Part I

Biology, Principles, and Applications
1 Classification, Composition of Fruits, and Postharvest Maintenance of Quality

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The quality of processed fruit products depends on their quality at the start of processing; therefore, it is essential to understand how maturity at harvest, harvesting methods, and postharvest handling procedures influence quality and its maintenance in fresh fruits between harvest and process initiation. Using such information, an appropriate system for harvesting and handling each kind of fruit can be selected and used in conjunction with an effective quality control program to ensure the best quality possible for fresh fruits when processed.

Quality attributes of fresh fruits include appearance, texture, flavor, and nutritive value. Appearance factors include size, shape, color, and freedom from defects and decay. Texture factors include firmness, crispness, and juiciness. Flavor components incorporate sweetness, sourness (acidity), astringency, bitterness, aroma, and off-flavors. Nutritional quality is determined by a fruit’s content of vitamins (A and C are the most important in fruits), minerals, dietary fiber, carbohydrates, proteins, and antioxidant phytochemicals (carotenoids, flavonoids, and other phenolic compounds). Safety factors that may influence the quality of fresh fruits include residues of pesticides, presence of heavy metals, mycotoxins produced by certain species of fungi, and microbial contamination.

Losses in fresh fruits between harvest and processing may be quantitative (e.g., water loss, physical injuries, physiological breakdown, and decay) or qualitative (e.g., loss of acidity, flavor, color, and nutritive value). Many factors influence fruit quality and the extent of postharvest losses that can occur in the orchard, during transportation, and throughout the handling system (sorting, sizing, ripening, cooling, and storage). The total time between harvesting and processing may also be an important factor in maintaining the quality and freshness of fruit. Minimizing the delays throughout the postharvest handling system greatly reduces quality loss, especially in highly perishable fruits such as strawberries, raspberries, blackberries, apricots, and cherries.
1.1 CLASSIFICATION OF FRUITS

Fruit are commonly classified by growing region as follows: temperate-zone, subtropical, and tropical. Growing region and environmental conditions specific to each region significantly affect fruit quality. Examples of fruit grown in each region are listed below.

1.1.1 TEMPERATE-ZONE FRUITS

1. Pome fruits: apple, Asian pear (nashi), European pear, quince
2. Stone fruits: apricot, cherry, nectarine, peach, plum
3. Small fruits and berries: grape (European and American types), strawberry, raspberry, blueberry, blackberry, cranberry

1.1.2 SUBTROPICAL FRUITS

1. Citrus fruits: grapefruit, lemon, lime, orange, pummelo, tangerine, and mandarin
2. Noncitrus fruits: avocado, cherimoya, fig, kiwifruit, olive, pomegranate

1.1.3 TROPICAL FRUITS

1. Major tropical fruits: banana, mango, papaya, pineapple
2. Minor tropical fruits: carambola, cashew apple, durian, guava, longan, lychee, mangosteen, passion fruit, rambutan, sapota, tamarind

1.2 CONTRIBUTION OF FRUITS TO HUMAN NUTRITION

Fruits are not only colorful and flavorful components of our diet, but they also serve as a source of energy, vitamins, minerals, and dietary fiber. The U.S. Department of Agriculture Dietary Guidelines encourage consumers to enjoy “five a day,” i.e., eat at least two servings of fruit and three servings of vegetables each day and to choose fresh, frozen, dried, or canned forms of a variety of colors and kinds of fruits and vegetables. In some countries, consumers are encouraged to eat up to 10 servings of fruits and vegetables per day. For more information access one or more of the following Websites: www.nutrition.gov, www.5aday.gov, and www.5aday.org.

1.2.1 ENERGY (CALORIES)

1. Carbohydrates: banana, breadfruit, jackfruit, plantain, dates, prunes, raisin
2. Proteins and amino acids: nuts, dried apricot, fig
3. Fats: avocado, olive, nuts

1.2.2 VITAMINS

1. Fresh fruits and vegetables contribute about 91% of vitamin C, 48% of vitamin A, 27% of vitamin B_6_, 17% of thiamin, and 15% of niacin to the U.S. diet.
2. The following fruits are important contributors (based on their vitamin content and the amount consumed) to the supply of indicated vitamins in the U.S. diet:
   - Vitamin A: apricot, peach, cherry, orange, mango, papaya, persimmon, pineapple, cantaloupe, watermelon
   - Vitamin C: strawberry, orange, grapefruit, kiwifruit, pineapple, banana, apple, cantaloupe
   - Niacin: peach, banana, orange, apricot
   - Riboflavin: banana, peach, orange, apple, avocado
   - Thiamin: orange, banana, grapefruit, apple
1.2.3 Minerals

1. Fresh fruits and vegetables contribute about 26% of the magnesium and 19% of the iron to the U.S. diet.
2. The following fruits are important contributors to the supply of indicated minerals in the U.S. diet:
   - Potassium: banana, peach, orange, apple, dried fruits such as apricot and prune
   - Phosphorus: banana, orange, peach, fig, raisin
   - Calcium: tangerine, grapefruit, orange
   - Iron: strawberry, banana, apple, orange

1.2.4 Dietary Fiber

1. All fruits and nuts contribute to dietary fiber. Dietary fiber consists of cellulose, hemicellulose, lignin, and pectic substances, which are derived primarily from fruit cell walls and skin.
2. The dietary fiber content of fruits ranges from 0.5 to 1.5% (fresh weight basis).
3. Dietary fiber plays an important role in relieving constipation by increasing water-holding capacity of feces. Its consumption is also linked to decreased incidence of cardiovascular disease, diverticulosis, and colon cancer.

