3 Fresh-Cut Fruits

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3.1 INTRODUCTION

Over the past 25 years the consumption of fresh fruit in the U.S. was reported to have grown by about 26%, according to the Economic Research Service-U.S. Department of Agriculture (Pollack, 2001). However, this does not reflect all fruit because the report does not include melon consumption, which was part of the vegetable category statistics. Over the same period, the U.S. consumption of fresh vegetables and melon has increased by 33%. In addition to awareness of the health benefits of a diet rich in fruits and vegetables, several factors are attributed to these changes, such as rising income, increased production, greater diversity and availability (of domestic and imported produce, on and off season), product convenience, storage, and transportation, among others (Pollack, 2001). Nevertheless, according to a USDA survey (1994 to 1996), the recommended number of at least two daily fruit servings is currently met by only 23% of the American population (USDA, 1998).

Frequently, convenience is an important factor in a consumer’s selection of produce, and fruit are no exception. From 1997 to 1999, over 40% of the total fruit intake was consumed as juice,
63% of which was solely orange juice (accounting for 86% of orange consumption). Another trend observed since the mid-1970s is that Americans are eating less canned produce, and more fresh and frozen items. Although over the past two decades the consumption of frozen fruit increased 36%, this constitutes a small fraction of all fruit consumed in the U.S. During the last two decades, another category of fruit product has been introduced in the market: fresh-cut fruit. Fresh-cut products have also been referred to as “lightly processed,” “minimally processed,” “fresh-processed,” “partially processed,” or “preprepared” products. According to the International Fresh-Cut Produce Association (IFPA),

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. These fruits and vegetables have been trimmed, peeled, washed, and cut into 100% usable product that is largely bagged or prepackaged to offer consumers high nutrition, convenience, and value while still maintaining freshness (IFPA, 2002).

The idea of minimal processing of fruit has been around in different parts of the world for some time, but at a different scale. Consumers could find convenient produce items already washed and peeled or either, cut on site at a local market or street stall. No special packaging or refrigeration was used; these products were directed toward immediate consumption. In the U.S., fresh-cut produce first appeared in retail markets in the 1940s, but second-quality, misshapen produce was used; quality was unpredictable and shelf life was limited. In the mid-1970s, fast-food chains were using shredded fresh-cut lettuce and chopped onions; in the mid 1980s, salad bars opened, and fresh-cut produce start replacing canned products (Garrett, 2002). Today, vegetables (mainly salads) constitute the main segment (~70%) of fresh-cut products. In addition to the convenience, there are other reasons for the success of fresh-cut produce, such as the absence of waste material. When utilizing fresh-cut produce, 100% is consumable, and there is also a substantial decrease in labor required for home produce preparation (e.g., no need for washing, trimming, etc.) and waste disposal. The amount of waste in peeling and coring fruit can be quite elevated; in pineapple it frequently exceeds 50% of the fresh fruit weight (including the crown). These advantages make fresh-cut produce well accepted items in the foodservice sector, commercial salad bars, and fast-food outlets (Price and Floros, 1993).

Examples of fresh-cut fruit available in the U.S. for retail and foodservice distribution are sliced apples, peaches, strawberries, oranges, grapefruit, mangoes, melons, watermelons, pineapple, citrus segments, and fruit salads. Fresh-cut fruit tend to be more perishable than the commodity from which they were prepared. The expected shelf life of fresh-cut fruit is around 7 to 8 d, in contrast to 10 to 14 d for fresh-cut vegetables (Kader, 2002). The limited commercial success of fresh-cut fruit is related to their perishability and consequently short shelf life.

### 3.2 EFFECTS OF FRESH-CUT PROCESSING ON PRODUCE PHYSIOLOGY

Whereas the processing of fruits generally extends their shelf life, as seen in the case of canning, freezing, and drying, fresh-cut processing increases the perishability of fruits (Cantwell and Suslow, 1999). The physical wounding of tissue caused by the preparation (peeling, cutting, slicing, dicing, etc.) of the fresh-cut products leads to many physical and physiological responses (Brecht, 1995; Saltveit, 1997). There is an increase in respiration rate and ethylene production, which impacts fruit quality and shelf life. Increased respiration rate is related to elevated cellular metabolism, which contributes to faster quality deterioration. Table 3.1 shows examples of respiration rates of fresh-cut fruit as compared to intact fruit. Respiration rates increase with the degree of injury or processing and with storage temperature. In a study with papayas (Pau and Chen, 1997), fruit were longitudinally halved, one half fruit was kept with seeds, and the other half was deseeded.
Opposite halves of the same fruit were used. The wound caused by slicing and deseeding led to increases in ethylene production five- and ninefold higher in the halves with seeds and in the deseeded halves, respectively, as compared to the intact fruit. The injury caused by wounding through slicing and deseeding of papaya fruit also led to yellowing of the fruit skin and softening of the mesocarp.

Wound-related production of ethylene is higher in fruit at the preclimacteric and climacteric stages than in postclimacteric period (Abeles et al., 1992). The response to injury may also be affected by the maturity stage of fruit. In a study by Cantwell and Suslow (1999), cantaloupe melon pieces processed from fruit at different maturity stages had similar respiration rates, but ethylene production was much higher in pieces from riper fruits.

The removal of protective epidermis or skin of the fruit leads to changes in gas diffusion, accelerates water loss, and favors microbial contamination. It is important to prevent cut-surface desiccation, which negatively impacts product appearance. Another consequence of fresh-cut fruit processing is cell disruption, which allows previously compartmentalized enzymes to come in contact with their substrates, leading to undesirable reactions such as development of enzymatic browning and accelerated softening.

