oxidation (Kamiya et al. 2004); benefits against type 2 diabetes (Owen et al. 2008); and cancer (Wang and Su 2001).

SAFETY OF NONI FRUIT

Although noni fruit is consumed in many countries, its safety has been a concern. A toxicological review by Potterat and Hamburger (2007), however, suggested noni juice to be a safe product for human consumption.

Following three cases of acute hepatitis in Austrian noni juice consumers, safety of noni juice was investigated by West et al. (2006b). The results of their human clinical safety study using liver function measurements as well as subacute and subchronic animal toxicity tests showed no adverse effect on liver. West et al. (2007) found no evidence of toxicity in the noni leaves which are also consumed by humans

as food. Toxicological (genotoxicity tests) and analytical investigation (chemical analysis for anthraquinones) of the noni fruit juice revealed no genotoxic potential for human consumption, as genotoxic anthraquinones were not detected in the noni juice (Westendorf et al. 2007). West et al. (2008a) administered freeze-dried noni fruit juice to pregnant SD rats and examined the number of live fetuses, resorption, fetal weight and length, or other skeletal abnormalities. They found little differences in dead fetuses, gross external abnormalities, or internal defects between the control and experimental SD rats, indicating that noni juice had little adverse effect or toxicity in developing embryos.

PROCESSED PRODUCTS

Fruit Juice and Powder

Lachenmeier et al. (2006) analyzed volatile compounds such as pentanoic acid, hexanoic acid, and their ethyl esters to determine authenticity of noni juice. Potterat et al. (2007) identified 3-Methyl-1,3-butanediol as a marker for identification of noni juice. Logsdon (2008) patented a process for production of a therapeutic noni juice with powerful antioxidant properties. As the slightly bitter flavor of noni juice is not acceptable to all consumers, Kan (2008) prepared a mixed fruit juice from noni, grapes and pineapple. The best results were obtained using a ratio of noni juice:grape juice:pineapple juice of 40:35:28; the product retained good flavor after sterilization at 85°C for 10 minutes. Yi et al. (2008) optimized a formula for a mixed fruit juice beverage containing 40% noni fruit juice, 58% pineapple juice, and 2% mango juice. This mixed fruit beverage contained 0.3% protein, 37.2 mg/100 mL vitamin C, and 0.54 mg/100 mL β-carotene. Valdes et al. (2009) optimized operating conditions for fourfold concentration of noni juice by membrane separation.

Nishigaki (2007) patented a process for the preparation of capsules containing noni fruit powder.

MISCELLANEOUS PRODUCT

Noni seed oil can be a potential source of safe and healthy vegetable oil. West et al. (2008b) reported noni seed oil to contain 59.4% linoleic acid.

SECTION 6: AMLA (INDIAN GOOSEBERRY)

INTRODUCTION

Amla or Indian Gooseberry (*Emblica officinalis* Gaertn or *Phyllanthus emblica* L.) is a deciduous tree that commonly grows in the tropical and subtropical parts of India, China, Indonesia, and Malaysia. Amla tree can grow even on low-fertility soils and with low rainfall. Amla fruit is considered an important dietary source of vitamin C (Raghu et al. 2007). It can be consumed as raw, pickle, jam, preserve (Murabba), candy, powder, and juice or beverage. Amla extract has strong antioxidant properties and inhibits lipid peroxidation and scavenges hydroxyl and superoxide free radicals *in vitro,* and it makes amla one of the principal constituents of many herbal preparations as per the Ayurveda system of medicine in India (Scartezzini and Speroni 2000; Scartezzini et al. 2006). An indigenous Indian preparation, Chyawanprash, developed by using mainly amla and a combination of 50 herbs, minerals, honey, and sugar is marketed in India and abroad to provide various health benefits. An exhaustive review is available on the chemistry and technology of amla fruit (Kalra 1988).

The amla fruit juice has been reported to possess hypolipidemic, antidiabetic, and antiinflammatory properties, and to inhibit HIV-1, tumor development, and prevent gastric ulcer (Sabu and Kuttan 2002).

AMLA CULTIVARS

Most amla varieties are classified according to the fruit size, color, and location (Singh et al. 1963). Green-tinged, Red-tinged, Pink-tinged, White-streaked, and Bansi Red are some of the varieties classified according to their color. Banarasi, Bansi Red, Chakaiya, Desi, Hathijool, and Pink-tinged are some of the important amla varieties that are recommended for commercial cultivation in the Northern India (Shankar 1969). Chakaiya variety is known for its heavy and regular fruit-bearing characteristics, while Banarasi bears relatively large-sized fruits, but total fruit yield per tree is lower than the former.

