Fresh-cut Fruits

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Introduction & Overview: Fresh-cut fruit products for both retail and food service applications have increasingly appeared in the market place recently. In the coming years, it is commonly perceived that the fresh-cut fruit industry will have unprecedented growth. For this reason, many leading fresh-cut salad manufacturers have targeted development of fresh-cut fruit products as part of their long-term business plans. However, processors of fresh-cut fruit products will face numerous challenges not commonly encountered during fresh-cut vegetable processing. The difficulties encountered with fresh-cut fruit, while not insurmountable, require a new and higher level of technical and operational sophistication.

Fresh-cut Defined for Fruits: The USDA and FDA definitions for "fresh" and "minimally- processed" fruits and vegetables imply that fresh-cut (pre-cut) products have been freshly-cut, washed, packaged and maintained with refrigeration. Fresh-cut products are in a raw state and even though processed (physically altered from the original form), they remain in a fresh state, ready to eat or cook, without freezing, thermal processing, or treatments with additives or preservatives (Anonymous, 1998a; Anonymous, 1998b). The International Fresh-cut Produce Association defines a fresh-cut product as fruits or vegetables that have been trimmed and/or peeled and/or cut into 100% usable product that is bagged or pre-packaged to offer consumers high nutrition, convenience and flavor while still maintaining freshness (www.fresh-cuts.org). Several commodities, although botanically fruits (eg*,* cucumber, pepper and tomato), will not be covered since they are commonly classified with salads, as vegetables.

Fresh-cut Physiology and Physiological Concerns: Once harvested, fruits are removed from their source of water, minerals and sustenance. Fruit tissues continue to respire, using available and stored sugars and organic acids and they begin to senesce rapidly. Postharvest quality loss is primarily a function of respiration, onset or progression of ripening (climacteric fruit), water loss (transpiration), enzymatic discoloration of cut surfaces, decay (microbial), senescence and mechanical damage suffered during preparation, shipping, handling and processing (Schlimme and Rooney, 1994; Watada et al., 1996). Fruits destined for fresh-cut processors should be harvested as ripe as possible. This makes it critical that temperature-dependent events related to respiration, water loss, pathological decay and ethylene production be strictly regulated during fruit shipment (or storage).

During the climacteric ripening stage of many fruits (see also "Ripeness at Cutting"), there is a dramatic increase in respiratory CO_2 and C_2H_4 production. Non-climacteric fruit, leafy vegetables, non-fruit vegetables as well as roots and tubers, do not have a surge in C_2H_4 production and generally have only slightly increased respiration as senescence approaches. However, if severely wounded (eg.*,* by fresh-cut processing), a significant stress-induced production of CO_2 and oftentimes C_2H_4 occurs (Abeles et al., 1992; Brecht, 1995). Fresh-cut processing increases respiration rates and causes major tissue disruption as enzymes and substrates, normally sequestered within the vacuole, become mixed with other cytoplasmic and nucleic substrates and enzymes. Processing also increases wound-induced C_2H_4, water activity and surface area per unit volume which, may accelerate water loss and enhance microbial growth since sugars also become readily available (King and Bolin, 1989; Watada et al., 1990; Watada and Qi, 1999; Wiley, 1994). These physiological changes may be accompanied by flavor loss, cut surface discoloration, color loss, decay, increased rate of vitamin loss, rapid softening, shrinkage and a shorter storage-life. Increased water activity and mixing of intracellular and intercellular enzymes and substrates may also contribute to flavor and texture changes/loss during and after processing. Therefore, proper temperature management during product preparation and refrigeration throughout distribution and marketing is essential for maintenance of quality.

Physical alterations and potential low O_2 atmospheres in packages may create significant negative changes in flavor, aroma and "mouth-feel." There are also synergistic interactions between numerous factors such as variety, source, season, initial maturity, optimum processing maturity, slicing and cutting equipment, sanitation and GRAS chemical treatments, packaging (including MAP), temperature management, shipping, handling and length of shelf-life. The combined effect of these factors may have negative consequences on postharvest shelf-life and sensory quality. Therefore, improperly preparing, packaging and handling fresh-cut fruit may compromise overall quality and decrease consumer acceptability.

Defining Fresh-cut Fruit Quality: Postharvest quality and post-cutting quality are unfortunately ambiguous or confused terms. Harvest indices used to deliver optimum quality whole fruits to storage facilities, terminal markets and the fresh markets oftentimes may not be appropriate for fruits destined to be processed (see also "Factors Affecting Fresh-cut Fruit Quality"). Growers often destructively sample fruit before making a decision to harvest. Processor assessment of fruit maturity before cutting either upon receipt, or after in-house storage is also advisable. For example, a lot of peaches that is optimally mature for fresh market may be shipped to a processor, and rejected because the fruit are too soft or ripe for cutting. Subsequently, determination of optimum maturity is commodity- and use-dependent. The processor must understand the physiology of the fruit and their finished product (and packaging) to accurately determine when fruit is at the appropriate maturity stage to process. Choice of variety, harvest condition, maturity, storage, and shelf-life for various fresh-cut fruits are active areas of research.

Proper initial maturity of fruit is essential, however, once processed, quality is most commonly and sometimes only assessed visually. Visual appearance is generally the determinant for commercial shelf-life. Although some studies have found that vitamin C and carotene degrade very little during short-term (about 1 week) refrigerated storage in some fresh-cut fruits (Wright and Kader, 1997a; Wright and Kader, 1997b), other researchers are attempting to retain fresh-cut quality for 3 to 4 weeks. Although some quality attributes may still be acceptable, overall quality in terms of aroma, taste and texture may be jeopardized (Anonymous, 2000b).

Firmness and Texture: Tissue softening is a very serious problem with fresh-cut fruit products that can limit shelf-life. Fresh-cut fruit firmness is an important quality attribute that can be affected by cell softening enzymes present in the fruit tissue (Varoquaux et al., 1990) and by decreased turgor due to water loss. For example, there was 26 to 49% firmness loss in four varieties of fresh-cut cantaloupe processed from ¾- to full-slip maturity fruit when stored in air at 4 °C (39.2 °F) (Beaulieu, unpublished data). Unwrapped watermelon slices lost 47% of their firmness after 4 days at 5 °C (41 °F) (Abbey et al., 1988) and firmness decreased in stored cantaloupe cubes (12 days in air at 5 °C) by more than 25% (Cantwell and Portela, 1997).

Flesh firmness of fresh-cut fruit products can be maintained by application or treatment with calcium compounds. Dipping fresh-cut products in solutions of 0.5 to 1.0% calcium chloride is very effective in maintaining product firmness (Ponting et al., 1971; Ponting et al., 1972). However, calcium chloride may leave bitter off flavors on some products. Firmness of slices from 12 untreated apple cultivars stored at 2 °C (35.6 °F) decreased steadily for 7 days and more rapidly thereafter (Kim et al., 1993). However, mild heat treatment of whole apples before processing retained firmness during storage in some fresh-cut apple cultivars (Kim et al., 1994).

Firmness can sometimes be maintained by CA storage. Firmness loss averaged 2.2 lb (10 N) in honeydew cylinders after 12 days of storage in air at 5 °C (41 °F) while CA storage (air + 15% CO_2) reduced the loss significantly in one of four cultivars tested (Portela and Cantwell, 1998). CA treatments (2% O_2 + 10% CO_2 at 5 °C; 41 °F) and 4 % O_2 + 10% CO_2 at 10 °C; 50 °F) were more beneficial than air storage in maintaining honeydew cube quality for up to 6 days at 5 °C (41 °F) (Qi et al., 1999). Additional information concerning firmness and fresh-cut keeping quality is presented in the "Ripeness at Cutting" section.

Color at the Cut Surface: An important issue in fresh-cut fruit processing is the control of discoloration (pinking, reddening or blackening) or browning at cut surfaces. Oxidative browning is usually caused by the enzyme polyphenol oxidase (PPO) which, in the presence of O_2, converts phenolic compounds in fruits and vegetables into dark colored pigments. Outlined below are a number of strategies that may be used to reduce PPO-mediated cut surface discoloration.

Reduced O_2: Because PPO requires O_2 to induce cut surface discoloration, reducing the amount of O_2 in a package of fresh-cut product by vacuum MAP or gas flushing may reduce cut surface discoloration, but not completely stop it. Careful design of a fresh-cut package is essential to assure that the proper amount of O_2 is present. Excessive levels of O_2 in a package may allow for cut surface discoloration to occur, while too little O_2 may cause anaerobic metabolism and production of off flavors and odors.

Acidification: PPO most effectively catalyzes cut surface discoloration at a neutral pH of approximately 7. Therefore, browning can be slowed by dipping products in mildly acidic food grade solutions of acetic, ascorbic, citric, tartaric, fumaric or phosphoric acid. However, these acids may leave off flavors and promote tissue softening and therefore must be used with care.

