

ESTABLISHMENT OF FAVORABLE PHYSICAL AND ENVIRONMENTAL CONDITIONS
FOR THE OPTIMIZATION OF THE TOTAL PRODUCT QUALITY
OF FRESH-CUT 'KENT' MANGOES

By

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To Norman Dea

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Abstract of Dissertation Presented to the Graduate School
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ESTABLISHMENT OF FAVORABLE PHYSICAL AND ENVIRONMENTAL CONDITIONS
FOR THE OPTIMIZATION OF THE TOTAL PRODUCT QUALITY OF FRESH-CUT
'KENT' MANGOES

By

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Mango (*Mangifera indica* L.) fruit popularity and consumption have increased significantly in recent years. With the expansion of fresh-cut products, there appears to be an incentive to improve the intrinsic qualities of fresh-cut mango. This study aimed to develop optimum procedures for preparing and handling fresh-cut mango slices to maintain maximum total product quality (i.e., aroma, appearance, texture, and nutritional value). Mature green mango fruit were ripened to three ripeness stages based on whole fruit firmness, then processed into fresh-cut slices and stored at 5 °C for 10 d. A ripeness stage equivalent to an initial fruit firmness of 30 N was the optimum for processing 'Kent' mangoes into fresh-cut slices. At that stage, a maximum shelf life of 7 d at 5 °C was achieved. The effect of the USDA-APHIS hot water (HW) quarantine treatment on the total product quality during subsequent storage at 5 °C for 10 d was evaluated. Overall, the results suggested that the HW quarantine treatment applied to whole, mature 'Kent' mangoes did not significantly affect the quality of the fresh-cut slices stored at 5 °C. The occurrence of chilling injury (CI) in fresh-cut mango was investigated using partially ripe 'Kent' mangoes stored for 10 d at chilling (5 °C) and non-chilling (12 °C) temperatures. It is unclear whether this storage period at 5 °C causes CI since no visual injury

symptoms were observed. However, occurrence of lower ascorbic acid content and increased softening at 5 °C suggest that the fresh-cut slices did experience chilling stress. The potential for storing fresh-cut mango in reduced O₂ plus elevated CO₂ atmospheres at a non-chilling temperature was examined. An O₂ partial pressure of 2.5 kPa combined with 10 kPa CO₂ prolonged the shelf life by only 1 d when fresh-cut slices were stored at 15 °C (4 d total) compared to storage in air, which was significantly less than the previously determined shelf life of 7 d in air at 5 °C. The commercial application of those findings was validated using a modified atmosphere packaging system designed to maintain beneficial O₂ plus CO₂ atmospheres at 5 °C or 15 °C.

CHAPTER 1 INRODUCTION

Alternative markets for subtropical fruits such as mango are essential for maintaining the viability of the Florida subtropical fruit industry. The convenience and quality of fresh-cut fruit are major factors that contribute to their increasing popularity in the food supply. Mango (*Mangifera indica* L.) is one of the most important subtropical fruits in the world and is currently ranked fifth in the total world production among fruit crops (FAO, 2007). Furthermore, mango is a fruit with good potential for marketing as a fresh-cut product due to its appealing flavor and texture and the added convenience that a ready-to-eat fresh-cut product would possess compared to whole fruit, which require peeling and cutting before eating. However, little is known about mango physiology and shelf life when processed into fresh-cut slices or cubes, and information is lacking regarding maintenance of fresh-cut mango flavor quality during marketing (Beaulieu and Lea, 2003).

Recently, a survey was conducted of some representatives of the fresh-cut fruit industry, focusing on the challenges encountered by the industry in sourcing desired mango cultivars and fruit size, preparing, and marketing fresh-cut mango products (Kader, 2008). It was suggested that the current 3% of market share for fresh-cut mango products could be increased to a much higher percentage of the total fresh-cut fruit production if year-round availability of preferred cultivars, flavor quality, and optimal ripeness stage for processing were more consistent (Kader, 2008). It was also reported in the same survey that 'Kent' and 'Keitt' are currently the preferred mango cultivars for fresh-cut due to a better availability for large sizes (8 or fewer mango per 4.5-kg box), relatively low fiber content, and good flavor consistency (Kader, 2008).

For fresh-cut fruits, both external and internal qualities are crucial for consumer acceptance and are therefore important marketing considerations (Chien et al., 2007). Fresh-cut

processors often prefer to process firmer and less mature fruit in order to extend shelf life, but at the expense of reduced sensory quality (Hodges and Toivonen, 2008). However, sensory attributes such as sweetness and characteristic aroma may be the most important indicators of quality-based shelf life from the consumer's point of view (Brecht et al., 2003). Moreover, the appearance, texture, nutritional value, and perceived safety are also very important contributors to the product quality (Hu and Jiang, 2007). All these factors depend upon the initial fruit quality and ripeness stage, and how they change during processing, handling, and marketing. For example, appearance and texture can be affected by ripening, decay, discoloration, dehydration, or physical damage, which all may occur during processing or marketing. Aroma and flavor can change due to exposure to adverse environmental conditions, interaction with packaging materials, or as a response to adverse handling or decay. While the nutritional value and safety of the product are not readily apparent to the consumer, they can be lost if the product is not packaged and handled properly (Forney, 2007).

In the fresh-cut processing industry, the assessment of the optimal ripeness stage at which the fruit should be processed into fresh-cut is of great interest as it will contribute to a best product quality with maximum shelf life based on both appearance and flavor. Nevertheless, there is a lack of information regarding the influence of the ripeness stage of the whole fruit at processing and its effect on the physiology and quality of fresh-cut mango products.

For all mangoes entering the United States, a quarantine heat treatment is mandated by the USDA-APHIS. It is known that heat treatments may have positive effects on fruit quality such as extending storability and marketability by inhibiting the ripening process, inducing resistance to chilling injury (CI), and altering the volatile profile of whole fruit (Lurie, 1998; Paull and Chen, 2000; Fallik, 2004;). But, if applied improperly, heat treatments can also cause heat injury, which

can accelerate ripening or cause other disorders such as poor color development, abnormal softening and flavor, inhibition of starch breakdown, and development of internal cavities (Lurie, 1998; Jacobi et al., 2001a, b, c). Therefore, the use of heat-treated mangoes for fresh-cut processing may compromise the composition and/or the sensory quality of the final product.

Moreover, the preferred storage temperature for fresh-cut fruits for best visual quality retention is around 5°C, which is considered a chilling temperature for chilling sensitive subtropical fruits like mango (Lizada, 1991). While fresh-cut products appear to be less sensitive to chilling temperatures than the respective whole fruit, studies have suggested that they may, like the whole fruit (Nair et al., 2004), develop some chilling injury symptoms that could reduce their sensory quality.

Furthermore, quality degradation arising from processing fresh-cut fruits can be minimized by the use of sharp cutting tools, enzymatic browning inhibitors, modified atmospheres (MA), and low temperatures. All fresh-cut products are marketed in plastic film bags or rigid plastic containers that reduce or prevent water loss by acting as barriers to water vapor transmission; most of these packages also possess semipermeable properties in terms of the respiratory gases oxygen (O₂) and carbon dioxide (CO₂) so that a beneficial atmosphere within the package is established and maintained. Beneficial effects of atmospheres containing reduced O₂ and/or elevated CO₂ levels on the maintenance of fresh-cut mango quality compared with storage in air have been reported (Izumi et al., 2003; Poubol and Izumi, 2005a, b; Rattanapanone et al., 2001). The ability of such 'modified atmosphere packaging' (MAP) to extend the shelf life of foods has been recognized for many years. In order to design an effective MAP system several pieces of information are required, namely, the product respiration rates when exposed to various temperatures and atmospheres, and the effects of those temperatures and atmospheres on the

quality and shelf life of the product. Based on that knowledge, the atmospheres that will provide benefit and/or that may accelerate physiological or microbial decay will be determined.

Assumptions

- 1) The selection of an optimal ripeness stage, based on fruit appearance or texture, and combining sensory and compositional quality, can be determined for 'Kent' mangoes. That information will lead to successful fresh-cut product marketability.
- 2) The use of heat-treated mangoes for fresh-cut processing may compromise the composition and/or the sensory quality of the final product.
- 3) A general agreement regarding the symptoms and incidence of CI in fresh-cut mango remains unsettled. There may be sufficient expectation that the flavor of fresh-cut mango could be improved by avoiding exposure to chilling temperatures to justify efforts to develop supplementary treatments and procedures that allow this product to be handled at higher temperatures than those currently being used.
- 4) For many fresh-cut products, low temperature is more effective than MAP in maintaining the overall quality of the product during handling and distribution; that is, MAP is more effective when fresh-cut products are being handled at above optimum temperatures. However, temperature abuses are to be expected during fresh-cut distribution and at the retail level. Therefore, it may be useful to design a MAP system optimized for the highest temperature typically encountered during handling and distribution so the negative effects of high temperature exposure on the fresh-cut mango will be minimized.

Objectives

The specific objectives are the following:

- 1) Determine the optimal ripeness stage for processing and marketing 'Kent' mango into a fresh-cut product with best quality and maximum shelf life in terms of visual, compositional, and sensory quality. Evaluate the effects of the USDA-APHIS hot water quarantine treatment on the visual, and compositional quality attributes aroma volatile production, respiration rate, and electrolyte leakage of fresh-cut 'Kent' mango slices during subsequent storage at 5 °C.
- 2) Evaluate the occurrence of CI in fresh-cut 'Kent' mango, using fresh-cut mango slices and whole mango fruit controls stored at a putative chilling (5 °C) versus non-chilling (12 °C) storage temperature.
- 3) Use controlled atmosphere (CA) storage of fresh-cut mango slices to determine the optimal reduced O₂ and/or elevated CO₂ concentrations that optimize the development of aroma and the overall sensory quality while inhibiting the symptoms responsible for reducing the shelf life, such as browning, water-soaking, and tissue softening.

- 4) Develop a MAP system using the optimal atmosphere that was determined in the previous objective to be suitable for the commercialization of fresh-cut 'Kent' mango slices.