HARVEST

In India, amla is ready for harvest by November–December, although fruits are allowed to stay on trees till February without much chance of fruit drops (Fig. 35.4). In Northern India, the optimum harvest time for amla is from mid-December to mid-January. At many places in Southern India, the amla is available all the year around. An average annual amla yield of 250–300 kg per tree is common (Kalra 1988).

CHEMICAL COMPOSITION

Amla is considered as one of the richest sources of ascorbic acid (Srinivasan 1944; Srivastava and Srivastava, 1964; Verma and Palod 1983; Raghu et al. 2007). Verma et al. (1984) reported ascorbic acid (vitamin C) content as 591 mg/100 g in amla fruit. However, as evident later in this section, vitamin C content of amla and amla products is quite variable. Amla is also known to be a rich source of reducing and nonreducing sugars, and pectin (Srivastava and Srivastava 1964; Nizamuddin et al. 1982).

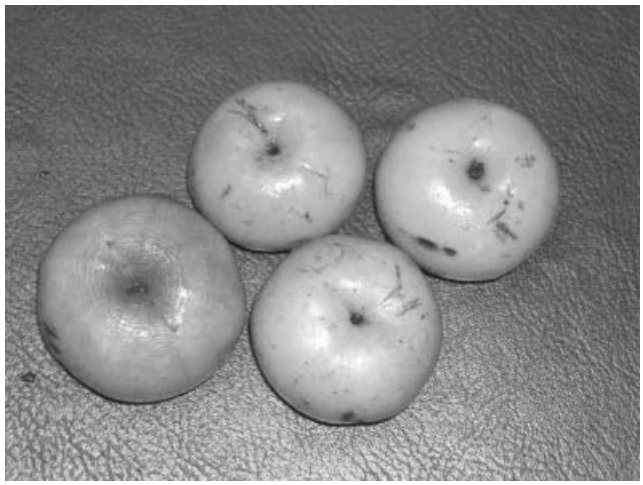

Figure 35.4. Amla fruits. (Adapted from Jiwan S. Sidhu)

Sethi and Anand (1982) analyzed commercially available amla preserves for chemical and microbiological quality. The ascorbic acid of amla preserve ranged between 5.0 and 26.0 mg/100 g. They detected presence of *Saccharomyces rouxii* var. *polymorphus* and *Bacillus cereus* in preserve samples analyzed. Taneja et al. (1982) reported a higher rate of decrease in ascorbic acid content in fungal infected amla fruits than the healthy fruits.

Raghu et al. (2007) analyzed amla and other ascorbic acid-rich plant sources using four analytical techniques, namely, 2,4-dinitrophenylhydrazine (2,4-DNPH), Indophenol-xylene, enzymatic, and HPLC methods. They observed overestimation of vitamin C by colorimetric methods (possibly due to the presence of tannins and other reducing agents) not only in amla but also other fruits as well. Ascorbic acid retention in amla fruits dried in shade was similar to sun-dried amla.

Proximate composition of amla fruits is presented in Table 35.6 (Barthakur and Arnold 1991).

Gowri et al. (2001) while investigating the influence of amla fruits (10 and 30% level) on the bioavailability of iron from staple cereal and pulse diets, found no improvement in iron bioavailability at either concentration. They suggested that the relatively high tannin content of amla fruits (0.25 g/100 g) could have counteracted the beneficial effects of ascorbic acid. However, Majeed et al. (2009) found no tannins or mucic acid gallates in amla fruit and suggested a new HPLC method to detect trace amounts of ascorbic acid in amla fruit juice or extract.

Table 35.6. Proximate Composition of Fresh Amla Fruit

Parameter	Amount
Moisture (%)	79.8
Titratable acidity (%, citric acid)	2.64
pH	2.94
Ash (%)	0.62
Protein (%) (N × 6.25)	0.69
Reducing sugars (%)	6.70
Ascorbic acid (mg/100 g)	588.9

Source: Barthakur and Arnold (1991).

Nisha et al. (2004) investigated the degradation kinetics of ascorbic acid in amla by different cooking methods, such as, normal, open pan cooking, pressure-cooking, and fuel-efficient EcoCooker (unsteady-state) heating process. According to their results, these methods of cooking gave similar magnitude of ascorbic acid degradation.