Reducing Agents: Ascorbic acid or erythorbate (an isomer of ascorbic acid) are two common compounds used in the food industry to prevent PPO-mediated cut surface discoloration. Ascorbic acid and erythorbate reduce PPO-induced discoloration at the cut surface by converting quinones (formed by PPO from phenolics) back to phenolic compounds. Unfortunately, once all the ascorbic acid or erythorbate is exhausted, PPO browning will proceed uninhibited. Ascorbic acid or erythorbate are commonly used as 1% solutions to prevent browning and discoloration of cut surfaces. These compounds are organic acids, so they may also reduce surface pH of commodities, further slowing browning.

Sensory Aspects: Fresh-cut vegetable salads have great consumer appeal due to their convenience, flexibility of use and probably due to the fact that their desirable flavor often comes about via condiments (croutons, spices or dressing) or because numerous products make up a medley mixture. However, consumer acceptance of fresh-cut fruits most often relies upon the inherent flavor and texture quality of the product, seldom with accompaniments. It is generally and unfortunately assumed that "if it looks good, it tastes good." Improving consistency in fresh-cut fruit product flavor and texture may enhance consumers desire to repeatedly purchase such products.

Soluble Solids Content (SSC) & Titratable Acidity (TA): Sweetness, flesh firmness and taste are very important characteristics for fresh-cut melon quality. In a midseason trial of 17 western cantaloupe varieties, there was an average 5% decrease in SSC (range 0 to 11%) and an average 8% decrease in sugar (range 0 to 21%) when cubes were stored 12 days (in air) at 5 °C (41 °F) (Cantwell and Portela, 1997). After 9 days at 10 °C (50 °F) or 15 days at 5 °C (41 °F), SSC in CA-stored melon pieces were higher than in air: 10.3 vs. 9.5% and 10.2 vs. 9.1% at 10 and 5 °C (50 and 41 °F), respectively (Cantwell and Portela, 1997). Cantaloupe balls prepared from four eastern varieties stored 8 days at 0 °C (32 °F) had an average SSC decrease of 9.7% with a range of 2.3 to 13% (Lange, 1998). SSC remained somewhat constant for 7 days storage at 4 °C (39.2 °F) in fresh-cut cantaloupe when harvest maturity was at least ½-slip, and cubes prepared from fruit harvested at ¼-slip had significantly lower initial SSC which, rapidly declined after only 5 days storage (Beaulieu and Baldwin, 2001). It is well established in the food industry that sugar content (SSC) is generally positively correlated with desirable flavor quality. However, occasionally too much sugar is perceived negatively. The best sugar range for storage of fresh-cut cantaloupe was 10 to 13 °Brix. However, some judged the 13 °Brix fruit as too sweet (Anonymous, 2000a).

TA and SSC have also been used to assess quality via the SSC:TA ratio in some fresh-cut fruits. Changes in TA, pH and SSC in apple slices from 12 cultivars that were stored at 2 °C (35.6 °F) for 12 days were small and varied by cultivar (Kim et al., 1993). Likewise, there were changes in SSC in fresh-cut strawberries stored under various CA for 7 days at 5 °C (41 °F). However, pH increased over time (Wright and Kader, 1997a). Fresh-cut persimmons stored under various CA had increased SSC for 3 d, then decreased SSC by day 8; pH tended to increase through storage (except when stored under 2% O_2) (Wright and Kader, 1997a). A 17% loss in SSC and a 2-fold increase in TA occurred after only 2 days storage at 20 °C (68 °F) (in cantaloupe slices, but the acidity change was attributed to lactic acid bacteria (Lamikanra et al., 2000). TA in fresh-cut oranges stored 8 days at 4 °C (39.2 °F) decreased 36% (Rocha et al., 1995).

Aroma & Flavor: An acceptable post-cutting visual appraisal does not necessarily imply that a product has satisfactory flavor quality. Excellent visual quality and acceptance by retailers and consumers often occur with fruits processed immature. For example, immature peaches and nectarines will process and hold visual quality for extended periods but, re-hardening and poor eating quality limit their use (Beaulieu et al., 1999; Gorny et al., 1998a). A mature green cantaloupe at < ½-slip delivers a fresh-cut product with optimum visual shelf-life, but insufficient sugar or volatile composition associated with a desirable, ripe, whole melon (Beaulieu and Grimm, 2001; Beaulieu and Baldwin, 2002; Pratt, 1971). 'Makdimon' melons harvested 2 days before fully-ripe (full-slip) developed only about 25% the total volatiles as 3 day-old, fully-ripe fruit (Wyllie et al., 1996). Volatiles increased with harvest maturity, and cubes prepared from ¼-slip fruit contained only 25 to 33% total volatiles as full-slip fruit (Beaulieu and Baldwin, 2002). Furthermore, these trends were conserved during 10 days at 4°C (39.2 °F) in fresh-cut products.

Flavor and aroma quality are important attributes for consumers and these attributes should be seriously examined when determining the shelf-life of fresh-cut fruit products. Nevertheless, the "quality" of intact vegetables and fruits is often determined almost exclusively based on appearance, sometimes to the exclusion of flavor and texture (Sapers et al., 1997). Much variability exists in the literature regarding acceptability based on sensory evaluations, and this variability oftentimes can be attributed to different experimental designs or sensorial analyses and cultural bias. For example, sensory evaluation determined that fresh-cut honeydew, kiwi fruit, papaya, pineapple and cantaloupe stored at 4 °C (39.2 °F) were unacceptable after 7, 4, 2, ~7 and 4 days, respectively (O'Connor-Shaw et al., 1994). However, fruit were not sanitized, nor were gloves worn during preparation and subsequent microbial decay and associated texture loss most likely limited post-cutting life. Sterilized, diced, cantaloupe stored at 4 °C (39.2 °F) in various CA were sensorially acceptable after 28 days (O'Connor-Shaw et al., 1996). Cantaloupe pieces stored at 2 °C (35.6°F) in ready to serve tray-packs were visually acceptable after 19 days but flavor scores fell after 13 days storage (Silva et al., 1987). An informal taste panel determined that fresh-cut honeydew melon stored in air at 5 °C (41 °F) for 6 days lacked acceptable textural characteristics and were flat in flavor (Qi et al., 1998). Fresh-cut pineapple stored at 4 °C (39.2 °F) had excellent visual appearance after 7 to 10 days storage, however fruit in the lower portion of containers developed off flavors associated with microbial fermentation (Spanier et al., 1998). Fresh-cut orange segments that had acceptable appearance after 14 days storage were found to have unacceptable flavor quality after only 5 days at 4 °C (39.2 °F) (Rocha et al., 1995). Likewise, undesirable flavor was the limiting factor in sliced wrapped watermelon stored 7 days at 5 °C (41 °F), even though aroma was still acceptable and microbial populations were not problematic until after 8 days (Abbey et al., 1988).

Establishing overall shelf-life limits for fresh-cut fruit, taking flavor quality into consideration, is difficult since initial product variability, potential post-cutting treatments and/or packaging affect flavor attributes differently. Washing whole products prior to processing and proper sanitation, in combination with optimum storage temperature, are critical to maintain quality and prolong product life. Little is known concerning what effect storage temperature has on volatile production and little flavor and sensory work has been performed on fresh-cut fruits.

Microbiology: Microbial decay can be a major source of spoilage of fresh-cut produce (Brackett, 1994). Microbial decay of fresh-cut fruit may occur much more rapidly than in vegetable products due to high levels of sugars found in most fruit. However, the acidity of fruit tissue usually helps suppress bacterial growth, but not growth of yeast and molds. There is no evidence to suggest that lower aerobic plate counts (APC) or total plate counts (TPC) immediately after processing correlate with increased shelf-life in fresh-cut vegetables. However, with fresh-cut fruit, very low APC, TPC and especially yeast and mold counts correlate with increased shelf-life.

The predominant microorganisms associated with spoilage of fresh-cut vegetables are bacteria (eg, *Pseudomonads spp*), whereas the predominant microorganisms associated with the spoilage of fresh-cut fruit products are yeasts and molds. In fresh-cut vegetables the proliferation of bacteria may be a symptom associated with tissue senescence and may not be a true cause of spoilage except in a few rare exceptions when pectinolytic *Pseudomonads* are present. However, in acidic fresh-cut fruit products, yeasts and molds are typically associated with product spoilage. Reducing initial yeast and mold counts, as well as slowing growth by low temperature storage at < 5 °C (41 °F), impacts product shelf-life (O'Connor-Shaw et al., 1994; Qi et al., 1999). In fresh-cut fruit with a neutral pH, such as cantaloupe, bacteria were the main source of spoilage (Lamikanra et al., 2000), and bacterial development was inhibited in fresh-cut watermelon by CA (3% O_2 and 15 or 20% CO_2). However, visual quality was compromised (Cartaxo et al., 1997).