1.2.5 Antioxidants

1. Fruits, nuts, and vegetables in the daily diet have been strongly associated with reduced risk for some forms of cancer, heart disease, stroke, and other chronic diseases. This is attributed, in part, to their content of antioxidant phytochemicals.
2. Red, blue, and purple fruits (such as apple, blackberry, blueberry, blood orange, cranberry, grape, nectarine, peach, plum, prune, pomegranate, raspberry, and strawberry) are good sources of flavonoids and other phenolic compounds that are positively correlated with antioxidant capacity of the fruit.
3. Orange-flesh fruits (such as apricot, cantaloupe, mango, nectarine, orange, papaya, peach, persimmon, and pineapple) and some red-flesh fruits (such as tomato, watermelon, and pink grapefruit) are good sources of carotenoids. Availability of lycopene to humans is increased during tomato processing.

1.3 Factors Influencing Composition and Quality of Fruits

1.3.1 Preharvest Factors

1. Genetic: selection of cultivars, rootstocks. Cultivar and rootstock selection are important because there are often differences in raw fruit composition, postharvest-life potential, and response to processing. In many cases, fruit cultivars grown for fresh market sale are not optimal cultivars for processing.
2. Climatic: temperature, light, wind. Climatic factors may have a strong influence on nutritional quality of fruits. Light intensity significantly affects vitamin concentration, and temperature influences transpiration rate, which will affect mineral uptake and metabolism.
3. Cultural practices: soil type, soil nutrient and water supply, pruning, thinning, pest control. Fertilizer addition may significantly affect the mineral content of fruit, while other cultural practices such as pruning and thinning may influence nutritional composition by changing fruit crop load and size.
1.3.2 Maturity at Harvest and Harvesting Method

Maturity at harvest is one of the primary factors affecting fruit composition, quality, and storage life. Although most fruits reach peak eating quality when harvested fully ripe, they are usually picked mature, but not ripe to decrease mechanical damage during postharvest handling. Harvesting may also mechanically damage fruit; therefore, choice of harvest method should allow for maintenance of quality.

1.3.3 Postharvest Factors

1. Environmental: temperature, relative humidity, atmospheric composition. Temperature management is the most important tool for extension of shelf life and maintenance of the quality of fresh fruit. Relative humidity influences water loss, decay development, incidence of some physiological disorders, and uniformity of fruit ripening. Optimal relative humidity for storage of fruits is 85 to 90%. Finally, atmospheric composition (O₂, CO₂, and C₂H₄, in particular) can greatly affect respiration rate and storage life.

2. Handling methods: Postharvest handling systems involve the channels through which harvested fruit reaches the processing facility or consumer. Handling methods should be chosen such that they maintain fruit quality and avoid delays.

3. Time period between harvesting and consumption: Delays between harvesting and cooling or processing may result in direct losses (due to water loss and decay) and indirect losses (decrease in flavor and nutritional quality).

1.4 Fruit Maturity, Ripening, and Quality Relationships

Maturity at harvest is the most important factor that determines storage life and final fruit quality. Immature fruits are more subject to shriveling and mechanical damage, and are of inferior quality when ripened. Overripe fruits are likely to become soft and mealy with insipid flavor soon after harvest. Fruits picked either too early or too late in the season are more susceptible to physiological disorders and have a shorter storage life than those picked at mid-season.

With very few exceptions (e.g., pears, avocados, and bananas), all fruits reach their best eating quality when allowed to ripen on the tree or plant. In general, fruits become sweeter, more colorful, and softer as they mature. However, some fruits are usually picked mature but unripe so that they can withstand the postharvest handling system when shipped long distances. Most currently used maturity indices are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide the needed flexibility in transportation and marketing.

Fruits can be divided into two groups: (1) nonclimacteric fruits that are not capable of continuing their ripening process once removed from the plant, and (2) climacteric fruits that can be harvested mature and ripened off the plant. Following are examples of each group:

Group 1: Berries (e.g., blackberry, cranberry, raspberry, strawberry), grape, cherry, citrus (grapefruit, lemon, lime, orange, mandarin, tangerine), pineapple, pomegranate, lychee, tamarillo, loquat.

Group 2: Apples, pear, quince, persimmon, apricot, nectarine, peach, plum, kiwifruit, avocado, banana, plantain, mango, papaya, cherimoya, sapodilla, sapota, guava, passion fruit.