A few commercially available products like amla preserve, amla juice, and an Indian tonic, Chyawanprash, have been analyzed for nutritional and microbiological quality by Garg et al. (2008). They found ascorbic acid to be highest in Chyawanprash (31.0–41.7 mg/100 g), whereas total phenols were the highest in amla juice (2.0–4.2%). Most of these commercial samples were found to be free of yeasts, molds, coliforms, and osmophiles, but contained *Bacillus* bacteria. Chyawanprash samples had heat resistant bacteria (possibly from the raw material), which may have survived the heating process. The detection of heat labile bacteria from the amla preserve and amla juice samples suggested a postprocessing contamination.

POSTHARVEST STORAGE AND SHELF LIFE

As amla fruits are hard, they can be transported to long distance without much loss in quality (Shankar 1969). Singh and Kumar (1997a) studied the effect of different storage conditions on the shelf life of fresh amla fruits. Ascorbic acid content decreased with extended storage period under all storage conditions, however, modified atmosphere storage in combination with zero-energy chamber were found to be effective in reducing loss of weight and ascorbic acid in fresh amla fruits. In another postharvest storage study of fresh amla fruits, Singh and Kumar (1997b) showed that treatment with 150 ppm kinetin was most effective in retaining ascorbic acid of fruits followed by treatment with 25 ppm gibberellic acid.

Due to acidic and astringent taste, fresh amla fruit is usually processed with sugar or made into pickle like products. However, formation of white specks on the interior and surface of fruit can adversely affect the acceptance of processed products. According to Premi et al. (1998), white specks are formed by the interaction of calcium with mucic acid (D-galactaric acid). In a subsequent study, Premi et al. (1999) suggested steeping fresh amla fruit segments in a solution containing 10% sodium chloride and 0.04% potassium metabisulfite to control development of white specks during the storage.

High electric field (HEF) can be applied to extend the shelf life of fresh amla fruits. Bajgai et al. (2006) treated fresh amla fruits packed in open polyethylene pouches with alternating current (AC) and direct current (DC) (HEF of 430 kV/m) for 2 hours to study weight loss, rotting, ascorbic acid retention, and hunter color values. HEF-treated fruits retained freshness, color and ascorbic acid better than untreated fruits. In another study, wax coating of injured fresh amla fruits was reported to extend the shelf life by about 3 weeks under ambient storage conditions (13.3°C, 65.6% RH) (Pathak et al. 2009). Singh et al. (2009) evaluated use of gunny bags, corrugated fiberboard boxes (CFB), wooden crates, bamboo baskets with polyethylene liners (PL), or newspaper liners (NPL) for storage of fresh amla fruits under ambient conditions (21–33°C, 65 ± 3% RH). As compared to control fruits, fresh amla fruits packed in CFB with NPL showed lowest spoilage at the end of 13 days of storage.

ANTIOXIDANT COMPOUNDS

Amla fruit extract has been shown to possess high antioxidative activity against linoleic acid oxidation or xanthine oxidase system (Kelawala and Ananthanarayan 2004; Asadul-Haque et al. 2006). Dried fruit rind of amla has been shown to possess nitric oxide (NO) radical scavenging activity (Kumaran and Karunakaran 2006). Gallic acid was found to be a predominant compound in the ethyl acetate extract of amla fruit rind and geraniin (a form of tannin) showed the highest NO scavenging activity among the isolated compounds. Kumar et al. (2006) reported high total phenolics (129 mg GAE/g dry basis) in dried amla powder.

Using a combination of HPLC with a diode array detector (DAD) and postchromatographic 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical derivatization, Pozharitskaya et al. (2007) separated a number of antioxidant compounds in amla extract and evaluated their free radical-scavenging activity. They ranked the free-radical scavenging activity of these compounds as: emblicanin B > emblicanin A > gallic acid > ellagic acid > ascorbic acid. Saito et al. (2008) reported that even after heating, ethanol extract from amla maintained both superoxide anion and hydroxyl radical scavenging activities. In addition to antioxidant activity, amla fruit extract has been shown to possess antibacterial activity against *Staphylococcus aureus* (Mayachiew and Devahastin 2008). A patent was granted to Sakaguchi and Teetamu (2006) for an antioxidative composition obtained from the amla fruit using different solvent systems. The ascorbic acid and total phenolics contents in amla fruit and its processed products are presented in Table 35.7.