Little research has been performed on food-borne human pathogens on fresh-cut fruits. Recently, Conway et al. (2000) determined that *Listeria monocytogenes* survived and proliferated on 'Delicious' apple slices stored at 10 or 20 °C (50 or 68 °F) in air or CA (0.5% O_2 + 15% CO_2), but did not grow at 5 °C (41 °F). CA had no significant effect on the survival or growth of *L. monocytogenes* at elevated temperatures. Botulinal toxin was not recovered in fresh-cut cantaloupe or honeydew inoculated with a 10-strain mixture of proteolytic and non-proteolytic *Clostridium botulinum* after 21 days at 7 °C (44.6 °F). However, toxin was recovered in some inoculated honeydew samples stored 9 days at 15 °C (59 °F) in hermetically sealed packages (Larson and Johnson, 1999).

Factors Affecting Fresh-cut Fruit Quality: Major factors affecting fresh-cut fruit quality are cultivar (Kim et al., 1993; Romig, 1995), pre-harvest cultural practices (Romig, 1995), harvest maturity (Gorny et al., 1998a), physiological status of the raw product (Brecht, 1995), postharvest handling and storage (Watada et al., 1996), processing technique (Bolin et al., 1977; Saltveit, 1997; Wright and Kader, 1997a), sanitation (Hurst, 1995), packaging (Cameron et al., 1995; Solomos, 1994) and temperature management during shipping and marketing (Brecht, 1999).

General Fresh-cut Physiology and Physiological Concerns: Most fruit are very susceptible to bruising and mechanical injury. This is very different from most fresh-cut vegetables, which may be derived from very durable root tissues (eg., carrots, radishes) or pliable leaf tissue (eg., iceberg lettuce, cabbage). Fresh-cut processing removes the fruit's natural cuticle or skin barrier to gas diffusion and microbial invasion, and severe disruption of the tissue often provokes increased respiration, C_2H_4 production, and enhanced susceptibility to water loss and microbial decay. All of these factors may contribute to decreased shelf-life via browning, off-color, softening and/or decay. Subsequently, methods for cutting and peeling fruit differ from vegetables. Therefore, mechanical size reduction (trimming, peeling, de-seeding, etc.) by high-speed cutting equipment may not be appropriate for some fresh-cut fruit products. Knife sharpness has a significant impact on shelf-life of fresh-cut lettuce products (Bolin et al., 1977; Bolin and Huxsoll, 1991), and this also applies to fresh-cut fruits. Pear slices cut with a freshly sharpened knife retained visual quality longer than fruit cut with a dull hand-slicer (Gorny and Kader, 1996). Sharpening of machine and hand knives as often as possible prolongs shelf-life of fresh-cut fruit due to reduced tissue injury.

Chilling Injury and Holding Temperatures: A significant number of fresh-cut fruits are not as chilling injury (CI) sensitive as the corresponding intact fruit before processing. Examples include pineapple, cantaloupe, honeydew, watermelon, peach, nectarine and mango. If these intact fruits are stored at a chilling temperatures, typically < 12 °C (54 °F), accelerated physiological breakdown and increased incidence of pathological decay occurs. CI symptoms are often manifested when fruit are subsequently placed at non-chilling temperatures, and may not be visible if maintained at chilling temperatures (Saltveit and Morris, 1990). Nonetheless, pre-cooling whole cantaloupe to below their optimal long-term storage temperature shortly before cutting is effective at increasing product shelf-life (Cantwell and Portela, 1997; Lange, 1998).

Fruit tissues normally damaged by storage at chilling temperatures are the inedible outer rind or skin portions. During fresh-cut processing, these tissues are normally removed and discarded. Although the optimal storage temperature for many whole CI-sensitive fruit is above 10 °C (50 °F), after processing storage at 0 °C is almost always the temperature that provides optimal shelf-life by reducing growth of spoilage microorganisms. However, the edible flesh of CI-sensitive fruits may still be susceptible to chilling injury, and no studies have indicated if flavor biosynthesis is inhibited or negatively affected by chilling temperatures.

Varieties, Growing Region and Season: Seed companies and numerous fresh-cut processors are already aware that a given variety performs optimally in certain growing regions and oftentimes has variable postharvest quality attributes depending on cultural practices, climate, season and harvest maturity. For example, the desirable volatile oil content of pineapple flesh is higher in Summer fruit (Haagen-Smit et al., 1945) and the proportions of dominant apple volatiles varied by season (López et al., 1998). The aforementioned interactions, in concert with breeding against or for specific traits to optimize shelf-life, must be considered when developing cultivars tailored for the fresh-cut industry (Romig, 1995). Several reports have documented that certain cultivars out-perform others with regard to fresh-cut shelf-life and quality (Anonymous, 2000a; Cantwell and Portela, 1997; Gorny et al., 1999; Kim et al., 1993; Lange, 1998). However, no single study can encompass all desirable varieties and singling out a “winner” can be compromised by seed source and seasonal/climactic variations. Furthermore, the industry may also be historically driven toward specific varieties (eg., western cantaloupes) when indeed optimum alternatives exist for local seasonal production (eg., eastern cantaloupes) (Lange, 1998).

Gorny et al. (1999) determined the shelf-life of peach and nectarine slices made from 13 cultivars of peaches and eight cultivars of nectarines that had been ripened to between 4 to 7 lb (18 to 31 N) firmness, cut, and then held at 0 °C (32 °F) with 90 to 95% RH. Shelf-life was 2 to 12 days among the cultivars tested. Of the peach cultivars tested, Cal Red, Red Cal, and Elegant Lady had the longest marketable shelf-life of 7.4, 7.2 and 6.7 days, respectively, while Summer Lady and Ryan Sun had the shortest (< 2 days). Among nectarines, Sparkling Red, Arctic Queen, and Zee Grand had the longest shelf-life of 12, 8 and 8 days, respectively, while the other cultivars had a shelf-life of 4 to 6 days. White flesh peaches and nectarines had a comparable shelf-life to yellow fleshed cultivars, with similar browning characteristics.

Based on visual quality, fresh-cut pear slices prepared from partially ripened ‘Bosc’ and ‘Bartlett’ fruit had the longest shelf-life in air at 10 °C (50 °F), being 3 and 4 days, respectively (Gorny et al., 1998b). ‘Anjou’ and ‘Red Anjou’ pear slices had a very short shelf-life of < 2 days each, due to severe cut surface enzymatic browning (Gorny et al., 1998b). However, ‘Bartlett’ and ‘Bosc’ pear slices experienced a much greater loss in firmness after slicing and storage in air at 10 °C (50 °F) than ‘Anjou’ and ‘Red Anjou’ slices.

Fruit Size and Yield: Typically, fresh-cut fruit processors will utilize either very large or very small fruit to maximize yields or to reduce the cost of raw ingredients. For example, fresh-cut melon processors will typically use very large 9-count-per-box fruit. This is because large melons are often available at lower prices in the marketplace, the yield from larger melon fruits is almost always higher and the labor to process one large fruit is often less than processing many smaller fruit. Very little research has been done to document the effects of fruit size on post-cutting shelf-life and quality. One study by Gorny et al. (2000) found that ‘Bartlett’ pear fruit size (120, 135, or 150 count) did not have a significant effect on fresh-cut slice shelf-life, based on flesh color and firmness, if slices were treated after cutting with 2% ascorbate + 1% calcium lactate + 0.5% (w/v) cysteine (pH 7). However, if slices were not treated, smaller fruit (135 or 150 count) discolored at their cut surface more rapidly than slices from large fruit (120 count). Small fruit (135 and 150 count) also had lower SSC than large fruit, and this may affect eating quality. These findings demonstrate that, in some cases, smaller whole fruit, which often receive lower prices in the marketplace, may be avoided for value-added fresh-cut products.

Physical Treatments: Many physical and chemical techniques, such as: edible coatings (Baldwin et al., 1995a; Baldwin et al., 1995b; Baldwin et al., 1996; Howard and Dewi, 1996; Li and Barth, 1998); disinfection (Hong and Gross, 1998; Sapers and Simmons, 1998); natural plant products (Buta et al., 1999; Kato-Noguchi and Watada, 1997; Leepipattanawit et al., 1997; Moline et al., 1999); C_2H_4 absorbents (Abe and Watada, 1991); gamma irradiation (Chervin and Boisseau, 1994; Hagenmaier and Baker, 1997); heat treatments or heat shock (Loaiza-Velarde et al., 1997); microbial competition (Breidt and Fleming, 1997; Liao, 1989); non-thermal physical treatments (Hoover, 1997) and pulsed-microwave irradiation (Shin and Pyun, 1997) have been studied as alternatives or adjuncts to MAP (Brecht, 1999), especially for fresh-cuts.