Fruits of the first group (nonclimacteric) produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of degreening (degradation of chlorophyll) in citrus fruits and pineapples. Fruits in Group 2 (climacteric) produce much larger quantities of ethylene in association with their ripening and exposure to ethylene treatment will result in faster and more uniform ripening.
Maturity indices used vary among fruits and often among cultivars within a specific fruit, but generally include one or several (combination indices) of the following: fruit size and shape, overall color, ground color of the skin, flesh color, flesh firmness, soluble solids content, starch content, acidity, and internal ethylene concentration. Listed below are some examples of maturity indices that can be used for selected fruits:

<table>
<thead>
<tr>
<th>Index</th>
<th>Fruits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elapsed days from full bloom to harvest</td>
<td>Apple, pear</td>
</tr>
<tr>
<td>Size</td>
<td>Most fruits</td>
</tr>
<tr>
<td>Shape (fullness of fruit shoulders and suture)</td>
<td>Stone fruits</td>
</tr>
<tr>
<td>Dry Weight</td>
<td>Avocado, kiwifruit</td>
</tr>
<tr>
<td>Color, external</td>
<td>All fruits</td>
</tr>
<tr>
<td>Color, internal</td>
<td>Stone fruits, mango</td>
</tr>
<tr>
<td>Firmness</td>
<td>Pome and stone fruits, berries</td>
</tr>
<tr>
<td>Compositional factors</td>
<td></td>
</tr>
<tr>
<td>Starch content</td>
<td>Apple, pear</td>
</tr>
<tr>
<td>Soluble solids content</td>
<td>Pome and stone fruits, grapes, kiwifruit</td>
</tr>
<tr>
<td>Acid content</td>
<td>Pomegranate</td>
</tr>
<tr>
<td>Sugar/acid ratio</td>
<td>Citrus fruits, grape</td>
</tr>
<tr>
<td>Tannin content</td>
<td>Persimmon</td>
</tr>
</tbody>
</table>

1.5 COMPOSITION AND COMPOSITIONAL CHANGES

The flesh of young developing fruits contains very little sugar, and the large amounts of starch, acid, and tannins make them inedible. As the fruits approach maturity, flesh cells enlarge considerably, and sugar content increases while starch, acid, and tannin contents decrease. In addition, certain volatile compounds develop, giving the fruit its characteristic aroma. Chlorophyll degradation (loss of green color) and synthesis of carotenoids (yellow and orange colors) and anthocyanins (red and blue colors) takes place both in the skin and the flesh with fruit ripening. All fruits soften as they ripen due to changes in cell wall composition and structure. In this section, we present an overview of fruit constituents in relation to quality and changes after harvest.

1.5.1 CARBOHYDRATES

Carbohydrates are the most abundant and widely distributed food component derived from plants. Fresh fruits vary greatly in their carbohydrate content, with the general range between 10 to 25%. The structural framework, texture, taste, and food value of a fresh fruit is related to its carbohydrate content.

Sucrose, glucose, and fructose are the primary sugars found in fruits (Table 1.1), and their relative importance varies among commodities. Sugars are found primarily in the cytoplasm and range from about 0.9% in limes to 16% in fresh figs. Sucrose content ranges from a trace in cherries, grapes, and pomegranate to more than 8% in ripe bananas and pineapple. Such variation influences taste since fructose is sweeter than sucrose, and sucrose is sweeter than glucose.

Starch occurs as small granules within the cells of immature fruits. Starch is converted to sugar as the fruit matures and ripens. Other polysaccharides present in fruits include cellulose, hemicellulose, pectin, and lignin, which are found mainly (up to 50%) in cell walls and vary greatly among commodities. These large molecules are broken down into simpler and more soluble compounds as a result of fruit softening. The transformation of insoluble pectins into soluble pectins is controlled, for the most part, by the enzymes pectinesterase and polygalacturonase. Reduced activities of these two enzymes have been associated with reduced juiciness and poor texture in peaches that were ripened after storage at 1°C for more than 3 weeks.
1.5.2 PROTEINS

Fruits contain less than 1% protein (vs. 9 to 20% protein in nuts such as almond, pistachio, and walnut). Changes in the level and activity of proteins resulting from permeability changes in cell membranes may be involved in chilling injury. Enzymes, which catalyze metabolic processes in fruits, are proteins that are important in the reactions involved in fruit ripening and senescence. Some of the enzymes important to fruit quality include the following:

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyphenoloxidase</td>
<td>Catalyzes oxidation of phenolics, resulting in formation of brown polymers</td>
</tr>
<tr>
<td>Pectinesterase</td>
<td>Catalyzes deesterification of galacturonans in pectin; may result in tissue firming</td>
</tr>
<tr>
<td>Polygalacturonase</td>
<td>Catalyzes hydrolysis of glycosidic bonds between adjacent polygalacturonic acid residues in pectin; results in tissue softening</td>
</tr>
<tr>
<td>Lipoxygenase</td>
<td>Catalyzes oxidation of lipids; results in off-odor and off-flavor production</td>
</tr>
<tr>
<td>Ascorbic acid oxidase</td>
<td>Catalyzes oxidation of ascorbic acid; results in loss of nutritional quality</td>
</tr>
<tr>
<td>Chlorophyllase</td>
<td>Catalyzes removal of phytol ring from chlorophyll; results in loss of green color</td>
</tr>
</tbody>
</table>