Liu et al. (2008b) have identified various phenolics in the methanol extract of dried amla fruits. Among these compounds, geraniin showed the highest antioxidant activity (4.7 and 65.7 μM of (inhibitory concentration$_{50}$) IC_{50} values DPPH and lipid peroxidation assay, respectively). In a subsequent study, Liu et al. (2008a) reported that total phenolics in amla fruit ranged from 81.5 to 120.9 mg GAE/g; flavonoids, 20.3 to 38.7 mg quercetin equivalents (QE)/g; and proanthocyanidins, 3.7 to 18.7 mg catechin equivalents (CE)/g. Luo et al. (2009) identified cinnamic acid, quercetin, 5-hydroxymethylfurfural, gallic acid, β-daucosterol, and ellagic acid in ethanol extract of air-dried amla fruit.

MEDICINAL PROPERTIES

In India, for centuries, amla has been used in Ayurvedic system of medicine. Kamal and Aleem (2009) reported the

Table 35.7. Ascorbic Acid and Total Phenolics Content of Fresh Amla Fruit and Its Processed Products

Ascorbic acid (mg/100 g)	Reference	Total Phenolics Content	Reference
206.8–468.8[a]	Raghu et al. (2007)	439.9 mg/g extract	Liu et al. (2008a)
589–596[a]	Verma et al. (1984)	81.5–120.9 mg GAE/g extract	Liu et al. (2008b)
591[a]	Verma and Palod (1983)	[b]4.0–12.1 g/100 g dry weight basis	Mishra et al. (2009)
1846.31[c]	Sethi (1986)	[a]174.0–176.6 mg/100 g	Mishra et al. (2009)
463–560[a]	Mishra et al. (2009)	[a]24.5–32.3 g/100, dry weight basis	Mishra et al. (2009)
3006–5432[d]			
624[a]	Mehta and Tomar (1979)	1.8% ([e] Chyawanprash)	Garg et al. (2008)
751.1–932.1[a]	Pathak et al. (2009)	[d]12.9%	Kumar et al. (2006)
31.0–41.7 ([e]Chyawanprash)	Garg et al. (2008)	[f]2.9%	Garg et al. (2008)
5.12–26.36 (Amla preserve[g])	Sethi and Anand (1982)	[d]4.6%	Mehta and Tomar (1979)

[a]Fresh amla fruit basis.
[b]In the residue after juice extraction.
[c]Fresh amla fruit (dry weight basis).
[d]Dried amla fruit powder.
[e]An Ayurvedic preparation.
[f]Preserved amla juice.
[g]Canned whole fruit in thick syrup.

cholesterol lowering activity of amla fruit and ginger among hyperlipidemic patients.

Amla fruit is rich not only in ascorbic acid but also in bioactive polyphenols. The ability of the amla fruit to eliminate harmful effects of oxidative stress and toxicity has been investigated by Anilakumar et al. (2004). Feeding rats with 5% or 10% amla reduced the oxidative stress and toxicity induced by dimethyl hydrazine (DMH). Amla reduced DMH-induced formation of micronuclei by 58% and the DMH-induced increase in renal γ-glutamyl transpeptidase by 50%. They suggested that amla is able to detoxify DMH partly by modulating the multicomponent antioxidant system.

A process for obtaining an amla fruit-based α-glucosidase inhibitor for preventing and improving obesity and diabetes was patented by Kihira (2006). Kihira and Teetamu (2006) were granted a patent for a beverage based on amla extract to control obesity. Sakaguchi et al. (2006) patented a preparation based on the enzymatic treatment of amla fruit, its juice, or extract for control of diabetic nephropathy.

Yokozawa et al. (2007) showed the effect of amla on the renal dysfunction during aging of rats. Ethyl acetate extract of amla fruit was able to reduce the inducible nitric oxide synthase (iNOS) and cyclooxygenase (COX)-2 expression levels by inhibiting nuclear factor-κB (NF- κB) activation in aged rats. The polyphenol-rich fraction of amla fruit has been suggested to provide a protective role against the fructose-induced metabolic syndrome in rats (Kim et al. 2010).

Reddy et al. (2009) investigated the modulatory role of amla extract against the alcohol-induced biochemical and biophysical changes in rat erythrocyte membranes. The following references reported potential medicinal benefits of amla fruit against various disease/metabolic conditions.