CHAPTER 2 LITERATURE REVIEW

Mango Fruit

Origin and Characteristics

Native to the Indo-Burmese region, the mango fruit (*Mangifera indica* L.) is renowned for its excellent taste, aroma and nutritional value (Tharanathan et al., 2006). Commonly referred as the “king” of tropical fruits or apple of the tropics, mango has been cultivated for more than 4000 years, and still its cultivation, importation and exportation continue to expand as its popularity grows and reaches more consumers worldwide.

After banana, mango is the second dominant tropical fruit species produced worldwide, followed by pineapple, papaya and avocado (FAO, 2003). Between 1971 and 2001, the production of mangoes has increased by nearly 50% (Saúco, 2004; Tharanathan et al., 2006). The global production of mangoes is forecast to reach 30.7 million tonnes by 2010, accounting for nearly 50% of world production of tropical fruits other than banana. By the end of the projection period approximately 77% of world mango output is expected to be produced in Asia and the Pacific, 13% in Latin America and the Caribbean, and 9% in Africa (FAO, 2003). India is expected to remain the world’s largest mango producing nation, accounting for 40% of total global output, with production forecast to reach 12.3 million tonnes (FAO, 2003).

Global mango imports, which, by 2010, are expected to reach 1.5 million tons, will continue to show the strongest growth in demand (Saúco, 2004). The United States and the European Union are the top importing nations, and Mexico (41%), the Philippines (7.8%) and Pakistan (7.6%) are forecast to be the leading mango exporters (Saúco, 2004).

Hundreds of mango cultivars are grown all over the world, but few of them are cultivated on a commercial scale (Lakshminarayana, 1980; Tharanathan et al., 2006). With the exception of

Southeast Asia, Australia and some African countries, which have their own cultivars such as ‘Alphonso’, ‘Kensington Pride’, and ‘Heidi’, most countries produce and export cultivars developed in Florida - mainly ‘Tommy Atkins’, ‘Kent’, ‘Keitt’, ‘Haden’, ‘Van Dyke’, ‘Sensation’, ‘Palmer’, and ‘Lily’ (Saúco, 2004).

The mango fruit is a fleshy drupe that belongs to the division *Phnerogamae*, subdivision *Angiospermae*, class *Dicotyledonea*, order *Sapindales*, family *Anacardiaceae*, genera *Mangifera*, and the cultivated specie being *indica*. The *Anacardiaceae* family consists of 64 genera, mostly trees and shrubs. Some of the species from this family are notorious for being highly poisonous like poison ivy (*Toxicodendron radicans*), but many others are of agricultural importance such as the cashew nut (*Anacardium occidentale* L.) and pistachio nut (*Pistacia vera* L.).

Mangoes vary considerably in size, color and organoleptic quality depending on cultivar, and growing conditions. The fruit pericarp includes a fairly thick, smooth, leathery, waxy peel (exocarp), which when ripe may vary in color with combinations of green, yellow, purple or red. The remainder of the pericarp consists of a thick edible pulp (mesocarp) surrounding a single, hard fibrous stone (endocarp). The stone occupies almost two-thirds of the fruit length and contains a starchy seed. Depending on the cultivar, the pulp coloration may range from pale yellow to deep orange with a flavor varying from turpentine to sweet. Fiber content also varies depending on the mango cultivar.

Mangoes can be classified into two major categories: Indian and Indo-Chinese (Tharanathan et al., 2006). Most of the Indian cultivars have intense peel coloration, possess a strong aroma, and are characterized by attractive fragrances, delicious taste and high nutritional value (Tharanathan et al., 2006). On the other hand, Indo-Chinese cultivars are perceived as ‘medicinal’ and have a turpentine flavor (Lizada, 1993).

The growth of mango fruit follows a simple sigmoidal curve (Chaplin et al., 1990; Lizada, 1993) and can be, according to Tharanathan et al. (2006), divided into four stages: 1) The juvenile stage of rapid cellular growth (up to 2 d after fruit set); 2) the stage of maximal growth rate and development (from day 21 to day 49) resulting from cell enlargement and culminating in fruit maturity; 3) the climacteric stage (between day 49 and day 77) in which the fruit reach maturation and ripen; and 4), the senescence or post ripening stage (from day 77 onwards), when the fruit tissue deteriorates and the fruit are prone to microbial attack followed by decay and death.

Mango cultivars traded commercially for consumption as ripe fruit are manually harvested at the mature-green stage and ripened during storage or transportation. Since flowering and subsequent fruit set occur over a number of weeks, mango fruit do not ripen at the same time on the tree, leading to a range of fruit with different physiological maturities present on the tree at the time of harvest (Jacobi et al., 2001c). Maturity indices at harvest are mostly cultivar dependent, but fruit shape, size, firmness, peel or flesh color, total soluble solids and/or specific gravity are commonly used (Saranwong et al., 2004, Jha et al., 2006; Subedi et al., 2007). On the other hand, postharvest ripening is often evaluated using indicators such as respiration rate (RR), skin color, and firmness (Li et al, 2008).

Since mango is a climacteric fruit, it will ripen rapidly after harvest (Baldwin et al., 1999). However, the maturity of the fruit at the time of harvest will greatly affect the rate of mango ripening and will influence the eating quality of the fruit (Medlicott et al., 1986; Seymour et al., 1990; Jacobi et al., 2001c). Mango fruit harvested immature will fail to ripen normally, and may develop internal white patches or cavitation. Immature mango fruit have lower soluble solids content (SSC) and SSC to acid ratio, and develop poor flavor. Mangoes harvested much beyond

the mature green stage will have a short shelf- life, and loss of flavor may occur before completion of the marketing process (Tucker and Seymour, 1991; Lalel et al., 2003d; Tharanathan et al., 2006).

Many chemical and physiological changes occur during ripening of mangoes that are initiated by the autocatalytic production of ethylene and occur in concert with the climacteric increase in the RR. Such physicochemical activities involve, for example, cumulative physiological loss in weight and volume, changes in pulp and skin color from white or green, respectively, to yellow or orange, development of characteristic aroma and taste, fruit softening, and conversion of starch to sugars (Lizada, 1993; Mitra and Baldwin, 1997; Jacobi et al., 2001a, c).

Postharvest changes in mango fruit intended for fresh consumption are of great interest since all of the events associated with ripening and senescence as well as the effects of postharvest handling techniques will have a direct impact on the quality of the ripe fruit. The next two sections will focus on the mechanisms of mango ripening and senescence as well as postharvest handling techniques that may affect the fruit quality.

Mango Fruit Physiology

Ripening and senescence

Ripening is a genetically programmed event, highly coordinated and irreversible, characterized by a series of physiological, biochemical, and organoleptic processes that lead to the development of a soft, edible, ripe fruit with desirable eating qualities, prior to its ultimate deterioration and death (Hadfield and Bennett, 1997; Tharanathan, 2006; Singh et al., 2007).

A spectrum of biochemical changes occur during climacteric fruit ripening. These include a transitory increase in ethylene production that is associated with an increase in RR, chlorophyll degradation, biosynthesis of carotenoids and anthocyanins as well as essential oils and flavor

components, and increased activity of cell wall degrading enzymes (Tucker and Seymour, 1991; Joyce et al., 2002; Tharanathan et al., 2006).

Ethylene biochemistry and physiology. In general, the ethylene production rates of ripening mango fruit are very low (Tucker, 1993). In ‘Carabao’ mango, the internal ethylene concentration prior to the onset of the climacteric period is approximately 0.01 $\mu\text{L/L}$. During the climacteric period, the internal ethylene concentration rises only to approximately 0.06 $\mu\text{L/L}$ and hardly any ethylene can be detected in the ripe mango (Lizada, 1991). Similarly ‘Alphonso’ mangoes contain between 0.02 to 0.18 $\mu\text{L/L}$ of ethylene during ripening (Tharanathan et al., 2006), while it has been observed that in ‘Kent’ mangoes the internal ethylene concentration can reach up to 0.272 $\mu\text{L/L}$ when the fruit ripen at 25 °C (Trinidad et al., 1997). During the climacteric period, ‘Kent’ mangoes were reported to contain ethylene up to 0.03 $\mu\text{L/L}$, which happened 8 d after harvest when allowed to ripen at 24 °C (Tovar et al., 2001a). In contrast, ethylene concentration during avocado ripening at 20 °C can reach up to 500 $\mu\text{L/L}$ (Van Eeden et al., 1990).

Postharvest mango ethylene production is mostly cultivar dependent and may precede or coincide with the rise of the respiratory climacteric. For example in ‘Carabao’, ‘Keitt’ ‘Golek’, and ‘Haden’ mangoes, the increase of ethylene production occurred simultaneously with the increase in RR while in ‘Kent’ mangoes the rise in ethylene production occurs before the increase in RR (Lizada, 1991; Trinidad et al., 1997). As the fruit become overripe, ethylene production ceases and the immediate ethylene precursor aminocyclopropene-1-carboxylic acid (ACC) accumulates. This phenomenon is attributed to an impairment of ACC oxidase, the enzyme that converts ACC to ethylene, as membrane integrity is lost (Yang and Hoffman, 1984).

It is universally accepted that ripening of mangoes can be triggered by the application of exogenous ethylene (Wills et al., 2001; Montalvo et al., 2007). The effect of exogenous ethylene on ripening of climacteric fruits follows a time-concentration relationship, that is, the higher the ethylene concentration and the longer the exposure time, the faster the onset of the initiation of ripening. Even though the recommended concentrations for commercial ethylene application for ripening avocado, banana, honeydew melon, kiwifruit, mango, and stone fruits fall between 10 and 100 $\mu\text{L/L}$ if fruit is kept at temperatures between 15 and 25°C (Saltveit, 1999), it was reported that an exogenous application of only 0.01 $\mu\text{L/L}$ ethylene was sufficient to accelerate by 17% the time of ripening of ‘Kensington Pride’ mangoes kept at 20 °C (Wills et al., 2001).

Respiratory activity. Respiration rate, commonly expressed as the rate of O_2 consumed and/or CO_2 produced per unit mass of commodity, is generally a good indicator of the metabolic activity associated with the biochemical changes that lead to ripening and senescence of fruit tissue (Ravinda and Goswami, 2008). The RR is also a good shelf life estimator since there is an inverse relationship between RR and shelf life. That is, usually the higher the RR the shorter the shelf life (Ravinda and Goswami, 2008).