1.5.3 LIPIDS

Lipids constitute only 0.1 to 0.2% of most fresh fruits, except for avocados, olives, and nuts. However, lipids are very important because they make up the surface wax that contributes to fruit appearance and the cuticle that protects the fruit against water loss and pathogens. Lipids are also important constituents of cell membranes. The degree of fatty acid saturation establishes membrane flexibility, with greater saturation resulting in less flexibility. Desaturation of fatty acids can occur upon chilling in chilling-sensitive fruits; in which case membranes undergo a phase change (liquid crystalline to solid gel) at chilling temperatures resulting in disruption of normal metabolism.

1.5.4 ORGANIC ACIDS

Organic acids are important intermediate products of metabolism. The Krebs (TCA) cycle is the main channel for the oxidation of organic acids in living cells and it provides the energy required...
Organic acids are metabolized into many constituents, including amino acids, which are the building blocks of proteins.

Most fresh fruits are acidic with a pH range of 3 to 5. Some fruits, such as lemons and limes, contain as much as 2 to 3% of their total fresh weight as acid. Total titratable acidity, specific organic acids present and their relative quantities, and other factors influence the buffering system and affect pH. Acid content usually decreases during ripening due to the utilization of organic acids during respiration or their conversion to sugars. Malic and citric acids are the most abundant in fruits (Table 1.2), except grapes (tartaric acid is the most important in most cultivars) and kiwifruits (quinic acid is the most abundant).

### 1.5.5 Pigments

Pigments, which are the chemicals responsible for skin and flesh colors, undergo many changes during the maturation and ripening of fruits. These include the following:

1. Loss of chlorophyll (green color), which is influenced by pH changes, oxidative conditions, and chlorophyllase activity
2. Synthesis and revelation of carotenoids (yellow and orange colors)
3. Development of anthocyanins (red, blue, and purple colors), which are fruit specific (Table 1.3)

Beta-carotene is a precursor to vitamin A and thus is important in terms of nutritional quality. Carotenoids are very stable and remain intact in fruit tissues even when extensive senescence has occurred. Anthocyanins occur as glycosides in the cell sap. They are water soluble, unstable, and are readily hydrolyzed by enzymes to free anthocyanins, which may be oxidized by phenoloxidases to give brown oxidation products.

### 1.5.6 Phenolic Compounds

Total phenolic content is higher in immature than in mature fruits and typically ranges between 0.1 and 2 g/100 g fresh weight. Fruit phenolics include chlorogenic acid, catechin, epicatechin,
leucoanthocyanidins, flavonols, cinnamic acid derivatives, and simple phenols. Chlorogenic acid (ester of caffeic acid) occurs widely in fruits (Figure 1.1) and is the main substrate involved in enzymatic browning of cut or otherwise damaged fruit tissues when exposed to air. Enzymatic browning occurs due to the oxidation of phenolic compounds and is mediated, in the presence of O$_2$, by the enzyme polyphenoloxidase (PPO). The initial product of oxidation is usually O-quinone, which is highly unstable and undergoes polymerization to yield brown pigments of higher molecular weight. Polyphenoloxidase catalyzes the following two reactions:

$$\text{Monophenol} + O_2 \overset{\text{PPO}}{\rightarrow} 2\text{ O-quinone} + H_2O$$

$$2\text{ 0-diphenol} + O_2 \overset{\text{PPO}}{\rightarrow} 2\text{ O-quinone} + H_2O$$

Normally phenolic compounds are separated from the PPO enzyme in the intact cells of plant tissue. Once the tissue is damaged, PPO and the phenolic compounds that it acts on are decompartmentalized and the above-mentioned reactions occur, leading to tissue browning. The extent of brown discoloration depends upon the total amount of phenolic compounds in the tissue and the level of PPO activity. Differences among cultivars of a given species in terms of browning potential in response to mechanical injury are related to the variation in the total phenolic content and PPO activity of the cultivar. Differences in phenylalanine ammonia lyase (PAL) enzyme activity influence phenolic content. Astringency is directly related to phenolic content, and it usually decreases with fruit ripening because of conversion of astringent phenolic compounds from the soluble to the insoluble nonastringent form. Loss of astringency occurs via (1) binding or polymerization of phenolics, (2) change in molecular size of phenolics, and (3) change in the hydroxylation pattern of phenolic compounds.

There is a strong positive relationship between phenolic content and antioxidant capacity of fruits and their products.
1.5.7 Volatiles

Volatiles are responsible for the characteristic aroma of fruits. They are present in extremely small quantities (<100 μg/g fresh wt.). The total amount of carbon involved in the synthesis of volatiles is <1% of that expelled as CO₂. The major volatile formed in climacteric fruits is ethylene (50 to 75% of the total carbon content of all volatiles). Ethylene does not have a strong aroma and does not contribute to typical fruit aromas.