Control of hypercholesterolemia (Jacob et al. 1988); protection against cytotoxic effects of arsenic (Biswas et al. 1999); reduction of oxidative stress in streptozotocin-induced diabetes (Rao et al. 2005); antiinflammatory activities (Asmawi et al. 1993); benefits for inflammatory bowel diseases (Deshmukh et al. 2010); antiinflammatory agent against allergic rhinitis (Pratibha et al. 2004); management of diabetic and cataract (Suryanarayana et al. 2004; Mishra et al. 2010); prevention of paracetamol-induced hepatotoxicity (Vidhya Malar and Mettilda Bai 2009); cytoprotective activity against chromium (IV) induced oxidative injury (Ram et al. 2003); modification of clastogenicity of lead and aluminum (Dhir et al. 1990; Roy et al. 1991); antifungal activity (Dutta et al. 1998); antibacterial activities (Godbole and Pendse 1960); gastroprotective effects like antisecretory, antiulcer, and cytoprotective properties (Al-Rehaily et al. 2002); antitumor activity (Jose et al. 2001); hyperthyroidism and hepatic lipid peroxidation (Panda and Kar 2003); anti-pyretic and analgesic activity (Perianayagam et al. 2004; Gupta et al. 2008); antitussive (control of coughing) activity against mucus secretion in the airways (Nosál'ová et al. 2003); antiproliferative activity (Zhang et al. 2004). Further, Alam and Gomes (2003) looked at amla root extract for snake venom neutralization.

PROCESSED PRODUCTS

Jain and Khurdiya (2002) suggested blanching amla fruits and separating segments for achieving highest soluble components and ascorbic acid in the juice. A number of mixed fruit juice beverages have been developed using amla fruit as one of the important ingredients (Deka et al. 2001; Deka et al. 2004). A patent was issued for a process for carbonated nonalcoholic beverage based on amla juice and certain herbs (Prakash 2009).

The initial vitamin C content of 624 mg/100 g in fresh amla fruit was shown to reduce to 121 mg/100 g in a preserve preparation (Mehta and Tomar 1979). Heat-resistant spore forming *Bacillus cereus* is a spoilage organism commonly found in amla preserves. Sethi and Anand (1984) suggested use of a number of chemical preservatives, such as, sulfur dioxide (692 ppm), sodium benzoate (800 ppm), sodium propionate (2800 ppm), or potassium sorbate (3000 ppm) for the control of this spoilage organism. Garg and Yadav (2007) detected the presence of osmophilic microorganisms (*Eurotium repens* and *Saccharomyces bailii*) in spoiled amla preserves, both of these fungi could be controlled with the use of 100 ppm of sulfur dioxide.

The fresh amla pulp's ascorbic acid content of 766 mg/100 g, was reduced by about 30% during sun drying to make amla powder having moisture of 9.1% (Ramasastri 1974). In the course of storage of amla powder at room temperature, the ascorbic acid content declined to 9.9 mg/g after 48 weeks. However, using a solar dryer for drying fresh amla fruit flakes, a higher retention of ascorbic acid (about 76.6%) was reported (Verma and Gupta 2004). Further, Murthy and Joshi (2007) reported better retention of ascorbic acid by fluidized bed drying of amla fruits than by solar or hot-air tray drying methods. Soaking amla fruit shreds in 70°Brix sugar syrup for 5 minutes before drying in a hot-air cabinet dryer to a moisture of 5%, resulted in better quality (color, flavor, texture, and overall quality) ready-to-eat finished product after storage for 6 months at 7 ± 2°C (Sagar and Kumar 2006; Kumar and Sagar 2009).

Rathore et al. (2006) described design specification and performance of a solar dryer vis-à-vis an electric dryer for handling about 1-ton batch amla pulp. Among the four dryer systems, namely, osmo-air drying, sun drying, indirect solar drying, and oven drying, a minimal amount of browning of amla powder was obtained by the osmo-air drying (Pragati et al. 2003).

SUMMARY

As discussed in this chapter each of the six super fruits possess specific bioactive compounds. Many health benefits such

as attenuation of oxidative stress, support to heart health, immune health, digestive health, eye health, anti-inflammatory, etc. are reported to be some of the benefits of consuming these fruits. Besides various compounds of interest, pomegranate contains punicalgins (the most abundant ellagitannins); wolfberry or goji berry is rich in zeaxanthin and other carotenoids; most of the health benefits of noni fruit are attributed to xeronine and anthraquinones; acai berries are rich in anthocyanins, monosaturated fatty acid, and vitamin A; chokeberry (aronia) is rich in anthocyanins and polyphenols; amla fruit, a rich source of vitamin C contains a unique compound geraniin.

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