### 3.3 UNIT OPERATIONS IN FRESH-CUT FRUIT PREPARATION

In order to maintain the highest possible quality of a fresh-cut fruit, it is important to observe adequate handling of the produce before preparation. It is necessary to keep produce under adequate storage conditions (temperature and relative humidity) and use gentle handling to minimize bruising and other physical injuries. Strict temperature control is the single most important factor in maintaining quality throughout the fresh-cut preparation and distribution. All unit operations should be carried out in cold processing rooms (≤5°C), and cleanliness is very important to ensure a high-quality and safe product. It is of utmost importance to use sanitary equipment and adopt Good Manufacturing Practices (GMP) in combination with Hazard Analysis Critical Control Point (HACCP) (IFPA, 1996a, 1997; Beuchat, 2000). The overall steps involved in the preparation of fresh-cut fruit follow.
3.3.1 Receiving, Inspection, and Storage of Raw Material

Fruit has to be inspected and evaluated according to high standards of safety and quality. It is well known that no processing can increase the quality of a diseased or misshapen ingredient. Therefore, it is very important that while awaiting processing, fruit should be kept under refrigeration (in general, 1 to 5°C) according to produce specifications. If a commodity is sensitive to chilling injury, it requires appropriate storage conditions, separate from nonsensitive fruit. For example, symptoms of chilling injury are seen in pineapple stored for prolonged periods at temperatures below 12°C (Paul and Rohrbach, 1985). Whereas some fruits, such as pears and apples, can be stored for extended periods of time while waiting to undergo processing, the effects of such storage on fresh-cut products may be undesirable. Gorny and coworkers (2000) observed significant shelf-life reduction in fresh-cut pears prepared from fruit that had been kept for increased storage periods at 1°C in air or controlled atmosphere (2% O₂ + 98% N₂).

3.3.2 Cleaning and Disinfection

With many fruit that have a smooth surface, such as apples and pears, the use of cold clean water may be enough for a first wash. However, some fruit may harbor a high microbial population on their external surface. Cantaloupes were one of three imported produce with the greatest incidence of pathogen contamination in a survey carried out by the Food and Drug Administration (FDA, 2002). Such fruit should be washed, scrubbed, and dipped in solutions of disinfectants. The most commonly used sanitizer is chlorinated water, but other possible chemicals for disinfection are hydrogen peroxide, surfactants, peroxycetic acid, trisodium phosphate, and ozone, among others (Heard, 2002; Beuchat, 2000; Cherry, 1999; Sapers and Simmons, 1998). The efficacy of chlorine and hydrogen peroxide treatment on the native microflora of cantaloupes, as well as on Escherichia coli population, was compared by Ukuku and coworkers (2001). Hydrogen peroxide proved to be more efficient against the surface microflora of cantaloupe, while chlorine was more effective against E. coli ATCC 25922.

3.3.3 Peeling, Deseeding, Trimming, Coring, and Cutting

In contrast to vegetables, which in many instances can be peeled and cut mechanically (such as carrots), for most fruit whose texture is soft, the removal of skins and rinds is carried out by hand. It is very important to use clean and sharp knives during this operation. The use of blunt blades causes excessive physical injury (tissue crushing) to the fruit tissue adjacent to the cut, accelerating quality deterioration. Fresh-cut cantaloupe melon prepared with sharp and blunt knives were compared (Portela and Cantwell, 2001). Melon pieces prepared using blunt knives had increased ethanol levels, off-odors, and electrolyte leakage compared to sharp-cut pieces. The marketable visual quality of sharp-cut melon lasted much longer; blunt-cut pieces developed a translucency, which is a common visual defect that indicates cell disruption in commercially prepared fresh-cut cantaloupe.

With citrus, enzymatic peeling has been reported as an alternative to hand peeling (Bruemmer et al., 1978; Pretel et al., 1996, 1998). Whole citrus fruit can be vacuum infused with solutions of pectic enzymes that will eliminate flavedo and albedo, with limited damage to the juice vesicles. After this treatment, peeled fruit have to be rinsed by immersion in water for removal of the enzyme solution.

3.3.4 Washing and Cooling

During the cutting steps there is release of tissue fluids that should be removed to avoid undesirable microbiological or chemical reactions. It is imperative to rinse the cut surfaces of the fruit. At this stage the use of cold water (~0°C) accomplishes the washing of the cut surfaces as well as cooling of the fruit pieces. For safety reasons, chlorinated water (usually 50 to 100 ppm) is frequently used.
All the equipment used in the processing (cutting tools and mats) are a potential source of contamination and require adequate sanitation.

In some cases it is necessary to use dipping solutions containing processing aids that will help prevent nonmicrobial quality deterioration such as surface browning and softening (Garcia and Barrett, 2002).

3.3.5 Dewatering

Excess moisture picked up during the washing operation should be removed prior to packaging. This step helps to prevent growth of microorganisms that remained after produce disinfection. Due to their delicate texture, fresh-cut fruit require passage through semi-fluidized beds with forced air to remove moisture.

3.3.6 Packaging and Distribution

In order to ensure the longest possible shelf life for fresh-cut fruit, it is important to choose appropriate packaging materials and storage conditions.

Temperature is always a critical factor in the shelf life of fresh-cut fruit. The importance of temperature control is related to food safety and extension of fresh-cut life by slowing respiration rate and preventing quality deterioration. As an example, the shelf life of sliced pineapple is reported to range from a few hours at 20°C and to greater than 5 weeks at 1°C (O’Hare, 1994). Throughout the unit operations involved in preparation and up to consumption, a cold chain should be maintained; ideally temperatures should not exceed 5°C, although preferably they should be closer to 1°C (IFPA, 1997). During the distribution of fresh-cut products, it is also important to avoid rough handling. Very often products are subjected to shock and vibration stress, which cause injury, leading to more rapid quality loss. In a study of fresh-cut watermelon cubes, results showed increased juice leakage and darkening of product vibrated in noncompartmentalized packages. Authors suggested that the placement of compartments that decrease movement of fruit pieces during transit can improve overall quality by reducing vibration (Fonseca et al., 1999).

3.4 Quality Aspects of Fresh-Cut Fruits

Fresh-cut fruit combine the convenience of a 100% usable product with the fresh-like quality characteristics of fresh fruit, e.g., appearance, flavor, and texture. The initial appeal of a convenient fresh-cut product will only be ensured of continued acceptability if the product quality meets the consumer’s quality criteria including appearance, product shelf-life, and relationship between perceived value and cost. Moreover, the product value as food also depends on its nutritional quality and its safety (Kader, 2002).