The RR is influenced by multiple factors including type of commodity, cultivar and maturity, storage temperature and atmosphere composition, however, temperature has been identified as the most important external factor influencing RR (Fonseca et al., 2002). Ravinda and Goswami (2008) showed that at 5 °C the initial RR of mature green ‘Amarapali’ mango were 14.5 and 16.5 $\text{mL/kg}\cdot\text{h}$ for R_{O_2} and R_{CO_2} , respectively, while at 30 °C the initial rates recorded were 59.7 and 55 $\text{mL/kg}\cdot\text{h}$ for R_{O_2} and R_{CO_2} . At 25 °C, the RR (CO_2 production) peak can even exceed 175 $\text{mg/kg}\cdot\text{h}$ in some mango cultivars (Lizada, 1991). For example, Lakshminarayana and Subramanyam (1970) reported that during storage at temperatures

between 11 and 12 °C ‘Alphonso’ mangoes produced CO₂ at 20 to 50 mg/kg·h, increasing to 40 to 250 mg/kg·h when stored at temperatures between 27 and 32 °C.

Furthermore, the patterns of respiration and ripening behavior vary among mango cultivars and for different climatic conditions and regions where the fruit are grown (Mitra and Baldwin, 1997). For example, in ‘Paini’ mango, the climacteric respiration started around 8 d after harvest when the fruit were stored at 28 °C, and the fruit were ready to eat by 12 d (Krishnamurthy et al., 1971). Similarly, ‘Alphonso’ mangoes ripened within 7 to 8 d after initiation of the climacteric rise, which occurred 5 d after harvest (Lakshminarayana, 1973). For ‘Kent’ and ‘Haden’ mangoes the climacteric peak was observed after 9 and 11 d, respectively (Burg and Burg, 1962).

It is unclear why the RR of climacteric fruit rises during the ripening process (Tucker, 1993). However, this rise is regarded as involving synthetic activities, probably involved in the development of enzymatic systems during fruit ripening (Krishnamurthy, et al., 1971). In fact, ripening changes involve a multiplicity of biochemical pathways that affect all the cell compartments (Yashoda, 2006).

Organoleptic quality

Texture. The ripening process of mango fruit involves several biochemical changes, causing alterations in texture, color, aroma and taste. Usually, texture and color are directly related to shelf life and consumer appeal.

Textural changes during ripening may arise from loss of turgor (a process associated with dehydration) and/or from enzymatic degradation of structural and storage polysaccharides (Tucker, 1993; Tharanathan et al., 2006). Textural softening in fleshy fruits during ripening is mainly a result of modification of the cell wall physicochemical properties, caused by the

degradation of cell wall polysaccharides, endogenously controlled and catalyzed by various enzymes (Lizada, 1991; Ali et al., 1995; Muda et al., 1995; Tharanathan et al., 2006).

Polysaccharides make up to 90-95% of the structural components of the cell wall, with the remaining 5 to 10% being largely composed of hydroxyproline-rich glycoprotein. Together the polysaccharides can be categorized as cellulose, hemicellulose or pectin (Tucker, 1993).

Pectins are likely to be the key substances involved in the mechanical strength of the primary cell wall and are important to the physical structure of the plant (Tharanathan et al., 2006). During fruit softening, an apparent dissolution of the pectin-rich middle lamella region of the cell wall can be observed, causing major changes in the pectic polymers of the wall. These changes result from the action of cell wall degrading enzymes, mostly hydrolases such as pectin methylesterase (PME), polygalacturonase (PG), and β -galacturonases.

During mango ripening the activity of hydrolases gradually increased, with the exception of PME, which decreased, with most of the enzymes showing maximum activity around the climacteric stage (Yashoda, et al., 2007). Chaplin et al. (1990) observed that the level of softening was dependent on the mango cultivar and was not uniform throughout the fruit. That is, 'Haden', 'Harumanis', 'Kensington' and 'Mulgoa' mangoes soften from the inside out with the inner mesocarp being significantly softer than the mid or outer regions at the ripe stage.

Pigmentation. During ripening, most mango cultivars change external color from green to yellow or orange; the red blush that often occurs is not associated with ripening but rather is produced in response to light exposure during fruit development. Mango colors are attributed to three characteristic classes of pigments: chlorophyll (green), carotenoids (yellow, orange, and red), and flavonoids (anthocyanins; red and purple), respectively. The relationship between the different pigments and how they affect color development of the peel in 'Tommy Atkins' and

'Alphonso' mangoes during ripening were reported by Medicott et al. (1986) and Lizada (1993). The development of the peel pigmentation is associated with the breakdown of the chloroplast thylakoid system during the initial stages of ripening causing the loss of chlorophyll and the development of the osmiophilic globules, increasing the content of carotenoids in the peel (Medlicott et al., 1986).

Pulp carotenoids continue to increase in the detached fruit as ripening proceeds, with the carotenoids level in the ripe fruit varying among cultivars (Lizada, 1993). The increase in carotenoids involves the development of many different carotenoids and xanthophylls (oxygenated carotenoid derivatives) compounds such as β -carotene, xanthophyll esters, xanthophylls, and lycopene in the plastids (Yashoda et al., 2006). In mango fruit, yellow β -carotene is the most prevalent carotenoid, representing 50% of the total carotenoid content, and it is present in highest concentration at the fully ripe stage (Czyhrinciw, 1969; Moore, 2003).

Composition of the edible fruit portion

Mango composition varies greatly among mango cultivars, production regions and cultivation practices, and of course, the stage of maturity of the harvested fruit.

Carbohydrates. The total sugar content of mango fruit accounts for 11.5 to 25% of the fresh weight, with glucose, fructose and sucrose being the major soluble sugars present (Lizada, 1993). The sugars accumulate directly through carbon supplied by photosynthesis during development and indirectly via starch degradation during ripening (Lakshminarayana, 1980; Peroni et al., 2008).

Starch, a polymeric mixture of essentially linear (amylase) and branched (amylopectin) α -glucans (Millan-Testa et al. 2005), is one of the most important components in unripe mango, accounting for up to 15% of the fruit fresh weight in mature green fruit (Tharanathan et al., 2006). The increase in the sucrose content is mainly attributed to the breakdown of starch during

ripening resulting in a ripe fruit in which starch is virtually absent (Lakshminarayana et al., 1970; Lakshminarayana and Vazquez-Salinas, 1978).

The hydrolysis of starch and synthesis of sugars have been associated with amylase activity (Mattoo and Modi, 1969; Fuchs et al., 1980). In 'Keitt' mangoes, the increase in α -amylase activity paralleled the decrease in starch content, achieving its maximum activity at maturity, while β -amylase activity was detected only during ripening (Bernardes Silva et al., 2008; Peroni et al., 2008). Fuchs et al. (1980) reported that during the first 4 d after harvest of mature green 'Haden' mangoes, there was enough amylase activity to initiate starch hydrolysis, but only later on, did an additional increase in the enzyme activity occur, resulting in an increase in the rate of starch hydrolysis.

The initial starch content in preclimacteric mango fruit and its degradation pattern during ripening are also dependent of the mango cultivar (Bernardes Silva et al., 2008). For example, in 'Keitt' mango, there was a steady accumulation of starch after fruit set, and a clear pattern of starch degradation during ripening (Bernardes Silva et al., 2008). Also, fructose predominated in this cultivar during fruit development and before the climacteric period (Bernardes Silva et al., 2008), while sucrose accounted for 57% of total sugar content in ripe fruit. Fructose and glucose made up 28 and 15% of the total sugar content in ripe 'Keitt' mango, respectively (Medlicott and Thompson, 1985). Castrillo et al. (1992) also reported that during ripening of 'Haden' mango, sucrose was the dominant sugar, accounting for over 60% of the total soluble sugar content at the ripe stage. Sucrose was the major sugar in mature green 'Balady' mango, followed by fructose and glucose in descending order while at the ripe stage glucose was the predominant sugar. However, at the overripe stage glucose and sucrose contents tended to decrease while fructose content increased (Sharaf et al., 1989). Fuchs et al. (1980) showed that in overripe 'Haden'

mango, the decrease in total sugar content resulted from the consumption of reducing sugars for respiration and for the energy-consuming ripening processes while no more starch was left in the fruit.

Chaplin et al. (1990) reported for 'Haden', 'Harumanis', 'Kensington', and 'Mulgoa' mangoes an increase in the SSC in the mesocarp during ripening with the inner mesocarp (except for 'Harumanis' mango) having higher SSC than the outer mesocarp. Yashoda et al. (2006) reported an increase in SSC (from 7 to 20%) during ripening of 'Alphonso' mango. Similar observations were also reported for 'Keitt' (Medlicott and Thompson, 1985), 'Dashehari' (Karla and Tandon, 1983) and 'Tommy Atkins' mangoes during ripening (Tasneem et al., 2004).

Organic acids. Titratable acidity (TA) declines as mango ripens, dropping in 'Badami' mango from 48 meq/100 g in the preclimacteric stage to 5.6 meq/100 g in the post climacteric stage (Tharanathan et al., 2006). A similar pattern has been reported for other mango cultivars (Karla and Tandon, 1983; Medlicott and Thompson, 1985; Selvaraj and Pal, 1988). In general, the predominant organic acid found in mango fruit is citric acid, which can vary from 0.13 to 0.71% FW, with malic and succinic acid found in significant quantities (Tharanathan, et al., 2006). In 'Keitt' mangoes, citric and malic acids were the predominant organic acids measured, but tartaric, oxalic, ascorbic, and α -ketoglutaric acids were also identified in minor amounts (Medlicott and Thompson, 1985).

Antioxidant compounds. Mango fruit are a rich source of antioxidants, which are compounds capable of quenching and neutralizing free radicals, preventing the oxidation of important bioactive components (Lounds-Singleton, 2003; Kondo et al., 2005). In mango, carotenoids, phenolics, and ascorbic acid are the compounds mostly responsible for the

antioxidant properties (Ribeiro et al., 2007). Carotenoids, as discussed previously, are responsible for the characteristic color of ripe mango and are synthesized during ripening.

The β -carotene, lycopene, and xanthophyll have been reported to quench singlet oxygen (Kondo et al., 2005). The antioxidant properties of such compounds are attributed to their conjugated double bonds, which provide a reactive electron-rich system susceptible to attack by electrophilic compounds (Moore, 2003).