Storage Time, Temperature, and Atmosphere: The beneficial effects of CA storage for whole fruit has been well documented and is widely employed throughout industry. However, CA storage markedly inhibits apple volatile production (Mattheis et al., 1995; Yahia, 1991; Yahia, 1994). Furthermore, fruit maturity at harvest has been shown to be important in terms of volatile production in melons (Beaulieu and Grimm, 2001; Beaulieu and Baldwin, 2002; Pratt, 1971; Wyllie et al., 1996) and apples (Brackmann et al., 1993; Hansen et al., 1992; Yahia et al., 1990); especially once apple fruit were removed from CA and ripened 10 days at 20 °C (Mattheis et al., 1995). In fresh-cut 'Gala' apples stored for 14 days at 1 °C in sealed pouches, sugars remained constant during storage, pH decreased, and TA, sweetness and sweet aromatic flavor all increased and then decreased (Bett et al., 2001). Therefore, certain packaged fresh-cut products may require active modification of the atmosphere to insure desirable flavor during consumption.

Gorny et al. (2001) determined that, compared to air storage, CA (2% O_2 + 98% N_2) storage at -1 °C (30.2 °F) of whole mature-green pears extended shelf-life of slices 1 to 2 d. There was a significant reduction in shelf-life of slices from pears stored at -1 °C (30.2 °F) in air or CA, compared to slices from freshly harvested pears. Therefore, it seems beneficial to use CA for off-season pears (as opposed to air-stored) to maximize post-cutting life of slices. However, research is needed to determine if volatile synthesis is impaired, similar to CA-stored apples.

Modified Atmosphere Packaging (MAP): MAP is widely used for fresh-cut vegetables, but with fruits, however, occasionally undesirable atmospheres can reduce quality due to off flavor and discoloration (Gil et al., 1998).

Heat Treatment: Slices prepared from heat-treated apples at 45 °C (113 °F) for 105 min, that did not display browning after treatment ('Delicious,' 'Empire,' 'Golden Delicious,' 'McIntosh' and 'New York 674'), were firmer (differences ranging from 12% for 'McIntosh' to 48% for 'Delicious') after 8 days storage at 2 °C (35.6 °F) than those prepared from non-treated apples (Kim et al., 1994). However, heat treatments often led to undesirable flesh browning in many other cultivars tested (Kim et al., 1994).

Irradiation: Irradiation of fresh-cut fruit products may be beneficial in reducing the number of bacteria present on the product. The current FDA limit for irradiation on fresh produce is 1.0 kGy, but to destroy yeasts and molds that may exist as spores, irradiation levels of 1.5 to 20 kGy are necessary (Brackett, 1987) and these levels are damaging to fruit tissues. Irradiation reduced ethylene production of all pre- versus post-climacteric apple slices and irradiation doses of up to 2.4 kGy had minimal effect on the respiratory physiology of tissues (Gunes et al., 2000). However, tissue softening occurred at doses above 0.4 kGy. Therefore, the use of irradiation to extend the shelf-life of fresh-cut fruit products has only limited benefits since the predominant spoilage microorganisms on fresh-cut fruit products are yeasts and molds.

Chemical Treatments: Retention of fresh-cut product firmness and inhibition of browning are common measures used to determine efficacy of chemical treatments. Calcium has been used as an agent for maintaining firmness on whole produce (Poovaiah, 1986) and its use in fresh-cut was inevitable. Other chemical treatments have also been explored and most GRAS applications used today involve chlorine, ascorbic acid and/or calcium salts for preservation.

Chlorination and Washes: In general, fresh-cut fruit should be rinsed just after cutting with cold (0 to 1°C, 32 to 33.8 °F), chlorinated water at pH 7.0. This may help extend product shelf-life by reducing microbial load, removing cellular juices at cut surfaces that may promote cut surface discoloration, and actually inhibit the enzymatic reactions involved in fruit browning (Brecht et al., 1993; Hurst, 1995).

Chlorination, as commonly used for fresh-cut salad sanitation (not exceeding 200 ppm total chlorine), may not be desirable for all fresh-cut fruits. Post-cutting washing and/or dipping may have negative consequences regarding increased water activity and "washing away" of desirable flavor attributes. Processors may or may not wash freshly-cut commodities that develop little or no browning (*eg.,* cantaloupe and honeydew), since chemical treatments are seldom applied and because removal of free surface water (centrifugation or spinning) from the cut fruit can be damaging. On the other hand, honeydew and cantaloupe pieces dipped in hypochlorite (pH 6, 50 $\mu L\ L^{-1}$) prior to packaging in 95% N_2 + 5% O_2 at 2.2 °C (36 °F) had no deleterious effect and microbial counts were lowered throughout storage (Ayhan et al., 1998).

Hydrogen peroxide (H_2O_2) is a strong oxidizing agent and a powerful, surface-contact sterilizer. It has been shown experimentally to reduce microbe populations on the surface of many produce items with minimal to no residue (Bolin and Huxsoll, 1989; Sapers and Simmons, 1998). However, the GRAS status regarding use on fresh-cut products is currently unclear.

Calcium Compounds and Firmness Retention: Application of aqueous calcium compounds (generally 1% $CaCl_2$ dips) help maintain fresh-cut apple, pear and strawberry firmness (Gorny et al., 1998b; Morris et al., 1985; Ponting et al., 1971; Ponting et al., 1972; Rosen and Kader, 1989). Softening of muskmelon sections was affected differently depending on calcium concentration (Lester, 1996). Softening was the major factor in quality loss in kiwifruit slices. However, these slices had a shelf-life of 9 to 12 days if treated with 1% $CaCl_2$ or 2% Ca-lactate, and stored at 0 to 2 °C with > 90% RH in 2 to 4% O_2 and/or 5 to 10% CO_2 (Agar et al., 1999; Massantini and Kader, 1995). Cantaloupe cylinders treated with 1, 2.5 and 5% $CaCl_2$ for 1 to 5 min and stored 10 days at 5 °C (41 °F) generally increased in firmness (Luna-Guzmán et al., 1999).

Ca-lactate has recently been shown to be as effective as the chloride form without imparting a bitter flavor at higher concentrations (Luna-Guzmán and Barrett, 2000). A 1% calcium lactate dip was an effective alternative to ascorbate in fresh-cut 'Bartlett' pears stored 1 to 2 days at 20 °C (68 °F), and 1% Ca-lactate with 2% ascorbate was most effective (Gorny et al., 1998b).

Anti-browning Compounds: Many fruits brown rapidly after cutting, and extensive work has been performed to address this quality loss. Cut surface discoloration or enzymatic browning, caused by formation of quinones in the presence of O_2 and PPO, has been the subject of much research (Sapers, 1993; Vámos-Vigyázó, 1981). Since sulfite use as an anti-browning agent in the U.S. requires labeling for fresh produce, alternative GRAS and experimental compounds have been investigated. Nevertheless, enzymatic browning still represents a major challenge with fresh-cut fruit (Sapers and Miller, 1998; Weller et al., 1997).

Ascorbate, citrate, isoascorbate and sodium erythorbate are some of the most commonly used agents to reduce or eliminate cut surface discoloration. Ascorbate was more effective than erythorbate in preventing surface browning in 'Winesap' and 'Red Delicious' apple plugs stored 24 hr, and 1% citric acid enhanced their effectiveness (Sapers and Zoilkowski, 1987). Cut surface discoloration was restricted in vacuum-packed carambola slices stored at 4.4 °C (40 °F) that were treated with 1 or 2.5% citrate plus 0.25% ascorbate (Weller et al., 1997). Ascorbate-2-phosphate and ascorbate-2-triphosphate also decreased cut surface discoloration in 'Red Delicious' apple plugs for 24 h (Sapers et al., 1989). 'Fuji' apple slices treated with 2% ascorbate had no browning or loss of visual quality for up to 15 days when stored at 10 °C (50 °F) in 0.25% O_2 (Gil et al., 1998). Calcium, in combination with ascorbate, was effective in preventing discoloration of fresh-cut apples (Ponting et al., 1972) and pears (Gorny et al., 1998b; Rosen and Kader, 1989). Browning was also reduced in fresh-cut 'Carnival' peaches treated with 1% Ca-lactate plus 2% ascorbate (Gorny et al., 1999). Browning was retarded in slightly under-ripe 'Bartlett' and 'd 'Anjou' pears treated with a combination of Na-erythorbate, $CaCl_2$ and 4-hexylresorcinol after 14 days storage at 4 °C (39.2 °F). However, fresh-cut 'Bosc' pears browned severely irrespective of inhibitor treatment (Sapers and Miller, 1998). On the other hand, a combination dip with 0.01% 4-hexylresorcinol, 0.5% ascorbate and 1% Ca-lactate extended shelf-life of 'Anjou,' 'Bartlett,' and 'Bosc' pear slices for 15 to 30 days (Dong et al., 2000). Furthermore, combined treatments with 1 mM 4-hexylresorcinol, 0.5 M isoascorbate, 50 mM potassium sorbate and 25 mM *N*-acetylcysteine decreased browning in fresh-cut 'Anjou,' 'Bartlett,' and 'Bosc' pear for 14 days. The preservative effect was unaffected by initial firmness (4.7 to 11.7 lb, 21 to 52 N) for 'Anjou' slices (Buta and Abbott, 2000).