Volatile compounds are largely esters, alcohols, acids, aldehydes and ketones (low-molecular-weight compounds). Very large numbers of volatile compounds have been identified in fruits and more are identified as advances in separation and detection techniques and gas chromatographic methods are made. However, only a few key volatiles are important for the particular aroma of a given fruit. Their relative importance depends upon threshold concentration (which can be as low as 1 ppb), potency, and interaction with other compounds.

1.5.8 Vitamins

The water-soluble vitamins include vitamins C, thiamin, riboflavin, niacin, vitamin B6, folacin, vitamin B12, biotin, and pantothenic acid. Fat-soluble vitamins include vitamins A, D, E, and K. Fat soluble vitamins are less susceptible to postharvest losses.

Ascorbic acid is most sensitive to destruction when the commodity is subjected to adverse handling and storage conditions. Losses are enhanced by extended storage, higher temperatures, low relative humidity (which may cause wilting), physical damage, and chilling injury. Postharvest losses in vitamins A and B are usually much smaller than losses in vitamin C. They are, however, susceptible to degradation at high temperatures in the presence of oxygen.

1.5.9 Minerals

Important fruit minerals include base-forming elements (Ca, Mg, Na, and K) and acid-forming elements (P, Cl, S). Minerals present in microquantities include Fe, Cu, Co, Mn, Zn, I, and Mo. High nitrogen content is often associated with reduced soluble solids content, lower acidity, and increased susceptibility to physiological disorders in fruits.
Potassium is the most abundant mineral found in fruits. It most often occurs in combination with organic acids. High potassium content is often associated with increased acidity and improved color of fruits.

Calcium is the second most important mineral constituent and is associated primarily with the cell wall. High calcium contents reduce CO$_2$ and C$_2$H$_4$ production rates, delay ripening, reduce the incidence of physiological disorders, and extend the storage life of apples and other fruits. Calcium deficiency has been associated with several physiological disorders such as bitter pit of apples.

Magnesium is a component of the chlorophyll molecule, which is responsible for the intensity of green color in fresh produce. Phosphorus is a constituent of cytoplasmic and nuclear proteins and plays a major role in carbohydrate metabolism and energy transfer. High phosphorus content may result in decreased acidity in some fruits.

### 1.6 BIOLOGICAL FACTORS INVOLVED IN POSTHARVEST DETERIORATION OF FRUITS

#### 1.6.1 Respiration

Respiration is the process by which stored organic materials (carbohydrates, proteins, and fats) are broken down into simple end products with a release of energy. Oxygen (O$_2$) is used in this process, and carbon dioxide (CO$_2$) is produced. The loss of stored food reserves in the commodity during respiration hastens senescence as the reserves that provide energy to maintain the commodity’s living status are exhausted. For the consumer, food value (energy value) is gone, flavor quality is reduced, and sweetness, especially, is lost. Salable dry weight is also lost (especially important for commodities destined for dehydration). The energy released as heat, which is known as vital heat, affects postharvest technology considerations such as estimations of refrigeration and ventilation requirements. The rate of deterioration (degree of perishability) of fruits is generally proportional to their respiration rate (Table 1.4).

#### 1.6.2 Ethylene Production

Ethylene, the simplest of the organic compounds affecting the physiological processes of plants, is a natural product of plant metabolism and is produced by all tissues of higher plants and by some microorganisms. As a plant hormone, ethylene regulates many aspects of growth, development, and senescence and is physiologically active in trace amounts (less than 0.1 ppm).

Ethylene biosynthesis starts with the amino acid methionine, which is energized by ATP to produce S-adenosyl methionine (SAM). The key enzyme in the pathway, ACC synthase, converts SAM to 1-aminocyclopropane-1-carboxylic acid (ACC), which is converted to ethylene by the action of ACC oxidase.

<table>
<thead>
<tr>
<th>Relative Respiration Rate and Perishability</th>
<th>Fruits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>Nuts, dates, dried fruits</td>
</tr>
<tr>
<td>Low</td>
<td>Apple, pear, kiwifruit, pomegranate, Chinese date (jujube)</td>
</tr>
<tr>
<td>Moderate</td>
<td>Citrus fruits, banana, cherry, nectarine, peach, plum, avocado (unripe), persimmon</td>
</tr>
<tr>
<td>High</td>
<td>Apricot, fig (fresh), avocado (ripe), cherimoya, papaya</td>
</tr>
<tr>
<td>Very high</td>
<td>Strawberry, blackberry, raspberry</td>
</tr>
</tbody>
</table>
Ethylene production rates, which depend on the fruit (Table 1.5), generally increase with maturity at harvest, physical injuries, disease incidence, increased temperatures up to 30°C, and water stress. On the other hand, ethylene production rates by fresh fruits are reduced by storage at low temperature and by reduced O₂ (less than 8%) and elevated CO₂ (above 1%) levels in the storage environment around the commodity.

### 1.6.3 Transpiration or Water Loss

Water loss is the main cause of deterioration because it results not only in indirect quantitative losses (loss of salable weight) but also in losses in appearance (wilting and shriveling), textural quality (softening, flaccidity, limpness, and loss of crispness and juiciness), and nutritional quality.