Phenolic compounds contribute significantly to mango flavor because of their astringency (Wu et al., 1993). Some of the phenolic compounds identified in mango are gallic acid, indigallic acid, gallotannin, quercetin, isoquercetin, and ellagic acid. The content of total phenolics in mango fruit varies between 48.4 to 208.7 mg/100 g, with 'Haden' and 'Ubá' mango cultivars having the lowest and highest concentrations, respectively (Ribeiro et al., 2007). In contrast to carotenoid content, polyphenol content is highest during mango fruit growth and decreases with ripening (Lakshminarayana et al., 1970; Karla and Tandon, 1983). Moreover, Abou Aziz et al. (1976b) showed that the skin of 'Paini' mango contained considerably more total phenolic compounds than the flesh but the content tended to decrease with storage time.

The apparent ascorbic acid (AA) content of the whole fruit increased after fruit set and reached its maximum value during the fifth week of development. Thereafter AA content declined to the eighth week, and then remained quite steady until harvest maturity. Mangoes are a fair source of AA, varying from 1.5 mg to 175 mg/100 g of ripe mango flesh (Wu et al., 1993). Ribeiro et al. (2007) reported that the total AA content of 'Tommy Atkins' and 'Ubá' mangoes was 9.79 and 77.71 mg/100 g, respectively. Cultivar variations and postharvest storage conditions may account for differences in AA content of the fruit.

Lipids. Lipids have been linked to color and flavor development during mango ripening. The products of their degradation through the β -oxidation are utilized in synthesis of carotenoids and terpenoids, which are important components of mango fruit related to color and flavor, respectively (Litz and Gomez-Lim, 2002). The major lipid component of mango pulp was reported to be mostly triglycerides, with monoglycerides, diglycerides and phospholipids as minor components (Tharanathan et al., 2006). The triglyceride fraction consists of myristic, palmitic, palmitoleic, stearic, oleic, linoleic and linolenic acids (Bandyopadhyay and Gholap, 1973a, b, Wu et al., 1993).

Ripening of mango is also associated with changes in glyceride content as well as in fatty acid composition. For example, Bandyopadhyay and Golap (1973) reported that the concentration of fatty acids increases during the ripening of 'Alphonso' mango. In general, while the fruit are maturing, the degree of unsaturation of the fatty acids becomes greater (Bandyopadhyay and Gholap, 1973; Gholap and Bandyopadhyay, 1980). It is also known that the ratio of palmitic (16:0) to palmitoleic (16:1) acid determines the flavor quality of the ripe fruit with a ratio less than one resulting in stronger characteristic aroma (Bandyopadhyay and Gholap, 1973).

Aroma volatiles. More than 300 aroma volatile compounds in the free form have been identified from different mango cultivars while about 70 compounds were identified as glycosidically bound aroma compounds (Lalel et al., 2003a, b; Pino et al., 2005; Lebrun et al., 2007). Unlike most other fruits¹, no specific character impact compounds can be attributed to the aroma of mango (Wilson et al., 1990). Nonetheless, it is generally recognized that mango aroma

¹ The character impact compounds responsible for the characteristic aroma of several fruit are known: apple characteristic aroma is associated with ethyl 2-methylbutyrate, lemon with limonene and citral, banana with amyl esters and isoamyl acetate, and grape with methyl anthranilate and ethylacetate (Kays, 1991).

varies qualitatively and quantitatively depending on the nature of the cultivar, harvest maturity, storage temperature, and atmosphere (Koulibaly et al., 1992; Lalel et al., 2003c, d; Nair et al., 2003; Mahattana-wee et al., 2005). As mentioned previously, lipid metabolism is the main contributor to aroma development in mango fruit (Gholap and Bandyopadhyay, 1980; Koulibaly et al., 1992; Lalel et al., 2003d, Nair et al., 2004).

Fatty acids originating from the breakdown of lipids are known to be precursors of terpenes, aldehydes, alcohols, aliphatic esters, acids, ketones, and lactones, which all contribute to the characteristic mango aroma (Bender et al., 2000a; Lalel et al., 2003d, f; Nair et al., 2004). Most of the volatile compounds derived from fatty acids are products of β -oxidation, one of the three main pathways for the production of volatiles in whole fruit. In addition, the isoprenoid pathway, contributes to the synthesis of many of the terpenes, and the shikimic pathway provides many of the volatile aromatic and phenolic compounds (Kays, 1991; Koulibaly et al., 1992; Lalel et al., 2003f).

In most mango cultivars studied, the characteristic aroma of the fruit is mainly derived from monoterpene and sesquiterpenes hydrocarbons which account with up to 90% to the total volatile compounds. Different levels of oxygenated constituents, including alcohols, aldehydes, ketones and esters also contribute toward the unique aroma of certain cultivars, such as 'Pari', 'Sindhu' and 'SB Chausa' (Lalel et al., 2003c; Lebrun et al., 2007; Pandit et al., 2009).

Engel and Tressl (1983) identified monoterpene hydrocarbons as an important class of volatiles that contribute to the characteristic flavor of Florida, Brazilian and Venezuelan mango cultivars. The terpene hydrocarbons are considered to be important contributors to the flavor of Florida mango cultivars, such as 'Keitt', 'Kent', and 'Tommy Atkins' (Torres et al., 2007). In

contrast, Indian cultivars have more oxygenated volatile compounds, such as esters, furanones, and lactones (Pandit et al., 2009).

The volatile 3-carene, described as giving an aroma typical of mango leaves or a mango-like aroma, is the major monoterpene hydrocarbon found in 'Haden', 'Keitt', and 'Tommy Atkins' mangoes. 3-Carene accounts for 71.4, 76.4 and 60.2% (w/w) of the total aroma volatiles in 'Haden', 'Keitt', and 'Tommy Atkins', respectively (Andrade et al., 2000; MacLeod and Snyder, 1985). 3-Carene is also the major volatile (26%) found in some Venezuelan mango cultivars (unknown cultivar) (MacLeod and de Troconis, 1982). Moreover, of three Sri Lanka mango cultivars, 'Willar' and 'Parrot' contained reasonable amounts of 3-carene, but the same compound was not detected in 'Jaffna'; nor was 3-carene found in the Indian cultivars 'Alphonso' and 'Baladi' grown in Egypt (MacLeod and Pesis, 1984). In the latter mango cultivars, cis- β -ocimene, myrcene or limonene were generally the major terpene compounds responsible for the mango flavor. In fact, cis-ocimene, α - and β -pinene, myrcene, and limonene are particularly important contributors to the flavor of fresh Indian mango cultivars, with either cis-ocimene or myrcene, depending on the cultivar, being the characteristic aroma compounds of green mango (Gholap and Bandyopadhyay, 1977; MacLeod and De Troconis 1982). The flavor of the 'Carabao' mango extract, with its typical, fatty, sulfury, butyric, pulpy and sweet character results from a combination of terpinolene and fatty acids, containing any trace of lactone (Naef et al., 2006). Similarly, in 'Kensington Pride' mango, where monoterpenes account for 49% (w/w) of the total volatile compounds, α -terpinolene (26%) is the main terpene present, followed by 3-carene (7%) (MacLeod et al., 1988). Terpinolene was also the major terpene found in 'Governor' mango (Koubilay et al., 1992), and was one of the two most abundant volatiles measured in 'Bowen' mangoes (Malundo et al., 1997). In contrast, the aroma of 'Alphonso' mango is

composed of ocimenes, linalool, and a complex mixture of lactones and sesquiterpenoid hydrocarbons (Naef et al., 2006). In another study, Mahattanatawee et al. (2005) reported that esters were the major aroma-active compounds present in 'Keitt' mango, contributing to a fruity note (e.g., ethyl butanoate, ethyl hexanoate), followed by aldehydes and alcohols, which contributed to the sweet-fruity and green notes.

Lalel et al. (2003e) suggested that the biosynthesis of mango aroma volatile compounds is ethylene dependent, and thus subject to change during fruit ripening. It was reported that the production of terpenes decreased during ripening of 'Kensington Pride' mangoes at 21 °C and peaked between day 2 and day 7, whilst ester production increased continuously during ripening (Lalel et al., 2003f; Lagunes et al., 2007). Similarly, aromatics compounds followed the same production pattern observed for terpenes; norisoprenoids (derivates of carotenoids) followed the same production pattern observed for esters, whilst aldehydes were higher in the hard mature green mangoes and decreased during ripening. When the volatile profiles of green, ripe, and overripe 'Keitt' mangoes were studied, it was found that despite many individual differences, the total concentration of volatiles for the three fruit maturities were approximately the same (56 µg/g, 54 µg/g, and 49 µg/g, respectively) (MacLeod and Snyder, 1985). However, some progressive changes were evident in certain groups of compounds during ripening. For example, the concentration of sesquiterpene hydrocarbons (especially β-caryophyllene) decreased regularly, whilst the concentration of esters increased with fruit ripening.

Considerable quantitative and qualitative differences were observed between the aroma volatiles found in the overripe fruit and those found in the ripe or green mangoes. Such differences were mainly due to the synthesis of alcohols, namely ethanol, 2-methylpropan-1-ol and 3-methylbutan-1-ol, which were suggested to be indicators that the fruit were overripe

(MacLeod and Snyder, 1985). Therefore, alcohols became the dominant group of volatiles found in the overripe mango while the relative concentrations of other groups of volatile compounds were correspondingly reduced (MacLeod and Snyder, 1985). In particular, monoterpene hydrocarbons diminished from more than 90% w/w of the total volatiles in the mature green or ripe fruit to less than 40% in overripe mango fruit. In addition, the amount of 3-carene was reduced by more than 50% whereas other terpenes, such as limonene, were reduced by even greater proportions (MacLeod et Snyder, 1985).