Several preharvest factors affect the quality of a commodity, such as genetic background, agronomic practices, environmental conditions during cultivation, and stage of maturity at harvest. Final product quality is influenced to a great degree by postharvest handling and fresh-cut preparation, from the initial unit operations up to distribution. As a result of the injury (wound) brought by cutting, cells are broken and undesirable reactions may result. Fresh-cut fruit may undergo surface browning, tissue softening, loss of flavor, and other deterioration reactions. Moreover, the leakage of nutrient-rich tissue fluids can potentially lead to microbial spoilage; peeling and removal of protective tissues lead to water loss and, consequently, quality defects such as surface drying, loss of gloss, and shrinkage are more noticeable.

3.4.1 Importance of Cultivar Selection

A high-quality fresh-cut product starts with fruit of superior raw material quality and the appropriate selection of fruit cultivars (cv.). In fact, cultivar selection is one of the most important considerations.
The most suitable cultivars should be selected, or developed, for compatibility with fresh-cut processing, packaging, and distribution. At this stage, many characteristics may be considered, such as fruit shape or size, flesh thickness, susceptibility to pre- and postharvest pathogens, susceptibility to browning, desiccation, texture loss, etc. (Romig, 1995).

Different fruit cultivars may vary in their respiration rates when cut for processing. A comparison of four pear cultivars commonly available in the U.S. (cv. Bosc, Bartlett, Anjou, and Red Anjou) showed that pears of the cv. Bartlett showed no difference in respiration rate when stored at 10°C in air and 90 to 95% relative humidity. However, slices prepared from the cv. Bosc had a 35% increase, cv. Anjou a 64% increase, and cv. Red Anjou a 232% increase in respiration in relation to the intact fruit of the same cultivar. The evolution of carbon dioxide in all cultivars was between two- and fourfold greater when temperature was increased from 0°C to 10°C (Gorny et al., 2000).

Varying composition of different cultivars will affect final product quality. The browning tendency of different fruit cultivars is exemplified for pears and apricots in Table 3.2. The pear cultivars evaluated in this study showed almost a fourfold range in their difference in lightness (DL value) between fresh and oxidized purees. Apricot cultivars showed a similar range of difference in browning tendency.

Bartlett pear slices had a large decrease (82%) in flesh firmness, in contrast with cultivar Anjou (12% decrease in firmness) after 6 d at 10°C (Gorny et al., 2000). Variations in the shelf life (ranging from 2 to 12 d at 0°C) of different cultivars of sliced peaches and nectarines are shown in Figure 3.1. Evaluation of shelf life was based on appearance; products developed surface browning, pit cavity breakdown, and limited dehydration, resulting in loss of sheen and gloss at the cut surface (Gorny et al., 1999).

### TABLE 3.2
Enzymatic Browning of Pear<sup>a</sup> and Apricot<sup>b</sup> Purees Prepared from Different Fruit Cultivars Harvested at Commercial Maturity

<table>
<thead>
<tr>
<th>Pear Cultivar</th>
<th>DL&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Apricot Cultivar</th>
<th>DL&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbe Fetel</td>
<td>–16.2</td>
<td>Bebeco</td>
<td>5.3</td>
</tr>
<tr>
<td>Comice</td>
<td>–15.1</td>
<td>Cafona</td>
<td>11.8</td>
</tr>
<tr>
<td>Conference</td>
<td>–14.1</td>
<td>Canino</td>
<td>16.7</td>
</tr>
<tr>
<td>Guyot</td>
<td>–9.9</td>
<td>Henderson</td>
<td>26.3</td>
</tr>
<tr>
<td>P 2198</td>
<td>–15.3</td>
<td>Moniqui</td>
<td>21.4</td>
</tr>
<tr>
<td>Williams</td>
<td>–13.3</td>
<td>Polonais</td>
<td>16.8</td>
</tr>
<tr>
<td>6.30.100</td>
<td>–4.8</td>
<td>P. Tyrinthe</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R. Fournes</td>
<td>17.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R. Roussillon</td>
<td>17.8</td>
</tr>
</tbody>
</table>

<sup>a</sup> Reflectance measurements expressed as DL, difference in lightness between oxidized and nonoxidized purees.

Many agronomic (soil type, fertilizer application, water supply, etc.) and environmental (climate and rainfall) factors also affect fruit quality. Sucrose is the main soluble sugar in muskmelon flesh, and adverse weather conditions in the weeks prior to harvest can have a negative effect on fruit sweetness. Short-term shading (5 d at ~ 50% reduced daylight) of muskmelon plants prior to harvesting promoted accumulation of acetaldehyde and ethanol and reduction of sucrose content in melon flesh (Nishizawa et al., 1998). Cultivars may also respond differently to conditions adopted in modified atmosphere packaging. Different cultivars of strawberries showed wide variation in response when exposed to 20% carbon dioxide for up to 9 d. Some cultivars (such as Honeoye and Kent) accumulated large levels of fermentation products associated with off-flavor development, such as acetaldehyde and ethanol.

Depending on the commodity, different traits may be relevant in selecting cultivars for fresh-cut preparation. While tendency to brown is important in fresh-cut apples and pears, there may be more interest in other quality attributes such as texture retention in sliced kiwifruit, absence of seeds in watermelon for fresh-cut use, reduced off-flavor production in strawberries, and a balance between sweetness and acidity in pineapple.

### 3.4.2 Optimum Degree of Ripeness for Processing

Quality and shelf life of fresh-cut fruit are affected by maturity stage. While a fresh-cut fruit is expected (by the consumer) to be at its optimum ripeness, with the best sensory attributes of flavor, taste, and firmness, this is usually not the best maturity stage for handling and processing. Often a fully ripe fruit may be at an advanced stage of softening for fresh-cut preparation, whereas an immature fruit may not present adequate eating quality (Kader and Mitcham, 1998). Synthesis of both flavor and color compounds occur relatively late in fruit maturation; therefore an early harvest may result in poor flavor and color. Shorter shelf life results from harvest of either immature or overripe fruit that are more susceptible to physiological disorders than fruit harvested at the proper maturity (Kader, 2002). In a study of sliced pears (cv. Bartlett), ripe fruit had a shelf life of ~2 d at 0°C, in contrast with partially ripe and mature-green slices with a shelf life of 8 d. However, the eating quality of mature-green fruit was compromised due to poor aroma and lack of juiciness (Gorny et al., 2000). Likewise, using quality scores based on appearance, firmness, and taste, honeydew melon cubes prepared from fruit at the immature to mature threshold stage (8.8% soluble solids) were rated as poor after storage of 3 d at 10°C, and as fair to poor after 7 d at 5°C. Melon
cubes from very mature fruit (13% soluble solids) were rated as *good to fair* after 7 d at 5°C and *fair* after 3 d at 10°C. Fresh-cut products from immature fruit did not have honeydew taste or aroma and deteriorated faster than product from mature fruit (Watada and Qi, 1999).