The dermal system (outer protective coverings) governs the regulation of water loss by the commodity. This system includes the cuticle, epidermal cells, stomata, lenticels, and trichomes (hairs). The cuticle is composed of surface waxes, cutin embedded in wax, and a layer of mixtures of cutin, wax, and carbohydrate polymers. The thickness, structure, and chemical composition of the cuticle vary greatly among commodities and among developmental stages of a given commodity.

Transpiration rate is influenced by internal or commodity factors (morphological and anatomical characteristics, surface-to-volume ratio, surface injuries, and maturity stage) and external or environmental factors (temperature, relative humidity, air movement, and atmospheric pressure). Transpiration (evaporation of water from the plant tissues) is a physical process that can be controlled by applying treatments to the commodity (e.g., waxes and other surface coatings or wrapping with plastic films) or by manipulation of the environment (e.g., maintenance of high relative humidity and control of air circulation).

### 1.6.4 Physiological Disorders

The following physiological disorders occur in fruits:

1. Freezing injury when fruits are held below their freezing temperatures. The disruption caused by freezing usually results in immediate collapse of the tissues and total loss.
2. Chilling injury when fruits (mainly those of tropical and subtropical origin) are held at temperatures above their freezing point and below 5 to 15°C depending on the commodity. This physiological injury is manifested in a variety of symptoms, which include surface and internal discoloration, pitting, water-soaked areas, uneven ripening or failure to ripen, off-flavor development, and accelerated incidence of surface molds and decay. A classification of fruits according to their sensitivity to chilling injury is shown in Figure 1.2.
3. Heat injury results from exposure to direct sunlight or to excessively high temperatures. Symptoms include surface scalding, uneven ripening, and excessive softening and desiccation.

4. Certain types of physiological disorders originate from preharvest nutritional imbalances such as calcium deficiency, causing bitter pit of apples.

5. Very low (<1%) oxygen and elevated (>20%) carbon dioxide concentrations can result in physiological breakdown of all fruits.

1.6.5 Physical Damage

Various types of physical damage (surface injuries, impact bruising, and vibration bruising, etc.) are major contributors to deterioration. Mechanical injuries are not only unsightly but also accelerate water loss, stimulate higher respiration and ethylene production rates, and favor decay incidence.

1.6.6 Pathological Breakdown

Decay is one of the most common or apparent causes of deterioration. However, attack by many microorganisms usually follows mechanical injury or physiological breakdown of the commodity, which allow entry to the microorganism. In a few cases, pathogens can infect healthy tissues and become the primary cause of deterioration.

*Some varieties are chilling sensitive.
1.7 ENVIRONMENTAL FACTORS INFLUENCING DETERIORATION OF FRUITS

1.7.1 TEMPERATURE

Temperature is the most important environmental factor that influences the deterioration rate of harvested fruits. For each increase of 10°C (18°F) above the optimum temperature, the rate of deterioration increases by two- or threefold. Exposure to undesirable temperatures results in many physiological disorders as mentioned above. Temperature also influences how ethylene, reduced oxygen, and elevated carbon dioxide levels affect the commodity. The growth rate of pathogens is greatly influenced by temperature and some pathogens, such as Rhizopus rot, are sensitive to low temperatures. Thus, cooling of commodities below 5°C immediately after harvest can greatly reduce Rhizopus rot incidence.

1.7.2 RELATIVE HUMIDITY

The rate of water loss from fruits depends upon the vapor pressure deficit between the commodity and the surrounding ambient air, which is influenced by temperature and relative humidity.

1.7.3 AIR MOVEMENT

Air circulation rate and velocity can influence the uniformity of temperature and relative humidity in a given environment and consequently rate of the water loss from the commodity.

1.7.4 ATMOSPHERIC COMPOSITION

Reduction of oxygen and elevation of carbon dioxide, whether intentional (modified or controlled atmosphere storage) or unintentional, can have a beneficial or harmful effect on deterioration. The magnitude of these effects depends upon commodity, cultivar, physiological age, O₂ and CO₂ level, temperature, and duration of storage. A summary of current and potential use of controlled atmospheres to maintain the quality of fruits during transport and storage is given in Table 1.6.

1.7.5 ETHYLENE

Ethylene is a natural plant hormone and its effect on harvested fruits can be desirable (degreening and ripening) or undesirable (abbreviated storage and softening). Ethylene effects are cumulative throughout the postharvest life of the fruit, and the magnitude of ethylene effects depends upon temperature, exposure time, and ethylene concentration. A concentration as low as 50 ppb ethylene

<table>
<thead>
<tr>
<th>Range of Postharvest Life (Months)</th>
<th>Fruits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1</td>
<td>Banana, mango, papaya, cherry, grape, fig, blackberry, blueberry, raspberry, strawberry</td>
</tr>
<tr>
<td>1 to 3</td>
<td>Avocado, olive, persimmon, pomegranate, some peach, nectarine, and plum cultivars,</td>
</tr>
<tr>
<td>3 to 6</td>
<td>Kiwifruit, some cultivars of Asian pears</td>
</tr>
<tr>
<td>6 to 12</td>
<td>Some cultivars of apples and European pears</td>
</tr>
<tr>
<td>&gt;12</td>
<td>Almond, filbert, macadamia, pecan, pistachio, walnut, dried fruits</td>
</tr>
</tbody>
</table>
enhances kiwifruit softening at 0°C. Avocados and “Fuyu” persimmons are also very sensitive to ethylene action; exposure to 1 ppm (or higher) ethylene increases chilling injury symptoms. Use of ethylene to degreen citrus fruits can accelerate their senescence and increase their susceptibility to decay-causing pathogens.