Fruit maturity at harvest had a great influence on the concentrations of fatty acid and aroma volatile compounds in the pulp of ripe 'Kensington Pride' mangoes (Lalel et al., 2003d). Besides the maturity of the fruit at harvest, temperature variations during ripening may also affect the fatty acid content of the fruit and further affect the biosynthesis of aroma volatile compounds in the ripe fruit. For example, it was reported that when 'Alphonso' mangoes were harvested at the fully ripe stage the fruit had a poor aroma compared with ripe fruit that had been harvested at the mature green or half-ripe stages. On the other hand, Bender et al. (2000a) reported that tree ripe 'Tommy Atkins' mangoes had higher levels of all volatile compounds measured, except for hexanal, than mangoes harvested at the mature green stage and ripened postharvest. In a recent study, Lebrun et al. (2007) applied the electronic nose (e-nose) technology to discriminate among harvest maturities using the volatile profiles and showed that, upon ripening, fruit harvested later in the season (115 d after flowering) had different volatile profiles (i.e., less terpenes) than earlier-harvested fruit (61 d past flowering), which affected the flavor quality of the ripe fruit. Similarly, Lalel et al. (2003d) reported that mango fruit ripened on the tree (i.e., harvested at the fully ripe stage) had high concentrations of esters and β -ionone but lower terpene levels. The low concentration of terpenes in the fruit harvested at the fully ripe

stage may be due to the high volatility of these compounds when the fruit are exposed to high daytime field temperatures.

Chilling Injury

Mango, like many other tropical and subtropical fruits, is susceptible to chilling injury (CI). The appearance of CI symptoms is a function of plant species, degree of maturity, time and temperature of exposure, and environmental factors during and after refrigerated storage (Wang, 1982; Lizada, 1991). In general critical temperatures in a range of 5 to 15 °C have been reported for different mango varieties and the degree of ripening (Abou-Aziz et al., 1976b; Chaplin et al., 1991; Thomas and Joshi, 1988). Mohammed and Brecht (2002) reported that after storage for 18 d at 5°C immature ‘Tommy Atkins’ had higher incidence of CI than half-mature (trace of CI) or mature fruit (no trace of CI) upon transfer to 20°C. Mature green ‘Manila’ mangoes stored at 6 or 12 °C for 12 d showed CI symptoms 4 d after transfer to 25 °C for ripening. The symptoms were more pronounced in fruit stored at 6 °C (Hidalgo et al., 1997).

It is recognized that the primary response to chilling temperatures involves a decrease in fluidity of the micro-domains of cell membranes, increasing membrane rigidity and leading to damage to critical membrane proteins (Wang, 1982; Kays, 1991). Such changes in the membrane structure are associated with loss of cell compartmentalization, which initiates a cascade of secondary reactions, such as increased RR, interference in energy production, slowing protoplasmic streaming, alteration of cellular structure, and increase in permeability and solute leakage (Wang, 1982; Kays, 1991). An increase in cell membrane permeability was observed in ‘Tommy Atkins’ mangoes stored at 4 or 9 °C for 10 days, as indicated by a modest increase in electrolyte leakage.(Nyanjage et al., 1999).

The symptoms of CI in mango fruit are often not apparent at the low temperatures, but develop later, when the fruit are brought to warmer temperatures for ripening or are displayed for

sale (Brecht and Yahia, 2009). Symptoms of CI in mango fruit include brown-grayish discoloration of the peel, skin pitting and sunken areas, prominence and discoloration of lenticels, uneven ripening after removal from low temperature, and failure to develop normal aroma and flavor, or normal skin and flesh color upon ripening (Abou-Aziz et al. 1976b; Thomas and Oke, 1983; Chaplin et al., 1991; Lizada, 1991; Nair et al., 2004). In severe cases, internal breakdown may develop when the fruit are transferred to higher temperatures for ripening (Lizada, 1991). Moreover, CI may cause a loss of resistance to fungal diseases, as observed in 'Alphonso' mangoes (Thomas and Oke, 1983). CI also results in fruit with poor eating quality and decreased nutritional value. Ascorbic acid is one of the quality indices that typically decreases with time in certain commodities while in low temperature storage (Tatsumi et al., 2006). Also, Chhaptar et al. (1971) reported that 'Alphonso' mangoes exposed to chilling temperatures had significantly lower sugar content and less starch breakdown, associated with a decrease in amylase activity, compared with fruit stored at non-chilling temperature.

Chilling temperatures also adversely affect volatile production. Nair et al. (2004) reported that total monoterpene, sesquiterpenes, hydrocarbon, esters, aldehydes, norisoprenoids and total aroma volatiles were significantly reduced in 'Kensington Pride' mangoes stored at a chilling temperature (5 °C) compared to the fruit stored at a non-chilling temperature (15 °C). This finding was attributed to inhibition of the biosynthesis of fatty acids from which aroma volatiles are biosynthesized. Storage of mature green and tree ripe 'Irwin' mangoes at low temperature (5 °C) caused negligible reduction in terpenes, however, a significant increase in the biosynthesis of aldehydes (such as heptanal, decenal, and nonenal), was most likely responsible for the production of off odors during low temperature storage. Moreover, the incidence of off flavor

was more important in the mature green 'Irwin' mangoes than in the tree ripe mangoes stored at chilling temperature (Shivashankara et al., 2006).

Several postharvest treatments have been shown to be effective ways to alleviate CI in mango fruit during exposure to low temperatures. These treatments include temperature conditioning (Thomas and Oke, 1983), which is the gradual reduction of the storage temperature, intermittent warming (Lizada, 1991), whereby mangoes are exposed for short periods of time at a non-chilling temperature at which partial ripening occurs, heat treatment (McCollum et al., 1993; Pesis et al., 1997) involving either hot water or heated air, chemical treatments such as methyl jasmonate (González-Aguilar et al., 2001) and diphenylamine (Tasneem et al., 2004), as well as film packaging (Pesis et al., 1997; Tefera et al., 2007) and CA storage (Pesis et al., 1997) in which reduced O₂ and/or elevated CO₂ atmospheres alleviate CI symptom development.

Postharvest Environment and Treatments

World trade of fresh mangoes is restricted by the highly perishable nature of this climacteric fruit (Lizada, 1993; Mitra and Baldwin, 1997). Under tropical conditions, mature green (i.e., green but physiologically mature) mango fruit will ripen within 6 to 7 d and will become overripe and spoiled within 15 d after harvest when kept at 20 to 25 °C (Jacobi et al., 2001a, b, c). Fruit softening is the main cause of deterioration, developing rapidly after harvest and causing the fruit to be more susceptible to bruising and damage by pathogen invasion (Brecht et al., 2003). To facilitate transportation and storage, the majority of the mango fruit destined for raw and ripe consumption is harvested at the mature green stage and ripened during transit and storage between the grower and the consumer. Typically, after the required quarantine heat treatment, mature green mangoes will be cooled down and stored at low temperature during transportation and storage. Before reaching the consumer, mangoes may be subjected to an ethylene treatment at 18 to 22 °C in order to synchronize ripening and promote even fruit

coloration. Afterwards, mangoes are left to ripen to the desired ripeness stage for marketing. The application of MA or CA, by reducing the O₂ and/or raising the CO₂ level in the transportation or storage environment is sometimes used and, if combined with proper temperature management, can be an effective way to slow down the ripening processes (Bender, et al., 2000a, b).

This section will review the commonly used postharvest treatments and their influence on mango ripening and quality.

Storage and ripening temperatures

Storage temperature has received the widest attention among the various postharvest environmental factors as it plays an important role in the postharvest physiology and quality of horticultural crops. Despite providing effective action against fruit decay, low temperature reduces the RR (Q₁₀) that provides the energy to drive the reactions occurring during ripening (Mohammed and Brecht, 2002; Kays, 1991). In addition, low temperature slows down the quantitative and qualitative changes in the normal complement of enzymes that bring about the characteristic synthetic and degradative changes associated with ripening, such as softening, color changes, and flavor and compositional changes and thus increasing fruit postharvest life (Kays, 1991; Ponce de León et al., 1997).

Mangoes are chilling sensitive and prolonged storage periods at lower temperatures, may result in CI as previously discussed. Low temperature tolerance varies among mango cultivars and origins, and is greatly dependent on the physiological stage of the fruit at harvest. Normally, it is recommended that mature green (preclimacteric) mango fruit should be stored at temperatures between 10 and 15 °C, depending on cultivar, origin, and harvest maturity, while ripe fruit can tolerate lower temperatures of 8 to 10 °C, before being allowed to ripen at room temperature (Karla and Tandon, 1983; Thomas and Oke, 1983, Chaplin, 1988; Medlicott et al., 1990). Despite appearing to have a longer shelf life in terms of appearance and firmness than

fruit harvested at more advanced stages of maturity, less mature mangoes stored at low temperature will fail to develop the same desirable organoleptic characteristics upon ripening as the more physiologically advanced fruit (Medlicott and al., 1990; Morais and Assis, 2004).

For best quality, mangoes should be ripened at temperatures between 18 to 22 °C (O'Hare, 1995). Ripening at temperatures above this range will cause most mango cultivars to develop mottled skin, stronger than desirable flavor; temperatures below this range will cause mangoes to be more acidic with reduced color development (O'Hare, 1995). For example, 'Tommy Atkins' mangoes ripened between 22 to 32 °C showed good overall quality, while when ripened above or below this range, acidity and sugar content were adversely affected (Lizada, 1991).

Temperatures between 20 and 22 °C have been reported to be the optimum for development of typical aroma, flavor and other quality attributes in ripe 'Alphonso', 'Tommy Atkins', 'Haden', 'Irwin', 'Keitt', and 'Kent' mangoes (Lalel et al., 2003d). Highest fruit quality was achieved when 'Kensington' mangoes were ripened at temperatures between 18 and 22 °C while fruit ripened at 13 °C or 30 °C developed poor skin color, which was related to poor carotenoid development and high chlorophyll retention (O'Hare, 1995).

Quarantine heat treatments

Mango fruit are a host for the Tephritid fruit flies that are considered a quarantine risk by many importing countries (Jacobi et al., 2001a). Before entering the U.S. all mangoes must undergo a mandatory thermal quarantine treatment to eliminate invasive pests, most commonly the Mediterranean fruit fly (*Ceratitis capitata*), the Mexican fruit fly (*Anastrepha ludens*), and the Caribbean fruit fly (*Anastrepha suspensa* Leow).