### 3.4.3 Microbial Spoilage

Although it is considered that whole fresh produce, for the most part, are among one of the safest foods (Brackett, 1987), the safety of fresh-cut products requires a great deal of attention. The processing that fruit undergo turn them more vulnerable to microbiological risks, and the sensory quality is meaningless if the product is unsafe (Brackett, 1992). Along the chain of steps involved in the production of fresh-cut products, from the growth of the raw material to the processing and distribution, there is potential for microbiological risk. Microbial contamination may (1) be of public health significance due to the presence of human pathogens, or (2) decrease the shelf life of the fresh-cut fruit due to spoilage microorganisms, and in addition render a major economic impact.

Appropriate care should start in the farm environment. Contamination may result from soil, poor agronomic practices such as use of raw or improperly treated animal manure as fertilizer, irrigation with contaminated water, animal contact, etc. During fruit picking and packing, contamination may occur through contact with food handlers who may be carriers of microbial pathogens. In general, all fruit arrive at the receiving section of the food processing plant with a microbial load. In the initial steps of processing, with peeling and cutting there is removal of protective barriers (skin, peel, rind) and release of nutrient-rich cellular fluids, conditions that provide increased risk for microbial contamination of the product. After some outbreaks occurred due to the consumption of cantaloupe from salad bars, scientists concluded that microorganisms present in the melon rind were most likely introduced into the fruit during cutting of the melons (Madden, 1992).

The normal microflora found on the surface of produce is diverse, but it generally includes a variety of fungi, mostly harmless bacteria and different species of yeasts. It is expected that different microorganisms will be present in produce that grows on top of the soil vs. a tree-borne fruit. Fungi constitute the majority of spoilage microorganisms found in fruits (Brackett, 1987). However, human pathogens may be present in the fruit microflora. *Clostridium botulinum*, *Clostridium perfringens*, and *Bacillus cereus* can be isolated from soils free of fecal contamination. *Listeria monocytogenes* can be found in decaying vegetation and soil, as can coliforms of nonfecal origin such as *Enterobacter* spp. and *Klebsiella* spp. Enteric microorganisms, among them *E. coli*, are linked to soils contaminated with feces, improperly composted manure or sewage, and contaminated irrigation water. In agricultural environments, animals (domestic and wild) constitute another source of pathogenic bacteria. Salmonellae are found in the intestine of many animals and are abundant in fecal material and sewage (Francis et al., 1999). Birds that feed at sewage works can be a vector for *L. monocytogenes* and enteric bacteria into farm environment. Enteric bacteria can be transmitted to flowers during pollination by insects (NACMCF, 1999). Viruses such as the Hepatitis A and Norwalk can also be found in foods. Fresh-cut product contamination may also occur during harvesting, processing and handling as a result of inadequate personal hygiene among employees, poor sanitation of the processing facilities, dirty cutting tools and work surfaces, and reuse of wash water or ice.

In addition, due to certain characteristics of the fresh-cut fruit processing and packaging, there are additional risks. While one of the initial steps in the processing of fresh-cut products is sanitation, not all microorganisms are eliminated. After breaking the fruit surface integrity with peeling and cutting, rapid bacterial growth can take place. However, the low pH of most fruits does not support the growth of most pathogens (Brackett, 1987). For example, the pH of pineapple ranges between 3.5 and 4 (Siriphanich, 1994). Nevertheless, high pH values are common in different types of melons (Lund, 1992), such as honeydew (pH 5.2 to 5.6), cantaloupe (pH 6.2 to 6.5), and watermelon (pH 6.3 to 6.7), and these fruit are particularly susceptible to microbial contamination and growth.
Storage temperature is a very important factor in controlling microbial growth. Although storage under refrigeration temperatures deters the growth of many microorganisms, some can grow at these conditions, as shown for *L. monocytogenes* (Nguyen-The and Carlin, 1994). With the use of certain types of packaging (such as in modified atmosphere packaging) and long periods of storage, some pathogenic microorganisms may attain numbers high enough to pose a health risk. This could result from the growth of a pathogen population under conditions where there is a suppression of the natural microflora that under normal circumstances would play a positive role in competing with pathogens. The long storage periods allow time for available pathogens to grow, and significant microbial populations may develop. Additionally, if temperature abuse occurs, anaerobic atmospheres can develop inside packages during extended storage (Francis et al., 1999). While these conditions do not favor the growth of some microorganisms, *C. botulinum* can grow under high CO\textsubscript{2}. Product appearance or sensory characteristics may not be affected and the potential health risk may not be perceived by the consumer (IFPA, 1996b).

Following the strict guidelines of GMP and a well-designed HACCP (Hazard Analysis Critical Control Points) plan are fundamental recommendations of the International Fresh-Cut Produce Association (1996a, 1997) in order to produce a microbiologically safe product.

### 3.4.4 Browning Control

Surface discoloration is probably the most common quality defect of fresh-cut fruit and the factor most limiting shelf life. During the peeling and cutting operations, cells are broken, and their contents include previously compartmentalized enzymes that are suddenly freed to come in contact with their substrates. A group of enzymes called polyphenol oxidases (PPO), which occur in particularly high amounts in fruits such as banana, apple, pear, avocado, and peach, are responsible for the discoloration referred to as enzymatic browning.

Enzymatic browning may be controlled through the use of physical and chemical methods; often both are employed. Physical methods commonly used include reduction of temperature and oxygen, and use of modified atmosphere packaging or edible coatings. Chemical methods depend on either treatment with compounds that inhibit polyphenol oxidase, remove its substrates (oxygen and phenolics), or function as preferred substrates. Various antibrowning agents can be used in postcutting dip solutions. An overview on preservative treatments for fresh-cut products was recently published (Garcia and Barrett, 2002).