### 1.8 HARVESTING PROCEDURES

Harvesting methods, especially those involving a once-over procedure, may determine uniformity of maturity at harvest, which in turn influences quality of the fruit. Maturity also influences susceptibility of the fruit to water loss and mechanical injury. The harvesting system used and its management have a direct effect on incidence and severity of mechanical injuries. Such injuries can result in tissue browning, accelerated water loss, higher respiration and ethylene production rates, and increased decay incidence. Physical injuries may also induce some undesirable compositional changes, such as loss of ascorbic acid content and development of off-flavors.

Management of the harvesting operation, whether manual or mechanical, can have a major impact on quality of the harvested fruits. Proper management procedures include selection of optimum time to harvest in relation to fruit maturity and climatic conditions, training and supervision of workers, and effective quality control.

### 1.9 POSTHARVEST HANDLING PROCEDURES

#### 1.9.1 DUMPING

Fresh fruits should be handled with care throughout the postharvest handling system in order to minimize mechanical injuries. Dumping in water or in floatation tanks should be used for fruits that withstand wetting. If dry dumping systems are used, they should be well padded to reduce impact bruising. Also, a bin cover may be used to permit inverting the bin and to regulate the flow of fruits out of the bin.

#### 1.9.2 WASHING

To clean fruit, water alone or with added cleaning agents and/or chlorine (typically 100 to 150 ppm) may be used. The final rinse should be made with fresh, clean water. Following washing, removal of excess surface water may be necessary and this can be done by blotting rollers or by air flow over the fruits.

#### 1.9.3 SORTING

Manual sorting is usually carried out to eliminate fruit exhibiting defects or decay. For some fruits, it may also be necessary to sort the fruit into two or more classes of maturity or ripeness (according to their color and firmness) before ripening or processing. Mechanical sorters, which operate on the basis of color, soluble solids, moisture, or fat content, are being implemented and may greatly reduce time and labor requirements.

#### 1.9.4 SIZING

In some cases, sizing the fruits into two or more size categories may be required before processing. Sizing can be done mechanically on the basis of fruit dimension or by weight. Mechanical sizing can be a major source of physical damage to the fruit if the machines were not adequately padded and adjusted to the minimum possible fruit drop heights.
1.9.5 Ripening

Ripening before processing may be required for certain fruits (e.g., avocado, banana, kiwifruit, mango, nectarine, papaya, peach, pear, persimmon, plum, and melons) that are picked immature. Ethylene treatment can be used to obtain faster and more uniform ripening. The optimum temperature range for ripening is 15 to 25°C and within this range, the higher the temperature the faster the ripening. Relative humidity should be maintained between 90 and 95% during ripening. Although 10 ppm ethylene is sufficient to initiate ripening, a concentration of 20 to 100 ppm for at least 2 d is recommended for commercial application.

Adequate air circulation within the room is important to ensure uniform distribution of ethylene. One method to achieve this is by forcing the ethylene-containing air through the fruit containers (forced-air ripening or pressure ripening). It is also important to avoid accumulation of carbon dioxide (produced by the commodity through respiration) above 1% in the ripening room since carbon dioxide counteracts ethylene effects. This can be accomplished by periodic air exchange (introduction of fresh air into the ripening room) or by using hydrated lime to absorb carbon dioxide.

1.9.6 Inhibiting Ethylene Action

Since July 2002, the ethylene-action inhibitor, 1-methylcyclopropene gas (1-MCP) under the trade name “SmartFresh” at concentrations up to 1 ppm was approved by the U.S. Environmental Protection Agency for use on apples, apricots, avocados, kiwifruit, mangoes, nectarines, papayas, peaches, pears, persimmons, plums, and tomatoes. The first commercial application has been on apples to retard their softening and scald development and extend their postharvest life. As more research is completed, the use of 1-MCP will no doubt be extended to several other commodities in the future.

1.9.7 Cooling

Cooling is utilized to remove field heat and lower the fresh fruit’s temperature to near its optimum storage temperature. Cooling can be done using cold water (hydrocooling) or cold air (forced-air cooling or pressure cooling). Highly perishable fruits, such as strawberries, bush berries, and apricots should be cooled to near 0°C (32°F) within 6 h of harvest. Other fruits should be cooled to their optimum temperature within 12 h of harvest.