'Red Delicious' apple slices treated with a combined anti-browning dip (4-hexylresorcinol, isoascorbic acid, *N*-acetylcysteine and calcium propionate), and held at 5 °C (41 °F) maintained visual quality for 5 weeks , yet microbial decay was evident after 4 weeks (Buta et al., 1999). Analyses of organic acids and sugars revealed that slices treated with combinations of antibrowning compounds retained higher levels of malate and had no decrease in sugar levels at 5 and 10 °C (41 and 50 °F), indicating that higher quality was maintained during storage. Fresh-cut mangoes treated with 1 mM 4-hexylresorcinol + potassium 50 mM sorbate ± 500 mM ascorbic acid in MAP at 10 °C (50 °F) maintained color and sensory characteristics, with low microbial growth for 14 days (Gonzalez-Aguilar et al., 2000). Cut surface discoloration was significantly reduced in fresh-cut banana slices treated with 500 mM citrate and 50 mM *N*-acetylcysteine and stored at 5 °C (41 °F) or 15 °C (59 °F) for 7 days, and no microbial decay was observed (Moline et al., 1999). A combination of 0.5% carrageenan and 0.5% citrate also inhibited browning in diced 'Granny Smith' and 'Red Delicious' apples for 7 to 9 days at 3 °C (37.4 °F) (Tong and Hicks, 1991).

Cysteine inhibits PPO-mediated enzymatic browning (Gunes and Lee, 1997; Joslyn and Ponting, 1951; Molnar-Perl and Friedman, 1990). Three mechanisms have been proposed to explain how thiol compounds inhibit enzymatic browning: 1) reduction of o-quinone back to o-dihydroxyphenol (Kahn, 1985), 2) direct inhibition of PPO (Dudley and Hotchkiss, 1989; Robert et al., 1996), and 3) the formation of a colorless cys-quinone adduct (Richard et al., 1991).

When cysteine is used as an inhibitor of enzymatic browning on sliced apples (Walker and Reddish, 1964) or pears (Sapers and Miller, 1998), pinkish-red off-colored compounds are formed due to phenol regeneration with deep color formation (Richard-Forget et al., 1992). If off-color formation can be prevented, cysteine may prove to be an effective replacement to bisulfites. Cysteine is a naturally occurring amino acid that has GRAS status for use as a dough conditioner (Code of Federal Regulations 21:184.1271 and 21:184.1272). Development of cut surface discoloration was reduced for only 1 day at 0 °C (32 °F) in 'Golden Delicious' fresh-cut apples treated with 0.1% cysteine (Nicoli et al., 1994). Ineffectiveness of the cysteine treatment was attributed to oxidation in the package, and likely due to the low concentration applied. Recently, Gorny et al. (2002) reported that a post-cutting dip (pH 7.0) of 2% ascorbate, 1% Ca-lactate plus 0.5% (w/v) cysteine significantly extended shelf-life of 'Bartlett' pear slices by inhibiting loss of firmness and preventing browning. Consumer panelists could not distinguish between pear slices treated with the preservative and controls. After 10 days in air at 0 °C (32 °F), 82 and 70% of consumers judged treated pear slices to be acceptable in appearance and flavor, respectively.

When used in combination with ascorbic acid, 4-hexylresorcinol is an effective inhibitor of cut discoloration on many fresh-cut fruit, including apples and pears especially (Buta and Abbott, 2000; Dong et al., 2000; Luo and Barbosa-Cánovas, 1996; Luo and Barbosa-Cánovas, 1997; Moline et al., 1999; Monslave-Gonzalez et al., 1993; Sapers and Miller, 1998). Between 1 and 7 $\mu L\ L^{-1}$ of residual 4-hexylresorcinol was necessary to prevent browning on fresh-cut pear slices stored up to 14 days at 2 to 5 °C (35.6 to 41 °F) (Dong et al., 2000). Although it is effective in preventing cut surface browning, it is not currently considered GRAS by the FDA and may not be used on fresh-cut fruit. It may also impart an unacceptable off flavor on fruit products.

Antimicrobials, Edible Coatings and Other Treatment Compounds: Hexanal is a natural aroma precursor in apples that is readily converted to aroma volatiles *in vivo* by fresh-cut apple slices (Song et al., 1996). Hexanal can not only enhance aroma, but it also reduced enzymatic browning at cut surfaces, as well as inhibited molds, yeasts, and mesophilic and psychrotrophic bacteria in 'Granny Smith' slices stored at 15 °C (59 °F) (Lanciotti et al., 1999). The inclusion of hexanal and (*E*)-hexenal in the MAP (70% N_2 + 30% CO_2) of sliced 'Granny Smith' apples reduced spoilage microbe populations, and increased color stability for up to 16 days at abusive storage temperatures (Corbo et al., 2000). Research is currently in the initial stages for the use of volatile on fresh-cut products and is currently not approved for use.

Methyl jasmonate is a naturally occurring volatile compound, found in many plants, that has hormone-like activity at low concentrations. Exogenously applied methyl jasmonate is effective in reducing mold growth on fresh-cut celery and peppers and may have applications as a naturally derived fungicide (Buta and Moline, 1998).

Edible coatings have been used in an attempt to preserve fresh-cut products because they act as barriers to water loss and gas exchange, creating a micro-modified atmosphere around products, and can serve as carriers for other GRAS compounds (Baldwin et al., 1995a). Ethylene production and CO_2 evolution were reduced in apple slices coated with double layers of buffered polysaccharide/lipid, stored at 23 °C (73.4 °F) (Wong et al., 1994). Use of a cellulose-based edible coating (Nature Seal™ 1020) on fresh-cut apple cylinders stored in over-wrapped trays at 4 °C (39.2 °F) increased shelf-life by about 1 week (Baldwin et al., 1996). The effectiveness of ascorbate to reduce browning and potassium sorbate to decrease microbial growth was superior when incorporated into this edible coating. A commercially available sucrose ester edible coating (Semperfresh™) also inhibits browning of fresh-cut fruit by acting as an O_2 barrier.

Peeled, packaged citrus products have a shelf-life of approximately 17 to 21 days, but fluid leakage can be problematic. Edible wax microemulsion coatings (up to 12% SSC) reduced leakage of dry-packed grapefruit segments by 80% after 2 weeks , and by 64% after 4 weeks (Baker and Hagenmaier, 1997). Coatings could be made with polyethylene, candelilla or carnauba wax, with lauric, stearic, palmitic, oleic or myristic acids. Carnauba wax was most effective, and coatings were not detected by informal taste panels (Baker and Hagenmaier, 1997).

Compendium of Recommendations and Data Related to Fresh-cut Fruit Products: Proper storage temperature and atmosphere are the two most important factors that influence post-cutting shelf-life of fresh-cut fruit. Tables 1 and 2 identify optimum storage atmospheres, temperatures and respiration rates for a range of fresh-cut fruits. This information may be used as a starting point for design and testing of MAP for fresh-cut fruit products. Fresh-cut fruit respiration rates, as well as response to atmospheric modification, will vary depending on many factors, including variety and maturity of fruit at cutting.

References:

Abbey, S.D., E.K. Heaton, D.A. Golden and L.A. Beuchat. 1988. Microbiological and sensory quality changes in unwrapped and wrapped sliced watermelon. J. Food Prot. 51:531-533.

Abe, K. and A.E. Watada. 1991. Ethylene absorbent to maintain quality of lightly processed fruits and vegetables. J. Food Sci. 56:1589-1592.

Abeles, F.B., P.W. Morgan and M.E. Saltveit, 1992. Ethylene in plant biology. Acad. Press.

Agar, I.T., B. Hess-Pierce and A.A. Kader. 1999. Postharvest CO_2 and ethylene production and quality maintenance of fresh-cut kiwifruit slices. J. Food Sci. 64(3):433-440.

Anonymous. 1998a. Food and Drugs. Food labeling. Code of Federal Regulations. 21. Section 101.95.

Anonymous. 1998b. Agricultural Marketing Service. Quality through verification program for the fresh-cut produce industry. The Federal Register. 63(172, 9/4/98). 47220-47224.

Anonymous. 2000a. Supplying quality cantaloupe for fresh-cut processing. Fresh Cut (Jan):6-12.

Anonymous. 2000b. No substitute for flavor in fresh-cut. Fresh Cut (May):22-28.

Ayhan, Z., G.W. Chism and E.R. Richter. 1998. The shelf-life of minimally processed fresh cut melons. J. Food Qual. 21:29-40.

Baker, R.A. and R.D. Hagenmaier. 1997. Reduction of fluid loss from grapefruit segments with wax microemulsion coatings. J. Food Sci. 62:789-792.

Baldwin, E.A., M.O. Nisperos-Carriedo and R.A. Baker. 1995a. Edible coatings for lightly processed fruits and vegetables. HortScience 30:35-38.

Baldwin, E.A., M.O. Nisperos-Carriedo and R.A. Baker. 1995b. Use of edible coatings to preserve quality of lightly (and slightly) processed products. CRC Crit. Rev. Food Sci. Nutr. 35:509-524.