Ascorbic acid is probably the most common antibrowning agent selected for use in fresh-cut fruit. The drawback of ascorbic acid is that it confers only temporary protection because it is oxidized in the process of preventing browning. While the inhibitory effect of ascorbic acid on browning is due to its reductant action on quinones, other common types of antibrowning agents available for use in fresh-cut fruits include acidulants (e.g., citric acid, malic acid) and chelators (e.g., EDTA), which are often used in combination in browning prevention. Antibrowning treatments commonly include ascorbic acid or its isomer erythorbic acid (\textit{d}-isoascorbic acid), citric acid, EDTA, cysteine, and its derivatives. Research papers have presented results on 4-hexylresorcinol, which has shown effective control of enzymatic browning in fruits (Sapers, 1993); however, 4-hexylresorcinol is currently only approved for use in the prevention of shrimp discoloration (McEvily et al., 1991).

No single antibrowning treatment can control enzymatic browning of all fresh-cut fruit because there is not just one possible solution for a particular fruit product. This can be illustrated by the examples shown in Table 3.3, where various antibrowning treatments selected by different authors for use in fresh-cut pears are presented. Although there has been commercial interest in the development of fresh-cut pear products, pear fruit presents some particular challenges, such as its high susceptibility to enzymatic browning and tissue softening. Fruit ripeness stage proved to be an important factor in the control of browning in pears. Overripe pears are generally prone to more severe discoloration (Sapers and Miller, 1998; Dong et al., 2000); optimal flesh firmness for
### TABLE 3.3
Examples of Treatments Suggested for Controlling Enzymatic Browning in Fresh-Cut Pears

<table>
<thead>
<tr>
<th>Pear</th>
<th>Firmness</th>
<th>Antibrowning Treatment</th>
<th>Comments</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bartlett</td>
<td>44.5 N</td>
<td>1% CaCl₂ + 0.5% O₂ atmosphere, 4% Sodium erythorbate, 0.2% CaCl₂, 100 ppm 4-Hexylresorcinol 1-min dip; storage at 4°C Modified Atmosphere Packaging (MAP)</td>
<td>Slightly underripe fruit. Use of 0.25% NaCl holding solution after cutting With Anjou pears, neutral dip (pH 7.7) more effective than acidic (pH 3.3) dip Less firm fruit browned more, and soft Bartlett pears developed tissue breakdown</td>
<td>Rosen and Kader (1989)</td>
</tr>
<tr>
<td>Anjou</td>
<td>4.0 kg</td>
<td>4% Sodium erythorbate, 0.2% CaCl₂, 100 ppm 4-Hexylresorcinol 1-min dip; storage at 4°C Modified Atmosphere Packaging (MAP)</td>
<td>Trials with 0.2% cysteine did not inhibit browning, and induced red or pink discoloration 4-Hexylresorcinol prevented core tissue browning</td>
<td>Sapers and Miller (1998)</td>
</tr>
<tr>
<td>Bartlett</td>
<td>5.7 kg</td>
<td>4% Sodium erythorbate, and/or 0.2% CaCl₂ and/or 4-Hexylresorcinol MAP</td>
<td>Shelf life at least 14 d (Anjou and Bartlett)</td>
<td></td>
</tr>
<tr>
<td>Bosc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anjou</td>
<td>36–45 N</td>
<td>0.01% 4-Hexylresorcinol</td>
<td>Partially ripe fruit was peeled</td>
<td>Dong et al. (2000)</td>
</tr>
<tr>
<td>Bartlett</td>
<td>45–67 N</td>
<td>0.5% Ascorbic acid 1% Calcium lactate 2-min dip</td>
<td>Shelf life of 30 d for Bartlett and Bosc, and 15–20 d for Anjou pears</td>
<td></td>
</tr>
<tr>
<td>Bosc</td>
<td>27–45 N</td>
<td>1% Calcium lactate 2-min dip Storage at 2–5°C in pouches partially vacuumed</td>
<td>Sensory panelists detected difference in taste as compared with water-treated control</td>
<td></td>
</tr>
<tr>
<td>Slices:</td>
<td></td>
<td>0.01 M 4-Hexylresorcinol</td>
<td>Browning inhibitor of both cut surface and edges of the slices</td>
<td>Buta and Abbott (2000)</td>
</tr>
<tr>
<td>Anjou</td>
<td>22 N</td>
<td>0.5 M Isoascorbic acid</td>
<td>Less inhibition in Bartlett pears</td>
<td></td>
</tr>
<tr>
<td>Bartlett</td>
<td>36 N</td>
<td>0.05 M Potassium sorbate pH 5.5 30-sec dip Storage at 5°C, 14 d</td>
<td>In Anjou initial firmness (21–52 N) did not affect browning control</td>
<td></td>
</tr>
<tr>
<td>Bosc</td>
<td>22 N</td>
<td>pH 5.5 30-sec dip Storage at 5°C, 14 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bartlett</td>
<td>45–58 N</td>
<td>2% Ascorbic acid 1% Calcium lactate 0.5% Cysteine pH 7.0 5-min dip at 20°C</td>
<td>When acidic (pH 3.7) dip was used, a pinkish-red discoloration was observed Dip alone was unable to control browning at the edges of flesh beneath the skin Sensory panelists did not perceive difference in taste</td>
<td>Gorny et al. (2002)</td>
</tr>
</tbody>
</table>

**Note:** Unless indicated, firmness was measured in whole fruit, and fresh-cut products were prepared from unpeeled fruit.

N = Newtons.
Fresh-cut processing needs to be determined in order to obtain a product of high quality and long shelf life. In addition, fruit cultivar is a very important factor to consider; as discussed previously, the browning potential can vary greatly among cultivars (Amiot et al., 1995). Pear fruit size was also shown to affect surface discoloration in pears. Gorny and coworkers (2000) found that pear slices prepared from small-size fruit discolor more than slices cut from larger fruit. This may indicate a difference in maturity and activity of the polyphenol oxidase enzyme.