In general, treatments that successfully kill the egg and larval stages of the fruit flies in the fresh fruit involve heating the fruit to a specific core temperature and maintaining the elevated temperature for a defined period of time (Jacobi et al., 2001b). For mango, the quarantine heat

treatment must reach and maintain the core pulp temperature between 45.6 and 46.1 °C for 10 min (USDA APHIS, 2005). To achieve this temperature, there are currently three methods approved by the U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS): vapor heat treatment (VHT), forced hot-air treatment (FHAT), and hot water immersion treatment (HWT) which is the treatment most widely used.

The use of HWT on a commercial scale for mango fruit is widespread in South America, Central America, and Mexico (Jacobi et al., 2001b). For mangoes imported into the U.S., the USDA APHIS requires a quarantine HWT consisting of immersion in 46 °C water for 65, 75, 90, or 110 min, depending on cultivar, weight, shape, and country of origin (Table 2-1).

For the HWT, water is used as a heat transfer medium. When properly circulated through a load of fruit, a uniform temperature profile is established in the water bath (Lurie, 1998). It is a relatively inexpensive method of heat disinfestation, and combines strict temperature control during treatment with ease of handling. Moreover, this method has the benefit of cleaning plant exudates from the fruit surface and killing decay organisms such as *Colletotrichum gloeosporioides*, which causes fruit anthracnose (Jacobi et al., 2001b; Tefera et al., 2007).

It is known that HWT can extend storability and marketing of fruit by inhibiting ripening or inducing resistance to CI and external skin damage during storage (Lurie, 1998; Paull and Chen, 2000; Jacobi et al., 1997; Fallik, 2004). Depending on the temperature and length of exposure, a heat treatment can delay, advance, decrease or increase the climacteric respiration peak as without affecting the magnitude of the respiratory climacteric (Lurie, 1998; McCullum et al., 1993). Heat treatment (50 °C for 60 min) was reported to accelerate ripening in 'Tommy Atkins' mango (Talcott et al., 2005). Nonetheless, if not executed under recommended conditions, HWT may cause heat injury to mangoes (Nyanjage et al., 1999).

Most of the concepts and experimental evidence that explain heat injury involve protein denaturation, disruption of protein synthesis and loss of membrane integrity (Paull and Chen, 2000). The severity and incidence of the symptoms depends on the mango cultivar, method of heat application, temperature differential, and duration of exposure (Jacobi et al., 2001b).

Heat injury may affect the external and internal tissues of mango fruit with skin damage, including skin scald and lenticels damage being commonly reported (Nyanjage et al., 1999; Lurie, 1998, Jacobi et al., 2001b) (Table 2-2). Accelerated water loss, and failure to achieve the desired peel color are also common symptoms of heat injury (Joyce et al., 1993). Internal damage can be detected by poor color development, abnormal softening, and lack of starch breakdown and development of internal cavitations. In addition, the fruit can fail to develop normal color and soften quickly, or show abnormal softening where some areas of the flesh remain hard while others soften (Lurie, 1998, Jacobi et al., 2001b). It was suggested that an increased activity of hydrolases was responsible for the changes in cell wall composition and tissue softening in heat treated 'Kensington' mangoes (Muda et al., 1995). Moreover, as observed in 'Kensington' and 'Carabao' mango cultivars, the maturity at the time of HWT influences the subsequent ripening-induced enzymes such as those involved in starch hydrolysis in the mesocarp. That is, higher incidence of 'spongy tissue', starchy areas with air pockets, developed within the mesocarp of heat treated immature mangoes compared with mature fruit, which showed no evidence of heat damaged tissue (Jacobi et al. 2001c; Esguerra et al., 1990).

Volatile production can also be affected by heat treatment. For example, in apples treated with hot air at 38 °C volatile production was inhibited immediately following the treatment but recovered afterwards (Lurie, 1998). Dang et al. (2008) observed that even though hot water dipping for 10 min at 52 °C did not significantly affect the volatile development of 'Kensington

Pride' mango (i.e., no significant difference in the concentration of total monoterpenes), there was a reduction in total sesquiterpene concentration and lower total lactone levels compared with the untreated fruit.

When heat treatments are applied to fruit at the proper maturity, performed under controlled conditions and followed by proper cooling to improve the recovery rate of treated fruit, they should not cause heat injury to mango fruit (Ponce de Leon et al., 1997). The marketability of mango may even be improved by the acceleration of certain ripening processes, such as increased yellowness and uniformity of skin color (McCullum et al., 1993; Jacobi et al., 2001b; Dang et al., 2008). In addition, mangoes undamaged by hot air or hot water treatments have comparable flavor, aroma, pH, total soluble solids, and total acidity levels than those of untreated fruit (Paull and Chen, 2000; Jacobi et al., 2001, Dang et al., 2008). For example, Ketsa et al. (2000) showed that hot air treated Thai mangoes (cv. Nam Dok Mai) stored at low temperature before ripening at 25 °C had lower incidence of disease, developed less CI and off flavor, and had similar ripe quality compared with the non hot air treated fruit.

Controlled atmosphere

Controlled atmospheres (CA) and modified atmospheres (MA) are extensively used for temporary storage or transportation of many horticultural crops including mango fruit. The principle of CA consists of reducing the concentration of O₂ and raising the concentration of CO₂ in the environment in order to reduce the metabolic rate of the produce. It is well documented that under optimal conditions, CA delays fruit ripening and the onset of senescence, and consequently reduces susceptibility to pathogen invasion. Moreover, in the case of climacteric fruits, low O₂ and/or high CO₂ delay ripening not solely through decreasing respiration per se, but largely through their inhibitory effects on ethylene biosynthesis and/or action (Beaudry, 1999).

However, too low O₂ levels and/or very high CO₂ levels can adversely affect produce quality. For example, symptoms of CO₂ injury in mango involve irreversible inhibition of ripening upon transfer to air at 20 °C. The symptoms are characterized by abnormal, grayish epidermal coloration, inhibition of normal aroma development, and development of off flavors (Bender et al., 2000a). Low O₂ injury also causes irreversible inhibition of ripening, especially inhibition of chlorophyll degradation, which results in abnormal color development (Bender et al., 2000a). Very low levels of O₂ and/or very high levels of CO₂ can also induce a shift from aerobic to anaerobic respiration, and can stimulate production of acetaldehyde and ethanol from pyruvate via the actions of pyruvate decarboxylase and alcohol dehydrogenase enzymes, respectively (Yahia and Vazquez-Moreno, 1993).

Mango cultivars vary greatly in their relative tolerance to reduced O₂ and elevated CO₂ concentrations. The levels and limits of O₂ and CO₂ tolerated by mangoes are affected by a number of factors; primarily cultivar, maturity stage, storage temperature, and storage time (Bender et al., 2000a, b).

In general, an environment with temperatures ranging from 10 to 15 °C with 90 to 95% relative humidity and 3 to 7% O₂ plus 5 to 8% CO₂ will increase the shelf life of mangoes (Kader, 2002b). For mature green 'Keitt' and 'Tommy Atkins' mangoes, Bender et al. (2000a) suggested an optimum atmosphere of 3 to 5% O₂ plus 5 to 8% CO₂ at 13 °C for a maximum shelf life of up to 3 wk. Tree-ripe fruit were also successfully stored for up to 3 wk at 8 °C with an atmosphere of 3 to 5% O₂ plus 5 to 8% CO₂ or at 5 °C with an atmosphere of 5% O₂ plus 10% CO₂. An improvement in storability of hot water treated 'Kent' and 'Tommy Atkins' mangoes stored at 12 °C under an atmosphere of 5% O₂ plus 10% CO₂ and 5% O₂ plus 5% CO₂, respectively, was also reported (Lizana and Ochagavia, 1997). However, Trinidad et al. (1997)

reported no beneficial effects of CA storage of non-HW treated mature green ‘Kent’ mangoes at 12 °C in 5% O₂ plus 5% CO₂ or 5% O₂ plus 10% CO₂. In fact, mangoes stored under the previous conditions developed strong off flavor due to elevated synthesis of acetaldehyde and ethanol during CA storage.

Fresh-cut Mango Fruit

The International Fresh-cut Produce Association defined 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 nutritional value, convenience, and flavor while maintaining freshness (Beaulieu and Gorny, 2004).

First available to restaurants, hospitals and other food service operators, fresh-cut fruits and vegetables are now readily available in supermarkets and are sold in numerous package sizes including individual (i.e., single serving) portions. In the USA, the fresh-cut industry is currently a multi-billion dollar business and is the fastest growing sector in the fresh produce business (Premier et al., 2007). This industry has led to new market opportunities such as the development of fresh-cut tropical and subtropical fruit products (Ngarmask et al., 2005).

Even though fresh-cut fruits and vegetables offer convenience, portion control, and labor savings, their marketability presents many challenges due to their very perishable nature (Gorny et al., 1999). There are, however, many ways to extend the shelf life and maintain the quality of fresh-cut products starting by choosing proper cultivars and ripeness stage, applying the best sanitation procedures during processing, using optimum storage temperature, and using adequate modified atmosphere packaging and/or using dips and coatings. The different ways to optimize fresh-cut product quality, particularly fresh-cut mango, as well as the physiological characteristics of these particular products will be discussed in the next sections.

Physiology and Quality

Fresh-cut products are wounded tissues that are prone to rapid deterioration. Therefore, their physiology differs from that of intact fruits and vegetables (Brecht, 1995; Toivonen and Brummell, 2008). Within seconds after removal of the protective skin (pericarp) and cutting the fruit into pieces, wound signals of different types (i.e., electrical, chemical, and hormonal) are sent through the tissues and initiate defense responses that promote wound healing, guard against bacterial attack, and generally protect cells from further stress. As a result of this peeling and cutting, the subcellular compartmentalization is disrupted at the cut surfaces, mixing substrates and enzymes, and initiating reactions that do not normally occur in the whole fruit or vegetable.

These physiological changes cause increased respiration rate and synthesis of wound-induced ethylene. They are also accompanied by loss of firmness and flavor, discoloration of cut surfaces, vitamin losses, and increase in water activity at the cut surface which accelerates water loss and enhances microbial growth (Beaulieu and Gorny, 2004; González-Aguilar et al., 2007b).