Baldwin, E.A., M.O. Nisperos, X. Chen and R.D. Hagenmaier. 1996. Improving storage-life of cut apple and potato with edible coating. Postharv. Biol. Technol. 9:151-163.

Beaulieu, J.C. and E.A. Baldwin, 2002. Flavor and Aroma of Fresh-cut Fruits and Vegetables. In: Lamikanra O. (ed) Fresh-Cut Fruits and Vegetables. Science, Technology and Market. Boca Raton, FL, CRC Press, pp. 391-425.

Beaulieu, J.C. and C.C. Grimm. 2001. Identification of volatile compounds in cantaloupe at various

developmental stages using solid phase microextraction. J. Agric. Food Chem. 49(3):1345-1352.
Beaulieu, J.C., K.L. Bett, E.T. Champagne, D.A. Ingram and J.A. Miller. 1999. Flavor, sensory and postharvest evaluations of commercial- versus tree-ripe fresh-cut 'Bounty' peaches. HortScience 34:504.
Bett, K.L., D.A. Ingram, C.C. Grimm, S.W. Lloyd, A.M. Spanier, J.M. Miller, K.C. Gross, E.A. Baldwin and B.T. Vinyard. 2001. Flavor of fresh-cut 'Gala' apples in modified atmosphere packaging as affected by storage time. J. Food Qual. 24:141-156.
Bolin, H.R. and C.C. Huxsoll. 1989. Storage stability of minimally processed fruit. J. Food Proc. Preserv. 13:281-292.
Bolin, H.R. and C.C. Huxsoll. 1991. Effect of preparation procedures and storage parameters on quality retention of salad-cut lettuce. J. Food Sci. 56:60-62,-67.
Bolin, H.R., A.E. Stafford, A.D. Jr. King and C.C. Huxsoll. 1977. Factors affecting the storage stability of shredded lettuce. J. Food Sci. 42:1319-1321.
Brackett, R.E. 1987. Microbiological consequences of minimally processed fruits and vegetables. J. Food Qual. 10:195-206.
Brackett, R.E. 1994. Microbiological spoilage and pathogens in minimally processed refrigerated fruits and vegetables. In: Wiley RC (ed) Minimally Processed Refrigerated Fruits and Vegetables. London, UK: Chapman and Hall, pp. 269-312.
Brackmann, A., J. Streif and F. Bangerth. 1993. Relationship between a reduced aroma production and lipid metabolism of apples after long-term controlled-atmosphere storage. J. Amer. Soc. Hort. Sci. 118:243-247.
Brecht, J.K. 1995. Physiology of lightly processed fruits and vegetables. HortScience 30:18-22.
Brecht, J.K. 1999. Postharvest quality and safety in fresh-cut vegetables and fruits. Coop. Reg. Res. Proj. S-294.
Brecht, J.K., A.U.O. Sabaa-Srur, S.A. Sargent and R.J. Bender. 1993. Hypochlorite inhibition of enzymatic browning of cut vegetables and fruit. Acta Hort. 343:341-344.
Breidt, F., and H.P. Fleming. 1997. Using lactic acid bacteria to improve the safety of minimally processed fruits and vegetables. Food Technol. 51:44-46, 48-51.
Buta, J.G. and J.A. Abbott. 2000. Browning inhibition of fresh-cut 'Anjou', 'Bartlett', and 'Bosc' pears. HortScience 35:1111-1113.
Buta, J.G. and H.E. Moline. 1998. Methyl jasmonate extends shelf-life and reduces microbial contamination of fresh-cut celery and peppers. J. Agric. Food Chem. 46:1253-1256.
Buta, J.G., H.E. Moline, D.W. Spaulding and C.Y. Wang. 1999. Extending storage-life of fresh-cut apples using natural products and their derivatives. J. Agric. Food Chem. 47:1-6.
Cameron, A.C., P.C. Talasila and D.W. Joles. 1995. Predicting film permeability needs for modified-atmosphere packaging of lightly processed fruits and vegetables. HortScience 30:25-34.
Cantwell, M. and Portela, S. 1997. Comparing varieties and storage method. FreshCut (Oct):14-18.
Cartaxo, C.B.C., S.A. Sargent and D.J. Huber. 1997. Controlled atmosphere storage suppresses microbial growth on fresh-cut watermelon. Proc. Fla. Sta. Hort. Soc. 110:252-257.
Chervin, C. and P. Boisseau. 1994. Quality maintenance of "ready-to-eat" shredded carrots by gamma irradiation. J. Food Sci. 59:359-361.
Conway, W.S., B. Leverentz, R.A. Saftner, W.J. Janisiewicz, C.E. Sams and E. Leblanc. 2000. Survival and growth of *Listeria monocytogenes* on fresh-cut apple slices and its interaction with *Glomerella cingulata* and *Penicillium expansum*. Plant Dis. 84:177-181.
Corbo, M.R., R. Lanciotti, F. Gardini, M. Sinigaglia and M.E. Guerzoni. 2000. Effects of hexanal, trans-2-hexenal, and storage temperature on shelf-life of fresh sliced apples. J. Agric. Food Chem. 48:2401-2408.
Dong, X., R.E. Wrolstad and D. Sugar. 2000. Extending shelf-life of fresh-cut pears. J. Food Sci. 65:181-186.
Dudley, E.D. and J.H. Hotchkiss. 1989. Cysteine as an inhibitor of polyphenol oxidase. J. Food Biochem.

13:65-75.
Gil, M.I., J.R. Gorny and A.A. Kader. 1998. Responses of 'Fuji' apple slices to ascorbic acid treatments and low-oxygen atmospheres. HortScience 33:305-309.
Gonzalez-Aguilar, G.A., C.Y. Wang and J.G. Buta. 2000. Maintaining quality of fresh-cut mangoes using antibrowning agents and modified atmosphere packaging. J. Agric. Food Chem. 48:4204-4208.
Gorny, J.R. and A.A. Kader. 1996. Fresh-cut fruit products. Fresh-cut Products: Maintaining Quality and Safety:1-14. UCD Postharv. Hort. Ser., No. 10. pp. 14.

Gorny, J.R. 1998. A summary of CA and MA requirements and recommendations for fresh-cut (minimally processed) fruits and vegetables. 5: Fresh-cut Fruits and Vegetables and MAP. Postharv. Hort. Ser. No. 19. CA '97. Proc. 7th Intl. Contr. Atmos. Res. Conf., pp. 30-66.
Gorny, J.R., B. Hess-Pierce and A.A. Kader. 1998a. Effects of fruit ripeness and storage temperature on the deterioration rate of fresh-cut peach and nectarine slices. HortScience 33:110-113.
Gorny, J.R., M.I. Gil and A.A. Kader. 1998b. Postharvest physiology and quality maintenance of fresh-cut pears. Acta Hort. 464:231-236.
Gorny, J.R., B. Hess-Pierce and A.A. Kader. 1999. Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treatments. J. Food Sci. 64:429-432.
Gorny, J.R., R.A. Cifuentes, B. Hess-Pierce and A.A. Kader. 2000. Quality changes in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size, and storage regime. J. Food Sci. 65:541-544.
Gorny, J.R., B. Hess-Pierce, R.A. Cifuentes and A.A. Kader. 2002. Quality changes in fresh-cut pear slices as affected by controlled atmospheres and chemical preservatives. Postharv. Biol. Technol. 24(3):271-278.
Gunes, G. and C. Lee. 1997. Color of minimally processed potatoes as affected by modified atmosphere packaging and anti-browning agents. J. Food Sci. 62:572-575-582.
Gunes, G., C.B. Watkins and J.H. Hotchkiss. 2000. Effects of irradiation on respiration and ethylene production of apple slices. J. Sci. Food Agric. 80:1169-1175.
Haagen-Smit, A.J., J.G. Kirchner, A.N. Prater and C.L. Deasy. 1945. Chemical studies of pineapple (*Ananas sativa* Lindl). I. The volatile flavor and odor constituents of pineapple. J. Amer. Chem. Soc. 67:1646-1652.
Hagenmaier, R.D. and R.A. Baker. 1997. Low-dose irradiation of cut iceberg lettuce in modified atmosphere packaging. J. Agric. Food Chem. 45:2864-2868.
Hansen, K., L. Poll and M.J. Lewis. 1992. The influence of picking time on the postharvest volatile ester production of 'Jonagold' apples. Lebensm. Wiss. Technol. 25:451-456.
Hong, J.H. and K.C. Gross. 1998. Surface sterilization of whole tomato fruit with sodium hypochlorite influences subsequent postharvest behavior of fresh-cut slices. Postharv. Biol. Technol. 13:51-58.
Hoover, D.G. 1997. Minimally processed fruits and vegetables: reducing microbial load by non-thermal physical treatments. Food Technol. 51:66-69, 71.
Howard, L.R. and T. Dewi. 1996. Minimal processing and edible coating effects on the composition and sensory quality of mini-peeled carrots. J. Food Sci. 61:643-645-651.
Hurst, W.C. 1995. Sanitation of lightly processed fruits and vegetables. HortScience 30:22-24.
Joslyn, M.A. and J.D. Ponting. 1951. Enzyme-catalyzed oxidative browning of fruit products. Adv. Food Res. 3:44.
Kahn, V. 1985. Effect of proteins, protein hydolyzates and amino acids on o-diphenolase activity on polyphenol oxidase of mushroom, avocado and banana. J. Food Sci. 50:111-115.
Kato-Noguchi, H. and A.E. Watada. 1997. Citric acid reduces the respiration of fresh-cut carrots. HortScience 32:136-136.
Kim, D.M., N.L. Smith and C.Y. Lee. 1993. Quality of minimally processed apple slices from selected cultivars. J. Food Sci. 58:1115-1117-1175.
Kim, D.M., N.L. Smith and C.Y. Lee. 1994. Effect of heat treatment on firmness of apples and apple slices.