3.4.5 Prevention of Textural Losses

Fruit texture is perceived by the consumer prior to taste. When biting into a piece of apple, crunchiness is perceived before juiciness. Softening or loss of tissue firmness is a quality defect that compromises the shelf life of many fresh-cut fruits. Examples of changes in the firmness of sliced kiwifruit and banana during storage in various ethylene concentrations are shown in Figure 3.2. Selection of appropriate fruit cultivars is important in avoiding apple fruit prone to mealiness, for instance, or choosing cv. with attractive characteristics of juiciness and crispness. However, textural defects may develop after preparation of the fresh-cut product. Figure 3.3 illustrates pear

![FIGURE 3.2 Changes in firmness of sliced kiwifruit and bananas kept at 20°C in atmosphere of 0, 2, or 20 ppm of ethylene in air. (From Watada, A.E., Ko, N.P., Minott, D.A. 1996. Factors affecting quality of fresh-cut horticultural products. Postharvest Biol. Technol. 9: 115–125.)](image1)

![FIGURE 3.3 Ripe fresh-cut pears (cv. Bartlett) a few minutes after cutting. Note the translucency at the edges of the pear pieces.](image2)
pieces prepared from ripe fruit, where translucent edges were noticeable just a few minutes after cutting. Fruit had been selected based on its superior eating qualities (flavor, sweetness, juiciness, and texture), but it was evidently inadequate for fresh-cut processing. In fresh-cut kiwifruit, flesh softening is the most noticeable change after cutting (Varoquaux et al., 1990); the cut surface darkens not due to enzymatic browning, but rather to the appearance of a translucent water-soaked tissue (Agar et al., 1999). The loss of firmness increases with storage temperature and time, while removal of ethylene from the storage atmosphere improves retention of slice texture.

The most common treatment used to improve texture retention is to dip fruit pieces in calcium solutions, as described for strawberries (Main et al., 1986), and pears and strawberries (Rosen and Kader, 1989). The firming effect of calcium is attributed to the formation of complexes with polygalacturonic acid residues in the middle lamella and cell wall (Van-Buren, 1979). Both calcium chloride and calcium lactate are frequently used. However, trained sensory panels have judged that calcium chloride imparts a bitter flavor to fresh-cut cantaloupe (Luna-Guzmán and Barrett, 2000). Moreover, typical melon flavor was better detected in cantaloupe treated with 1% calcium lactate as compared with 1% calcium chloride. In this study, we found that the initial firming effect of both calcium chloride and calcium lactate on melon cylinders was the same; however calcium lactate–treated samples tended to maintain higher firmness during storage.

A combined treatment using low-temperature blanching prior to dipping in calcium solution has been associated with a decrease in pectin esterification by pectinmethylesterase, creating potential sites for cross-linking with calcium (Stanley et al., 1995). A study of the effect of combined calcium chloride dips and heat treatment on firmness of fresh-cut cantaloupe carried out in our group showed improved firmness as compared with a calcium dip alone. However, it may be that rather than pectinmethylesterase activation, the results observed could be related to a membrane or turgor pressure effect. No significant difference was observed in the amount of bound calcium between samples treated at 60, 40, or 20°C (Luna-Guzmán et al., 1999).

The texture of fresh-cut apples has been reported to improve with the application of heat treatments to apples prior to slicing (Kim et al., 1994). Three apple cv. (Delicious, Golden Delicious, and McIntosh) that had been kept in cold storage (2°C, 90% RH) for less than 2 months were treated for 1.75 h in a water bath at 45°C, then held overnight at 2°C. Fruit were sliced and stored at 2°C for 21 d in unsealed polyethylene bags. Whereas untreated control samples exhibited a steady loss of flesh firmness during storage, heat-treated samples showed an initial increase in firmness (up to 7 d for cv. Golden Delicious and up to 14 d for cv. Delicious), followed by a decrease in firmness. At 7 d of storage, the difference in firmness between heat-treated and control samples were 12% for cv. McIntosh, 34% for Golden Delicious, and 28% for Delicious. The greatest difference observed was with cv. Delicious at 14 d of storage, where the heat-treated sample was ~40% firmer than the untreated control.

### 3.4.6 Appearance and Sensory Quality

The most appealing attributes of fresh-cut products include their perception of freshness, taste and flavor, in addition to convenience. When assessing quality, consumers take product appearance into consideration as a primary criterion. Appearance can be characterized by size, shape, color, gloss, condition, and absence of defects. However, product color contributes more than any other single factor (Kays, 1999).

While appearance may have a major impact on consumers, sensory quality (taste, aroma, texture) is what will ensure consumers’ repeated acceptance of a fresh-cut product. Most of the quality indexes used by both academia and industry for these products are visual, based on appearance; little research has been done on sensory quality of fresh-cut produce (Beaulieu and Baldwin, 2002). General methods for determining quality characteristics of fresh produce are described elsewhere (Mitcham and Kader, 1998).
The relative importance of each quality characteristic depends on the commodity; for instance, gloss is relevant for peach slices but may not be for persimmon wedges. When the optimum ripeness stage for fresh-cut preparation occurs before full ripening and fruit flavor has yet to completely develop, even a fresh-cut product with very good appearance will lack the characteristic flavor of a perfectly ripe fruit. In addition, some flavor components may disappear after processing, or in other cases off-flavors may develop due to either physiological changes in the fruit tissue or microbial spoilage after packaging. Nevertheless, it has been reported that when off-flavors of microbial origin are detected, product appearance is likely to be compromised (Huxsoll et al., 1989).

3.4.7 Nutritional Aspects

In addition to their sensory appeal, for nutritional reasons fruit should be an important part of a healthy diet. Although it is generally low in calories due to its high moisture content, fruit supplies vitamins, minerals, phytonutrients, and fiber to the diet. One of the most significant contributions to our diet comes from the high content of vitamin C and precursors of vitamin A (carotenoids) found in fruits. While citrus fruits are well known as sources of vitamin C, kiwifruit, melons, tomatoes, and berries are also significant sources of this vitamin. Good sources of carotenoids include yellow-fleshed peaches and nectarines, mangoes, papaya, and persimmons. Apples and pears are good sources of fiber, as are many berries (Margen et al., 1992).