Respiration and wound-ethylene

Wounding and mechanical injuries result in increased rates of respiration and ethylene production. In fresh-cut fruit, the effects of processing on tissue metabolism may be observed very rapidly, often within minutes to a few hours after cutting (Toivonen and Brummell, 2008). In general, high respiration rates measured in fresh-cut fruits are directly associated with a rapid increase in the tissue metabolism and consequently with accelerated loss of acids, sugars, and other components that determine flavor quality and nutritive value (Cantwell and Suslow, 2002).

Nevertheless, wounding was found to have only a minor effect on the RR and ethylene production of fresh-cut mangoes. In fact, it was found that the peel is the major contributor to ethylene and CO₂ production (Chatanawarangoon, 2000). Preparation of fresh-cut mango cubes which involved peeling and cutting, resulted in ethylene and CO₂ production rates 1.5 times

lower than that of the whole fruit (Chatanawarangoon, 2000). Allong et al. (2001) reported that in 'Julie' and 'Graham' mangoes high RR were measured immediately after slicing but RR decreased significantly within the first 12 h of storage at 5 °C or 10 °C. Tovar et al. (2001) reported that although 'Kent' mango slices did not lose their ability to synthesize ethylene, the rates of ethylene produced during storage at 5, 13 or 24 °C were too low to be detected.

Furthermore, the wound response is usually greater in preclimacteric and climacteric fruit than in postclimacteric fruit. For example, slices from mature-green 'Julie' and 'Graham' mangoes had higher RR throughout storage at 5 °C or 10 °C than slices from firm-ripe fruit. Firm-ripe fruit RR decreased within 12 h of storage to rates that were similar to those of whole fruit (Allong et al., 2001).

Appearance

The visual quality of fresh-cut fruits and vegetables can be assessed using several attributes, including overall appearance, absence of defects, shape and size, glossiness, and most importantly, color. In fact, appearance is a primary quality attribute and greatly influences the consumer purchase decision. Many non visible factors have major effects on the appearance of fresh-cut products such as the initial maturity of the fruit (Beaulieu and Gorny, 2004), as well as wound-related effects and microbial colonization (Toivonen and Brummell, 2008).

Maturity of the fruit will greatly influence the initial color of the fresh-cut product. During ripening of mango fruit, carotenoid compounds are synthesized, leading to the development of yellow-orange color. Tovar et al. (2001) reported that slices from partially-ripe 'Kent' mango continued to ripen during post-cutting and storage, even though the extent of ripening never reached that of the whole fruit. This indicates that changes in color, not related to enzymatic browning, may occur during storage of fresh-cut mango. In fact, during storage at 5 °C, fresh-cut 'Ataulfo', 'Keitt', and 'Kent' mangoes showed changes in color associated with decreased L*

(lightness) and b^* values, indicating darkening of the slices (González-Aguilar, et al., 2007a). Similarly, during storage at 5 °C, ‘Tommy Atkins’ mango cubes became watery and the surface slightly discolored, however, cubes from ripe mangoes darkened more than those from less ripe fruit (Rattanapanone and Watada, 2000). ‘Kensington’ mango slices stored for 6 d at 3 °C developed a glassy appearance and darkened progressively. The type of darkening observed in fresh-cut mango seems to consistently develop throughout the flesh, in contrast to superficial browning that is occasionally observed on the sub-epidermal tissues (Souza et al., 2006).

Enzymatic browning is also responsible for changes in the color of fresh-cut fruit. This oxidative browning is caused by the enzyme polyphenol oxidase (PPO), which in the presence of O_2 converts phenolic compounds into dark-colored pigments. Abou-Aziz et al. (1976a) showed that the skin of ‘Paini’ mango contains considerably more phenolic compounds than the flesh, but the phenolic content decreases as the fruit ripen during storage. Thus, complete removal of the mango epidermal and sub-epidermal tissue with a very sharp knife is often recommended in order to avoid superficial brown discoloration of fresh-cut mango (Limbanyan et al., 1998; Gil et al., 2006). Moreover, enzymatic browning during fresh-cut mango storage can also occur near the endocarp side of the mango slices or chunks, since higher PPO and phenolic concentrations were detected at that location (Dea et al., 2007).

Texture

Wounding hastens senescence and induces tissue softening, which is considered a major shelf life limitation of fresh-cut fruit (Beaulieu and Gorny, 2004; Soliva-Fortuny and Martín-Belloso, 2003). Many of the textural changes occurring on fresh-cut fruit are a continuation of the normal ripening events that lead to softening (Toivonen and Brummell, 2008).

In whole fruit, cell walls undergo a natural degradation during fruit ripening, reducing cell wall firmness and intercellular adhesion. Softening is attributed to changes in turgor pressure and

in the structure and composition of cell walls, such as disassembly of the pectic matrix, mediated at least in part, by the sequential action of PME and PG enzymes (Beaulieu and Gorny, 2004; Pinheiro and Almeida, 2008). Also, softening may be attributable to the accumulation of osmotic solutes in the cell wall space and partly to postharvest water loss from ripening fruit (Toivonen and Brummell, 2008). Texture changes during mango ripening have been study extensively (Tandon and Karla, 1984; Chaplin et al 1990; Tucker, 1993; Muda et al., 1995; Yashoda et al., 2006), but not many reports have been published for fresh-cut mango texture changes.

Tissue softening is frequently the major problem limiting the shelf life of fresh-cut products (Agar et al., 1999), which even if refrigerated can become unacceptable in as little as 2 d for tropical fruit such as papaya (O'Connor et al., 1994). This accelerated softening is due to the induction of a number of hormonal (ethylene production) and other signals (hydraulic, electrical), which mediate defense and stress responses due to wounding (fresh-cut processing) (Toivonen and Brummell, 2008). These signals can then induce the activation of suites of defense stress genes and result in protein expression (Karakurt and Huber, 2003). It is well known, for example, that PG is an ethylene regulated enzyme and that its activity is increased by damage such as bruising (Toivonen and Brummell, 2008). In papaya, the levels of PG and β -galactosidase increased after cutting and remained higher than in intact fruit during subsequent storage (Karakurt and Huber, 2003).

Taste and aroma

Cut fruit products rapidly lose their typical flavor, even when stored under refrigerated conditions. It is well-known that cut fruit can develop staleness or loss of freshness within a day of refrigerated storage (Lamikanra and Richard, 2002). Taste and aroma quality are important attributes for consumers and therefore should be carefully evaluated when determining the shelf life of fresh-cut products, since an acceptable post-cutting visual appraisal does not necessarily

imply that a product has satisfactory flavor quality (Beaulieu and Gorny, 2004). Unfortunately, little sensory research has been published on the flavor quality of fresh-cut fruits, or other fresh-cut products, in contrast with extensive research that has been conducted on the flavor of whole fruit (Soliva-Fortuny and Martín-Belloso, 2003).

Establishing overall shelf life limits for fresh-cut fruit, taking flavor quality into consideration, is difficult since initial fruit variability, potential post-cutting treatments and/or packaging may affect flavor attributes differently (Beaulieu and Gorny, 2004). Moreover, acceptance of fresh-cut fruit products by retailers and consumers based on visual appearance is often associated with processing of immature or unripe fruit, which have less desirable taste and aroma (Beaulieu and Gorny, 2004).

Physical stresses that inevitably occur during fresh-cut processing result in enzymes coming in contact with substrates, contributing to changes in flavor. Such changes are mainly due to the loss of the principal flavor-related volatiles and the synthesis of stress related off flavor volatiles such as ethanol (Lamikanra et al., 2002; Hodges and Toivonen, 2008).

During storage of fresh-cut cantaloupe, the breakdown of esters is an early and important reaction step that, by providing precursors for the synthesis of secondary aroma volatile compounds, leads to loss of freshness (Lamikanra et al., 2002; Lamikanra and Richard, 2002; Beaulieu, 2005). Sothornvit and Rodsamran (2008) showed that longer storage time and higher temperature significantly damaged fresh-cut 'Nam Dokmai' mango flavor by favoring the development of off flavor associated with fermentative metabolites such as ethanol and acetaldehyde, which sensory panelists identified as the main attribute affecting flavor.

Even though sugars and acids are also important contributors to the overall flavor of fresh-cut fruit, associated biochemical parameters such as pH, acidity, soluble solids content, and

organic and amino acids were not recommended as good quality indicators (Lamikanra and Richard, 2002). For example, the amounts of such biochemical parameters measured in cut cantaloupe after 2 wk storage at 4 °C were not significantly different from the amounts present in the freshly cut fruit (Lamikanra and Richard, 2002). Similar observations have also been reported for fresh-cut mango (Ngarmsak et al., 2005; Gil et al. 2006; Donadon et al., 2004; Tovar et al., 2001).

Nutritional value

The initial nutritional value of a fresh-cut product can only be as good as the corresponding whole fruit. Thus, any preharvest or postharvest event that affects the quality of the whole fruit can jeopardize the final nutritional value of the fresh-cut product.

Wounding (i.e., cutting or slicing) can lead to the degradation of carotenoids (Wright and Kader, 1997a, b). When cells are disrupted by wounding, carotenoids are exposed to unfavorable conditions such as low pH, oxygen or light exposure that promote carotenoid degradation (Wright and Kader, 1997a). Ethylene production is also induced by wounding, hastening tissue senescence, including fatty acid oxidation by lipoxygenase (LOX), which in turn contributes to carotenoid co-oxidation (Wright and Kader, 1997a, b; Brecht et al., 2004). A reduction of 25% of the initial total carotenoid content of fresh-cut ‘Ataulfo’ mango was observed 9 d after slicing and storage at 5 °C (Gil et al., 2006).