J. Food Proc. Preserv. 18:1-8.
King, A.D. and H.R. Bolin. 1989. Physiological and microbiological storage stability of minimally processed fruits and vegetables. Food Technol. 43:132-135.
Lamikanra, O., J.C. Chen, D. Banks and P.A. Hunter. 2000. Biochemical and microbial changes during the storage of minimally processed cantaloupe. J. Agric. Food Chem. 48:5955-5961.
Lanciotti, R., M.R. Corbo, F. Gardini, M. Sinigaglia and M.E. Guerzoni. 1999. Effect of hexanal on the shelf-life of fresh apple slices. J. Agric. Food Chem. 47:4769-4776.
Lange, D. 1998. Eastern cantaloupe varieties and their potential for fresh-cut melon products. FreshCut (Aug):17-18.
Larson, A.E. and E.A. Johnson. 1999. Evaluation of botulinal toxin production in packaged fresh-cut cantaloupe and honeydew melons. J. Food Prot. 62:948-952.
Leepipattanawit, R., R.M. Beaudry and R.J. Hernandez. 1997. Control of decay in modified atmosphere packages of sliced apples using 2-nonanone vapor. J. Food Sci. 62:1043-1047.
Lester, G.E. 1996. Calcium alters senescence rate of postharvest muskmelon fruit disks. Postharvest Biol. Technol. 7:91-96.
Li, P. and M.M. Barth. 1998. Impact of edible coatings on nutritional and physiological changes in lightly processed carrots. Postharvest Biol. Technol. 14:51-60.
Liao, C.H. 1989. Antagonism of *Pseudomonas putida* strain PP22 to phytopathogenic bacteria and its potential use as a biocontrol agent. Plant Dis.. 73:223-226.
Loaiza-Velarde, J.G., F.A. Tomas-Barberan and M.E. Saltveit. 1997. Effect of intensity and duration of heat-shock treatments on wound-induced phenolic metabolism in iceberg lettuce. J. Amer. Soc. Hort. Sci. 122:873-877.
López, M.L., M.T. Lavilla, M. Riba and M. Vendrell. 1998. Comparison of volatile compounds in two seasons in apples: Golden Delicious and Granny Smith. J. Food Qual. 21:155-166.
Luna-Guzmán, I. and D.M. Barrett. 2000. Comparison of calcium chloride and calcium lactate effectiveness in maintaining shelf stability and quality of fresh-cut cantaloupes. Postharv. Biol. Technol. 19:61-72.
Luna-Guzmán, I., M.I. Cantwell and D.M. Barrett. 1999. Fresh-cut cantaloupe: effects of $CaCl_2$ dips and heat treatments on firmness and metabolic activity. Postharv. Biol. Technol. 17:201-213.
Luo, Y. and Barbosa-Cánovas, G.V. 1996. Preservation of apple slices using ascorbic acid and 4-hexylresorcinol. Food Sci. Technol. Int. 2:315-321.
Luo, Y. and Barbosa-Cánovas, G.V. 1997. Enzymatic browning and its inhibition in new apple cultivar slices using 4-hexylresorcinol in combination with ascorbic acid. Food Sci. Technol. Int. 3:195-201.
Massantini, R. and A.A. Kader. 1995. Storability and quality preservation of sliced kiwifruits (Conservazione e mantenimento qualitativo delle fette de kiwi) (Italian). Industrie Alimentari. 34:357-360.
Mattheis, J.P., D.A. Buchanan and J.K. Fellman. 1995. Volatile compound production by Bisbee Delicious apples after sequential atmosphere storage. J. Agric. Food Chem. 43:194-199.
Moline, H.E., J.G. Buta and I.M. Newman. 1999. Prevention of browning of banana slices using natural products and their derivatives. J. Food Qual. 22:499-511.
Molnar-Perl, I. and M. Friedman. 1990. Inhibition of browning by sulfur amino acids. Apples and potatoes. Agric. Food Chem. 38:1652-1656.
Monslave-Gonzalez, A., G.V. Barbosa-Cnovas, R.P. Cavallieri, A.J. McEvily and R. Iyengar. 1993. Control of browning during storage of apple slices by combed methods. 4-Hexylresorcinol as an anti-browning agent. Food Sci. 58:797-800.
Morris, J.R., W.A. Sistrunk, C.A. Sims and G.L. Main. 1985. Effects of cultivar, postharvest storage, preprocessing dip treatment and style of pack on the processing quality of strawberries. J. Amer. Soc. Hort. Sci. 110(2):172-177.
Nicoli, M.C., M. Anese and C. Severini. 1994. Combined effects in preventing enzymatic browning reactions in minimally processed fruit. J. Food Qual. 17:221-229.
O'Connor-Shaw, R.E., R. Roberts, A.L. Ford and S.M. Nottingham. 1994. Shelf-life of minimally

processed honeydew, kiwifruit, papaya, pineapple and cantaloupe. J. Food Sci. 59:1202-1215.
O'Connor-Shaw, R.E., R. Roberts, A.L. Ford and S.M. Nottingham. 1996. Changes in sensory quality of sterile cantaloupe dice stored in controlled atmospheres. J. Food Sci. 61:847-851.
Ponting, J.D., R. Jackson and G. Walters. 1971. Refrigerated apple slices: effects of pH, sulfites and calcium on texture. J. Food Sci. 36:449-450.
Ponting, J.D., R. Jackson and G. Watters. 1972. Refrigerated apple slices: preservative effects of ascorbic acid, calcium and sulfites. J. Food Sci. 37:434-435.
Poovaiah, B.W. 1986. Role of calcium in prolonging the storage-life of fruits and vegetables. Food Technol. 40:86-89.
Portela, S.I. and M.I. Cantwell. 1998. Quality changes of minimally processed honeydew melons stored in air or controlled atmosphere. Postharv. Biol. Technol. 14:351-357.
Pratt, H.K. 1971. Melons. In: A.C. Hulme (ed) The Biochemistry of Fruits and Their Products. Acad. Press, NY, pp. 207-232.
Qi, L., A.E. Watada and J.R. Gorny. 1998. Quality changes of fresh-cut fruits in CA storage. Fresh-cut Fruits and Vegetables and MAP:116-121. Postharv. Hort. Ser. No. 19. CA '97. Proc. 7th Intl. Contr. Atmos. Res. Conf.
Qi, L., T. Wu and A.E. Watada. 1999. Quality changes of fresh-cut honeydew melons during controlled atmosphere storage. J. Food Qual. 22:513-521.
Rattanapanone, N. and A.E. Watada. 2000. Respiration rate and respiratory quotient of fresh-cut mango (*Mangifera indica* L.) in low oxygen atmosphere. Proc. 6th Intl. Symp. Mango. 509:471-478.
Richard-Forget, F.C., P.M. Goupy and J.J. Nicholas. 1992. Cysteine as an inhibitor of enzymatic browning. 2. Kinetic studies. J. Agric. Food Chem. 40:2108-2114.
Richard, F.C., P.M. Goupy, J.J. Nicolas, J.M. Lacombe and A.A. Pavia. 1991. Cysteine as an inhibitor or enzymatic browning. 1. Isolation and characterization of addition compounds formed during oxidation of phenolics by apple polyphenol oxidase. J. Agric. Food Chem. 39:841-847.
Robert, C., F. Richard-Forget, C. Rouch, M. Pabion and F. Cadet. 1996. A kinetic study of the inhibition of palmito polyphenol oxidase by L-cysteine. Int. J. Biochem. Cell Biol. 28:457-463.
Rocha, A.M.C.N., C.M. Brochado, R. Kirby and A.M.M.B. Morais. 1995. Shelf-life of chilled cut orange determined by sensory quality. Food Control. 6:317-322.
Romig, W.R. 1995. Selection of cultivars for lightly processed fruits and vegetables. HortScience 30:38-40.
Rosen, J.C. and A.A. Kader. 1989. Postharvest physiology and quality maintenance of sliced pear and strawberry fruits. J. Food Sci. 54:656-659.
Saltveit, M.E. 1997. Physical and physiological changes in minimally processed fruits and vegetables. In: F.A. Tomas-Barberan and R.J. Robins (eds) Phytochemistry of Fruits and Vegetables, Claredon Press, pp. 205-220.
Saltveit, M.E. and L.L. Morris. 1990. Overview on chilling injury of horticultural crops. In: Wang CY (ed), Chilling injury of horticultural crops. CRC Press, pp. 4-15.
Sapers, G.M. 1993. Browning of foods: Control by sulfites, antioxidants, and other means. Scientific status summary. Food Technol. 47:75-84.
Sapers, G.M., P.H. Cooke, A.E. Heidel, S.T. Martin, R.L. Miller. 1997. Structural changes related to texture of pre-peeled potatoes. J. Food Sci. 62:797-803.
Sapers, G.M., K.B. Hicks, J.G. Phillips, L. Garzarella, L. Pondish, R.M. Matulaitis, T.J. McCormack, S.M. Sondey, P.A. Seib and Y.S. El-Atawy. 1989. Control of enzymatic browning in apple with ascorbic acid derivatives, polyphenol oxidase inhibitors, and complexing agents. J. Food Sci. 54:997-1002, 1012.
Sapers, G.M. and R.L. Miller. 1998. Browning inhibition in fresh-cut pears. J. Food Sci. 63:342-346.
Sapers, G.M. and G.F. Simmons. 1998. Hydrogen peroxide disinfection of minimally processed fruits and vegetables. Food Technol. 52:48-52.
Sapers, G.M. and M.A. Zoilkowski. 1987. Comparison of erythorbic and ascorbic acids as inhibitors of enzymatic browning in apple. J. Agric. Food Chem. 52:1732-1733-1747.