While it has been assumed that fresh-cut products would have lowered nutrient content than the commodities they are derived from (Klein, 1987; McCarthy and Matthews, 1994), some experimental data do not indicate this. The shelf life of fresh-cut persimmons and peaches was limited before major losses of carotenoids were detected (Wright and Kader, 1997b). The same was observed with the vitamin C content of strawberries and persimmons (Wright and Kader, 1997a). However, significant oxidation of ascorbic acid was determined when washing fruit slices with chlorinated water (100 ppm sodium hypochlorite) in comparison to washing with water. An intermediate level of oxidized ascorbic acid, or dehydroascorbic acid, was obtained when washing the whole fruit in chlorinated water before slicing it. Fresh-cut kiwifruit stored for 6 d at different temperatures showed a gradual decrease in total vitamin C content with increased temperature. While a loss of 8% in relation to initial vitamin C level in kiwifruit occurred at 0°C, there was a decrease of 13 and 21% at 5 and 10°C, respectively. In ethylene-free storage, ascorbic acid levels were threefold higher than in control slices stored in air (Agar et al., 1999). Losses of ascorbic acid in whole pears stored under controlled atmosphere conditions (low O₂ and high CO₂) revealed that in the cv. Rocha, losses occurred mainly during long-term storage, while in the cv. Conference, most of the ascorbic acid decreased when pears were transferred to controlled atmosphere storage. It is a common practice to store apples and pears under controlled conditions for extended periods of time prior to processing. Lowered levels of ascorbic acid in the fruit flesh will increase susceptibility to browning (Veltman et al., 2000).

In recent years there has been a great interest in phytochemicals due to a variety of potential health benefits they may have. This is an emerging field of research, and very little information is available on concentrations of such compounds in different plant tissues, and even less on possible effects of cultivar, agronomic practices, maturity stage, and postharvest handling on the retention of phytochemicals. In a study with whole apples stored at 1°C for 2 months, the cv. Granny Smith and Delicious had increased antioxidant levels of up to 10-fold, but in longer storage substantial decreases in antioxidants were reported (Curry, 1997).

3.5 Shelf Life Extension of Fresh-Cut Fruit

Once the negative consequences brought about by injuries caused by fresh-cut processing are recognized, it is important to search for means of extending the shelf life of fresh-cut fruits. The
objective is to maintain a fresh-like appearance, flavor, and nutritional quality of the product while ensuring its safety. Among the most common strategies used to extend the shelf life of fresh-cut fruits are temperature management and modified atmosphere packaging. Other benefits can be found with the application of edible coatings. It is important to consider that the consumer perceives a fresh-cut product as fresh-like produce, just minimally prepared to be ready for eating. It is not expected that many chemicals are added to such products or that they are treated in ways that are not considered wholesome by the public. The perception of fresh-cut products as “natural” is part of its appeal. In a survey on the perception of convenience products, consumers revealed the desire that such products maintain fresh characteristics longer without the use of food preservatives (Bruhn, 1994).

3.5.1 Temperature Management

Temperature control is very critical in prolonging the shelf life of fresh-cut products, serving to minimize losses due to wound-related responses and microbial spoilage. At low temperatures, respiration rates and enzymatic activities are reduced, and general metabolic rates are also lowered, extending product shelf life. The growth of some spoilage microorganisms and foodborne pathogens is decreased under the low-temperature conditions recommended for fresh-cut fruit processing and storage.

The results presented in Table 3.1 show the effect of temperature on respiration rates in some fruits. Fresh-cut fruit ideally should be kept close to 0°C, even for chilling-sensitive fruit, because the quality deterioration that results from storage at nonchilling temperatures is more damaging than that resulting from chilling injury (Watada et al., 1996). Rapid cooling of fresh-cut produce reduces respiration and deterioration rates, as well as microbial spoilage. However, it is of paramount importance to maintain product under refrigeration throughout the processing and distribution, and up to consumption.

3.5.2 Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) can extend the shelf life of produce by minimizing water loss, reducing respiration and ethylene production rates, decreasing metabolic activity, and reducing microbial growth and decay. The widely used MAP aims at the creation of an ideal gas composition inside the package. The modification of the atmosphere surrounding the fresh-cut produce can be achieved either through the establishment of an active modified atmosphere (gas flushing) in the package or be generated over time by the fruit pieces respiring in the sealed package. Despite additional costs, active MAP has been preferred because of the limitations in regulating a passively established atmosphere (Kader and Watkins, 2000).

In modified atmospheres, O2 levels are generally reduced and CO2 is increased; high levels of CO2 lead to a decreased sensitivity of plant tissues to ethylene (Kader et al., 1989). When O2 levels are lowered, respiration of produce begin to decrease, and generally continues to decrease with lowering O2 levels down to a level where anaerobic respiration takes place. Among the responses of plant tissue to low O2 levels include reduction in respiration, reduced ethylene synthesis and perception, reduced chlorophyll degradation, reduced cell wall degradation, and reduced phenolics oxidation. Negative responses to low O2 include induction of fermentation, accumulation of acetaldehyde, ethanol and lactate, and reduced biosynthesis of aroma compounds (Beaudry, 2000). In the establishment of safe atmospheres it is important to determine product tolerance to low O2 levels and high CO2 levels.

Watkins (2000) reviewed the effects of high CO2 on produce. In general, fruit tolerances for high concentrations of CO2 and low O2 vary for the same commodity between fresh-cut products and the intact fruit. It is important to experimentally determine the appropriate gas composition for each particular product, which extends the product shelf life and also prevents the damaging...
effects of low levels of O₂ or high levels of CO₂. These may lead to anaerobic respiration and increase susceptibility to decay. An adequate MAP should help achieve a decrease in respiration while preventing anaerobic respiration. In the design of the optimal MAP, it is of utmost importance to know the ideal atmosphere for each particular fresh-cut fruit product and its respiration rate under a certain temperature. In addition, it is necessary to avoid temperature abuse during storage; otherwise the atmospheric composition inside the package changes, which negatively impacts the product. Recommended atmospheres for storage of selected fresh-cut fruits were reviewed by Gorny (1997).