1.9.8 Storage

Short-term or long-term storage of fresh fruits may be needed before processing to regulate the product flow and extend the processing season. A classification of fresh fruits according to their optimum storage temperature and potential storage life is shown in Table 1.7. In all cases, the relative humidity in the storage facility should be kept between 90 and 95%. To reduce decay, elevated CO₂ (15 to 20%) may be added to the atmosphere within pallet covers for strawberries, bush berries, and cherries; sulfur dioxide (200 ppm) fumigation may be used on table grapes.

There is a continuing trend toward increased precision in temperature and relative humidity management to provide the optimum environment for fresh produce during cooling, storage, and transport. Precision temperature management tools, including time–temperature monitors, are becoming more common in cooling and storage facilities. Several manufacturers have developed self-contained temperature and RH monitors and recorders, which are small and can be packed in a box with the product. Data are read by connecting these units to a personal computer with the appropriate software made by the manufacturer. Infrared thermometers are used to measure surface temperature of products from a distance in various locations within storage facilities. Electronic thermometers (with very thin, strong probes for fast response) are used for measuring product temperature during cooling, storage, and transport operations.
1.9.9 **FOOD SAFETY GUIDELINES**

Over the past few years, food safety has become and continues to be the number one concern of the fresh produce industry. A training manual for trainers titled *Improving the Safety and Quality of Fresh Fruits and Vegetables* was published by the USFDA in November 2002 to provide uniform, broad-based scientific and practical information on the safe production, handling, storage, and transport of fresh produce. It is available electronically (in English and Spanish) at the following Internet site: [http://www.jifsan.umd.edu/gaps.html](http://www.jifsan.umd.edu/gaps.html).

1.9.10 **FOOD SECURITY GUIDELINES**

On March 19, 2003, The U.S. Food and Drug Administration (FDA) released food security guidance documents for food producers, processors, and transporters. These documents are available electronically at [http://www.cfsan.fda.gov/~dms/secguid6.html](http://www.cfsan.fda.gov/~dms/secguid6.html) and are voluntary recommendations from the FDA and not mandatory regulations. The goal is to help operators of food handling facilities identify preventive measures to minimize the security risks to their products.

1.10 **SUMMARY: KEYS TO SUCCESSFUL HANDLING OF FRESH FRUITS**

1.10.1 **MATURITY AND QUALITY**

1. Harvest at the proper maturity stage that will result in the best eating quality.
2. Eliminate fruits with defects in the orchard or soon after delivery to the processing plant.

1.10.2 **TEMPERATURE AND HUMIDITY MANAGEMENT PROCEDURES**

1. Harvest during the cool part of the day.
2. Keep in the shade while accumulating fruits in the orchard.
3. Transport fruits to the processing plant as soon as possible after harvest and use refrigerated transport vehicles for distances that require more than a few hours.
4. Avoid delays at the processing plant. If delays cannot be avoided, cool and hold fruits at or near their optimum storage temperature until processed.
5. Maintain proper temperature and relative humidity during ripening of fruits requiring such treatment (with or without added ethylene).

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**TABLE 1.7**

Classification of Fruits According to Their Optimum Storage Temperatures and Potential Storage Life

<table>
<thead>
<tr>
<th>Potential Storage Life (Weeks)</th>
<th>0 to 2°C</th>
<th>3 to 5°C</th>
<th>12 to 14°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2</td>
<td>Apricot, bush berries, strawberry, fig</td>
<td>Cantaloupe, ripe avocado</td>
<td>Cherimoya, guava, pineapple</td>
</tr>
<tr>
<td>2 to 4</td>
<td>Cherry, nectarine, peach, plum</td>
<td>Tangerine and mandarin, carambola</td>
<td>Avocado, banana, mango, papaya, honeydew melon</td>
</tr>
<tr>
<td>4 to 6</td>
<td>Grape, tamarillo</td>
<td>Orange, pomegranate, kumquat</td>
<td>Grapefruit, lime, pummelo</td>
</tr>
<tr>
<td>&gt; 6</td>
<td>Apple (nonchilling sensitive cultivars), pear, cranberry, kiwifruit, “Hachiya” persimmon</td>
<td>Apple (chilling sensitive cultivars)</td>
<td>Lemon, “Fuyu” persimmon</td>
</tr>
</tbody>
</table>
1.10.3 Physical Damage

1. Handle fruits with care during harvesting, hauling to the processing plant, and during handling operations within the plant.
2. Avoid drops, impacts, vibrations, and surface injuries of fruits throughout the handling system.
3. Use containers that would provide adequate protection of the commodity from physical injuries when stacked during temporary storage.

1.10.4 Sanitation Procedures

1. Sort out and properly discard decayed fruits.
2. Clean harvest containers, processing plant machinery, cooling and storage facilities, and transit vehicles periodically with water, soap, and disinfectants.

1.10.5 Expedited Handling

1. Reduce the time between harvest and cooling the fruits.
2. Avoid exceeding the fruit’s storage life, based on flavor quality, before processing.

REFERENCES


**INTERNET SITES**


http://www.uckac.edu/postharv: University of California Kearney Agricultural Center.