Schlimme, D.V. and M.L. Rooney. 1994. Packaging of minimally processed fruits and vegetables. In: Wiley RC (ed) Minimally Processed Refrigerated Fruits and Vegetables, Chapman and Hall, pp. 135-182.

Shin, J.K. and Y.R. Pyun. 1997. Inactivation of *Lactobacillus plantarum* by pulsed-microwave irradiation. J. Food Sci. 62:163-166.

Silva, J.L., T. Chanrittisen, C.W. Shannon and G.R. Ammerman. 1987. Shelf-life of refrigerated cantaloupe and watermelon pieces. Res. Rep. Miss. Agric. Forestry Expt. Stat. 12:1-4.

Solomos, T. 1994. Some biological and physical principles underlying modified atmosphere packaging. In: R.C. Wiley (ed) Minimally Processed Refrigerated Fruits and Vegetables, Chapman and Hall, U.K.

Song, J., R. Leepipattanawit, W. Deng and R.M. Beaudry. 1996. Hexanal vapor is a natural, metabolizable fungicide: Inhibition of fungal activity and enhancement of aroma biosynthesis in apple slices. J. Amer. Soc. Hort. Sci. 121:937-942.

Spanier, A.M., M. Flores, C. James, J. Lasater, S. Lloyd and J.A. Miller. 1998. Fresh-cut pineapple (*Ananas* sp.) flavor. Effect of storage. In: E.T. Contis ET, C.T. Ho, C.J. Mussinan, T.H. Parliment, F. Shahidi and A.M. Spanier (eds) Developments in Food Science. Food Flavors: Formation, Analysis, and Packaging Influences, pp. 331-343.

Tong, C.B.S. and K.B. Hicks. 1991. Sulfated polysaccharides inhibit browning of apple juice and diced apples. J. Agric. Food Chem. 39:1719-1722.

Varoquaux, P., I. Lecendre, F. Varoquaux and M. Souty. 1990. Changes in firmness of kiwifruit after slicing. (Perte de fermeté du kiwi après découpe). Sci. Aliment. 10:127-139.

Vámos-Vigyázó, L. 1981. Polyphenol oxidase and peroxidase in fruits and vegetables. CRC Crit. Rev. Food Sci. Nutr. 15:49-127.

Walker, J.R.L. and C.E.S. Reddish. 1964. Note on the use of cysteine to prevent browning in apple products. J. Sci. Food Agric. 15:902-904.

Watada, A.E., K. Abe and N. Yamauchi. 1990. Physiological activities of partially processed fruits and vegetables. Food Technol. 44:116, 118, 120-122.

Watada, A.E., N.P. Ko and D.A. Minott. 1996. Factors affecting quality of fresh-cut horticultural products. Postharv. Biol. Technol. 9:115-125.

Watada, A.E. and L. Qi. 1999. Quality of fresh-cut produce. Postharv. Biol. Technol. 15:201-205.

Weller, A., C.A. Sims, R.F. Matthews, R.P. Bates and J.K. Brecht. 1997. Browning susceptibility and changes in composition during storage of carambola slices. J. Food Sci. 62:256.-260.

Wiley, R.C. 1994. Minimally Processed Refrigerated Fruits and Vegetables, Chapman and Hall, London, U.K.

Wong, D.W.S., S.J. Tillin, J.S. Hudson and A.E. Pavlath. 1994. Gas exchange in cut apples with bilayer coatings. J. Agric. Food Chem. 42:2278-2285.

Wright, K.P. and A.A. Kader. 1997a. Effect of slicing and controlled-atmosphere storage on the ascorbate content and quality of strawberries and persimmons. Postharv. Biol. Technol. 10:39-48.

Wright, K.P. and A.A. Kader. 1997b. Effect of controlled-atmosphere storage on the quality and carotenoid content of sliced persimmons and peaches. Postharv. Biol. Technol. 10:89-97.

Wyllie, S.G., D.N. Leach and Y. Wang. 1996. Development of flavor attributes in the fruit of *C. melo* during ripening and storage. In: G.R. Takeoka, R. Teranishi, P.J. Williams and A. Kobayashi (eds) Biotechnology for Improved Foods and Flavors, Washington, D.C., Amer. Chem. Soc., pp. 228-239.

Yahia, E.M. 1991. Production of some odor-active volatiles by 'McIntosh' apples following low-ethylene controlled-atmosphere storage. HortScience 26:1183-1185.

Yahia, E.M.. 1994. Apple flavor. Hort. Rev. 16:197-234.

Yahia, E.M., T.E. Acree, F.W. Liu. 1990. The evolution of some odor-active volatiles during the maturation and ripening of apples on the tree. Lebensmitt. Wissensch. Technol. 23:488-493.

Table 1. Respiration rates (mg CO_2 kg^{-1} h^{-1}) for fresh-cut fruits in air at various storage temperatures.

	Temp. (ºC)				
Fresh-Cut Product	**0 to 2.5**	**4 to 5**	**10**	**15**	**20 to 23**
apple, sliced					
'Fuji'	-	-	6.7 - 19.0	-	-
cantaloupe, cubed	4.0 - 16.0	5.9 - 31.2	11.4	-	54.0
honeydew, cubed	3.6 - 10.2	-	-	18.9 - 85.1	-
kiwifruit, sliced	2.0 - 6.0	-	-	-	32.4 - 46.8
orange, sliced	-	5.3 - 5.7	-	-	30.8 - 32.9
peach, sliced	6.0 - 12.0	11.7 - 44.9	32.3 - 100.7	-	-
pear, sliced					
'Bartlett'	0.0 - 10.0	-	22.8 - 30.4	-	90.0
'Bosc'	-	-	15.2 - 26.6	-	-
'd'Anjou'	-	-	13.3 - 26.6	-	-
'Red d'Anjou'	-	-	11.4 - 26.6	-	-
pineapple, cubed					
mature green	4.0 - 5.0	-	6.7 - 15.2	-	-
Golden	11.0 - 14.0	-	24.7 - 30.4	-	-
pomegranate, arils	1.0 - 4.0	2.9 - 5.9	5.7 - 11.4	-	-
strawberry, sliced	-	11.1	-	-	315.0

Information from (Gorny, 1998), with updates based on references cited within this chapter. To get mL kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU per ton per day or by 61 to get kcal per metric ton per day.

Table 2. Storage atmosphere recommendations for selected fresh-cut fruits.

		Atmosphere		
Fresh-Cut Product	**Temp. (ºC)**	**% O_2**	**% CO_2**	**Efficacy**
apple, sliced	0 – 5	< 1	-	moderate
cantaloupe, cubed	0 – 5	3 - 5	6 - 15	good
honeydew, cubed	0 – 5	2	10	good
kiwifruit, sliced	0 – 5	2 - 4	5 - 10	good
mango, cubed	5	2 - 4	10	moderate
orange, sliced	0 – 5	14 - 21	7 - 10	moderate
peach, sliced	0	1- 2	5- 12	poor
pear, sliced	0 - 5	0.5	< 10	poor
persimmon, sliced	0 - 5	2	12	poor
pomegranate, arils	0 - 5	-	15 - 20	good
strawberry, sliced	0 - 5	1 - 2	5 - 10	good
watermelon, sliced	3	3	10 - 20	poor

Information from (Gorny, 1998), with updates such as Rattanapanone and Watada (2000), based on references cited within this chapter.