Another important aspect in the application of modified atmosphere packaging is the appropriate selection of packaging material. Common packages include flexible film pouches, rigid trays overwrapped with flexible films, and rigid plastic containers with gas diffusion windows. The most common polymeric film used in MAP is oriented polypropylene; other examples are low-density polyethylene (for bagged products), monolayer polyvinyl chloride (for overwrapped trays), and blends of low- and medium-density polyethylene with ethylene vinyl acetate; microperforated films have been studied as a way of overcoming anaerobic conditions in the package (Al-Ati and Hotchkiss, 2002).

A comparison of different systems for storage of fresh-cut cantaloupe was carried out using the cv. Athena, considered adequate for fresh-cut processing (Bai et al., 2001). Cantaloupe cubes were stored either in (1) pouches where they were allowed to develop a “natural” modified atmosphere (nMAP) through produce respiration, or (2) packages that were flushed with a gas mixture containing 4 kPa of O₂ plus 10 kPa of CO₂ (fMAP), or (3) packages where the package film was perforated with a needle (PFP). In cantaloupe melons, quality deterioration is primarily related to the development of tissue translucency; salable quality may be limited when the level of translucency is greater than 20%. Although shelf life of cantaloupe cubes (Figure 3.4) was prolonged under both nMAP (9 d) and fMAP (12 d) conditions, a faint off-odor was detected in all samples by day 12, with the exception of one of the three replicate trials for the fMAP.

Fresh-cut fruits do not respond to MAP as well as young vegetative fresh-cut tissues; the effects of MAP on control of senescence rate have been only marginally effective. Many factors influence the atmospheric composition at equilibrium inside the package. Film type, thickness, area, weight

![Figure 3.4](image-url)
of fresh-cut fruit in the package, temperature, relative humidity, and product respiration rate are all important. In spite of the advances occurring in film technology, currently available films are not considered as satisfying the requirements of fresh-cut fruit. Current films meet the needs of either CO₂ or O₂ because they allow permeability of CO₂ at higher rates than O₂, which constitutes a shortcoming of MAP for fresh-cut fruit application (Al-Ati and Hotchkiss, 2002). More research is needed in establishing the most appropriate atmospheres for fresh-cut fruits, which are expected to vary with cultivar, growing location, and duration of storage prior to processing (Gorny, 1997).

### 3.5.3 Humidity

Humidity is another important factor that should be controlled in fresh-cut fruit product handling and storage. Although water is the most abundant (80 to 90% of the fresh weight) component of fruit tissues, even small changes (~5%) in the water content of fruit are detrimental to quality. In fresh-cut products the removal of skin or rind and cutting lead to exposure of a large surface as seen in fruit slices, cubes, and wedges, which are prone to great water loss. Surface dehydration occurs quickly and has a negative impact on product appearance, resulting in a product exhibiting less gloss, greater wrinkling, wilting, or flaccidness. However, poor appearance is not the only possible defect resulting from water loss; cellular metabolism may be affected, fruit ripening may be accelerated, and ripening related softening significantly impacted (Paul, 1999). Desiccation may also favor the development of microorganisms that tolerate low moisture, such as fungi (Brackett, 1987). In the dewatering operation, it is important to avoid excessive water loss. Moreover, reduction of moisture loss can be achieved by decreasing the capacity of the surrounding air to hold water. This is done by lowering the temperature, increasing the relative humidity, or creating a barrier to water loss. The last mentioned is commonly done through the use of polymeric films in packaging; moisture retention can also be attained with edible coatings, as exemplified with fresh-cut papaya, where desiccation is a major problem (Siriphanich, 1994). However, in film-packaged products, water is formed as a result of respiration, and it condenses inside the package and becomes available for microbial growth (Al-Ati and Hotchkiss, 2002). This is another point demonstrating the need to avoid product temperature abuse and maintain lower respiration rates.

### 3.5.4 Edible Coatings

The use of edible coatings is another method of extending the shelf life of fresh-cut fruit. Edible coatings consist of thin layers of protective materials applied to the surface of the fruit as a replacement for the natural protective tissue (epidermis, peel). Edible coatings are used as a semi-permeable barrier that help reduce respiration, retard water loss and color changes, improve texture and mechanical integrity, improve handling characteristics, help retain volatile flavor compounds, and reduce microbial growth. It is possible to create a modified atmosphere enrobing fresh-cut produce in edible coating (Baldwin et al., 1995; Baldwin et al., 1996; Nisperos and Baldwin, 1996).

Different food additives can be incorporated into coating formulation, such as coatings with antioxidants (Baldwin et al., 1995). Control of surface browning in apples by ascorbic acid was improved when it was incorporated into an edible coating formulation compared to dipping. A carboxymethylcellulose-based coating did not control enzymatic browning of cut apples, but when such a coating was combined with additives (antioxidant, acidulant, and preservative), browning control was superior to dipping the fresh-cut produce in solutions with the same additives (Baldwin et al., 1996).

Examples of browning inhibition in apple slices have been described for different edible coatings (Avena-Bustillos and Krochta, 1993; Kinzel, 1992). Edible coatings made from apple puree to which lipids and beeswax were added helped control moisture loss and browning of fresh-cut apples (McHugh and Senesi, 2000). Coated and wrapped (“apple wraps”) fresh-cut apple products were compared; apple pieces were either coated with (dipped in) a solution of 70% apple puree, 27%
vegetable oil, 1.5% ascorbic acid, and 1.5% citric acid or wrapped in a film of the same composition. Moisture loss was significantly reduced in apple wraps during storage at 5°C for 12 d. While coatings inhibited browning by 80% over a period of 3 d, wraps showed a 100% inhibition of browning for up to 10 d at 5°C, in addition to maintaining texture, fruity flavor, and odor.

It is important to understand the need for an integrated approach in the processing of fresh-cut fruits. In order to ensure prolonged shelf life, all steps should be carried out taking into consideration the requirement for superior fruit quality of cultivars selected for fresh-cut, adoption of good sanitation practices, gentle handling throughout processing, adequate temperature management, and appropriate choice of packaging and storage conditions. All these factors should be seen as a way of ensuring not only extended shelf life, but also a convenient high quality product that is safe, nutritionally sound, and appealing to the senses.

REFERENCES


Lund, B.M., Baird-Parker, T.C., Gould, G.W. 2000. *The Microbiological Safety and Quality of Food.* Aspen, Gaithersburg, MD.