Ascorbic acid (AA), a key marker compound for determining the extent of oxidation in fresh-cut vegetables and fruits, is also easily oxidized during fresh-cut processing. AA levels are affected by temperature, humidity, atmosphere composition, light intensity, heat, ascorbate oxidase enzyme, and pro-oxidant metals as well as cutting techniques, type of packaging and storage time (Brecht et al. 2004). However, under certain conditions AA content may increase during storage. For example, slices of ‘Kent’ and ‘Haden’ mangoes kept at 5 and 13 °C showed

increased ascorbate content with time, but the levels never reached that of whole fruit (Tovar et al., 2001). Similar results suggesting ascorbate synthesis were reported for ‘Alphonso’ mango, where an increase in AA concentration was observed during refrigerated storage at 5, 7, 10 and 15 °C (Thomas, 1975; Tovar et al., 2001). Gil et al. (2006) also reported an increase in AA content in fresh-cut slices and whole strawberries stored at 5 °C. Ôba et al. (1994) demonstrated that the activity of L-galactono- γ -lactone dehydrogenase was induced in injured tissue of potato tubers and that was considered to be responsible for ascorbate synthesis, suggesting that the same metabolic process may also occur in wounded mango tissue. Moreover, it has been suggested that increases in total AA content during storage of fruits and vegetables might be attributable to the synthesis of AA from monosaccharides, since in plants most AA synthesis starts with preformed D-glucose (Liao and Seib, 1988; Loewus and Loewus, 1987; Tolbert and Ward, 1982). Also, considering that the AA concentration is often reported on a fresh weight basis, an increase in AA may be influenced by water loss during storage rather than to actual increase in AA (Nunes et al., 1998).

Nevertheless, even if some nutritional losses are expected during the shelf life of a fresh-cut product, it has been shown that for several fresh-cut fruits (i.e., strawberry, persimmon, peach, papaya, mango, strawberry, pineapple, kiwi fruit, cantaloupe, and watermelon) the visual quality is appreciably reduced prior to when statistically significant nutrient loss has occurred (Wright and Kader, 1997a, b; Lamikanra and Richard, 2002; Rivera-López et al., 2005; Gil et al., 2006).

Factors Affecting Fresh-cut Mango Quality

The choice of the cultivar is of prime importance in determining the quality of the final fresh-cut product. As previously discussed different mango cultivars, may have different organoleptic and compositional qualities and besides may behave differently when processed

into fresh-cut products. For example, just after slicing ‘Carabao’ mango cubes showed lower respiration rate and higher firmness and L-ascorbic acid content than ‘Nam Dokmai’ mango cubes processed under identical conditions (Poubol and Izumi, 2005a, b).

Moreover, cultural practices, harvest maturity, postharvest handling, ripeness stage, and storage conditions (i.e., temperature, humidity, atmosphere) are all factors that may affect the wound response in fresh-cut tissues (Portela and Cantwell, 2001; Cantwell and Suslow, 2002; Beaulieu and Gorny, 2004).

Ripeness stage

It is well known that fruit physiological and metabolic activities differ depending on the ripeness stage (Allong et al., 2001). In general, when selecting less mature fruit for processing, a longer shelf life is often anticipated due to better firmness retention and decreased changes in appearance compared with processed ripe fruit. However, when using unripe fruit for processing, the amount and composition of volatiles present or released by the end product, and consequently the flavor, will not be satisfactory and the final fresh-cut product will lack good sensory quality (Gorny et al, 2000; Beaulieu and Lea, 2003; Beaulieu and Gorny, 2004). An over-mature fruit on the other hand will have superior eating quality but shorter shelf life (Watada and Qi, 1999). Thus, determining the optimal ripeness stage that combines acceptable shelf life and eating quality is the key to successful commercialization of fresh-cut fruits and vegetables.

Beaulieu and Lea (2003) showed that the shelf life of fresh-cut mango cubes prepared from firm ripe ‘Keitt’ and ‘Palmer’ fruit (9 to 10% SSC and flesh firmness of 86 to 92 N penetration force with 11-mm probe) and stored at 4 °C was limited to 11 d due to lack of aroma. In contrast, cubes prepared from soft ripe fruit (12 to 14% SSC and 27 to 29 N flesh firmness) had superior color and better initial flavor, but the shelf life was reduced to 7 d due to poor and mushy texture,

followed by loss of aroma and general discoloration. Allong et al. (2000) reported that for 'Julie' mango, slices from half-ripe fruit stored at 5 °C or 10 °C and firm-ripe fruit stored at 5 °C had a shelf life of 8 d based on an overall acceptability score. Similarly for half ripe 'Graham' mango slices stored at 5°C and firm ripe slices stored at 5°C and 10 °C, a shelf life of 8 d was also achieved. However, for firm ripe 'Julie' mango slices stored at 10 °C and half ripe 'Graham' mango slices stored at 5 °C, the shelf life was limited to 4 d due to poor appearance and low SSC/TA ratio. They concluded that, if stored at 5°C, half-ripe mangoes would be ideal for fresh-cut purposes as they maintained acceptable texture, appearance, and taste after processing when stored at 5 °C.

Processing practices

The sharpness of the cutting blade used for processing greatly affects the quality attributes of fresh-cut products (Hodges and Toivonen, 2008). That is, as a consequence of membrane rupture, a blunt blade will cause accumulation of liquid in the intercellular spaces, which can in turn reduce gas diffusion and induce anaerobic respiration, producing off odor due to ethanol synthesis, whereas a sharp blade minimizes tissue damage and associated wound stress responses such as increased respiration and ethylene production (Portela and Cantwell, 2001; González-Aguilar et al., 2007a; Oms-Oliu et al., 2008).

The cutting shape may also influence the metabolism of fresh-cut tissue. For example, when stored at 5 °C or 10 °C, slices from fresh-cut papaya had better SSC retention, lower weight loss, and better overall quality index than cubes from the same papaya fruit (Riviera-Lopez et al., 2005). Moreover, trapezoidal cuts were shown to extend melon shelf life compared to slices or cylinder cuts (Aguyao et al., 2004).

Washing after cutting may improve firmness retention of fresh-cut fruit by removing from the cut surfaces solutes and stress-related signaling compounds such as acetaldehyde and

phenolics (Toivonen and Brummell, 2008). Moreover, washing increases the activities of catalase, peroxidase and superoxide dismutase enzymes which are involved in scavenging oxygen free radicals that contribute to membrane injury (Toivonen and Brummell, 2008).

Temperature

Good temperature management during postharvest handling, processing and distribution is of prime importance to help preserve the quality and safety of fresh-cut fruits and vegetables (Zhang, 2007). Moreover, temperature has a direct relationship with the shelf life of fresh-cut products. That is, the lower the temperature the longer the shelf life of the fresh-cut fruit or vegetable. For example, Rattanapanone et al.(2001) reported that the marketable period of fresh-cut ‘Tommy Atkins’ and ‘Kent’ mango cubes was 3 to 5 d at 10 °C, but could be extended to 5 to 8 d at 5 °C. Similarly, the shelf life of ‘Carabao’ mango cubes ranged from 4 to 6 d at 5 °C, but was only 3 to 4 d when stored at 13 °C (Poubol and Izumi, 2003).

Since fresh-cut products are stored or displayed at the retail store for only for a short period of time and because they are extremely perishable compared with the whole fruit or vegetable, exposure to a temperature that causes a slight amount of CI is preferred over a temperature that causes more rapid deterioration due to ripening and senescence (Watada and Qi, 1999). A significant number of fresh-cut fruits do not seem to be as chilling sensitive as the corresponding intact fruit. Furthermore, CI symptoms are often only manifested when fruit are transferred to non-chilling temperatures and may never become visible if the product is maintained exclusively at chilling temperatures. For instance, no visible CI symptoms were observed in fresh-cut ‘Keitt’ and ‘Palmer’ mango cubes when stored for 14 d at 4 °C (Beaulieu and Lea, 2003). Allong et al. (2001) also reported that mature green ‘Julie’ and ‘Graham’ mangoes slices stored at 5 °C did not develop visible symptoms of CI in mature-green fruit, while in the corresponding whole fruit, severe epidermal pitting was observed after 6 d of storage at 5 °C. Although visible symptoms of

CI were not evident, it is likely that the mature-green mango slices underwent non-visible physiological changes as a result of exposure to the chilling temperature. In fact, some authors have suggested that fresh-cut products may be subject to CI despite little visual manifestation of injury. For example, higher respiration rates of fresh-cut products compared with the corresponding whole fruit may in some cases, and to some extent be an indicator of CI (Brecht et al., 2004). Moreover, poor flavor retention in fresh-cut products, especially fruits, due to the inhibition of aroma volatile production is a widely recognized problem and may also be caused by CI (Beaulieu and Gorny, 2004).

Sanitation and microbiological quality

Although there have been a number of reports about microbiological contamination involving whole fresh produce and fresh-cut vegetables (Abadias et al., 2008), there is still little information about microbial contamination of fresh-cut fruits. Microbial growth on fresh produce is affected by several external factors, namely product origin, agricultural production practices, harvesting and processing techniques, initial quality and maturity of the fruit, transportation mode, storage temperature, and the use of CA, MA or MAP (Ngarmsak et al., 2006). On fresh-cut fruits, the outflow of nutrients to the cut surfaces, the active metabolism of fruit tissues, as well as the absence of treatments able to ensure microbial stability and the confinement of the fresh-cut product, all tend to favor an increase in the growth of naturally occurring microbial populations present on fresh-cut products (Lanciotti et al., 2004).

Beaulieu and Gorny (2004) indicated that aerobic plate counts, total plate counts and, more significantly, yeast and mold counts correlated closely with the shelf life of fresh-cut fruits. Microbial growth can be very fast on fresh-cut fruits, and can quickly lead to unacceptable losses in quality (Premier et al., 2007). The low pH of most fruits restricts the natural microflora to acid-tolerant microorganisms, such as fungi and lactic acid bacteria. However, fruits may also be

a vehicle for non acid-tolerant microorganisms, although these may not grow (Brackett, 1987). Moreover, while the acidic pH of most fruits prevents the development of most pathogens they are not totally without risk (Brackett, 1987). Human pathogens may gain entry to fruit products when animal fertilizers or contaminated irrigation water or water used for rinsing come into contact with fruits during production and processing (Brackett, 1987; Bordini et al., 2007).

In fresh-cut products, such as fruits, microorganism minimum detection levels based on visual observation of spoilage may vary depending on the sort of microorganism and type of product. For example, in ‘Carabao’ mango cubes, mesophilic and psychrotrophic aerobic and lactic bacterial counts detection level was reached at 2.4 log CFU/g, while for yeast the detection level was 3.0 log CFU/g (Poubol and Izumi; 2005a, b). In fresh-cut slices from firm-ripe ‘Julie’ and ‘Graham’ microbial populations became visible at counts at or above 4.0 log CFU/g. For fresh-cut melon, spoilage became detectable by consumers when yeast counts reached a level above 5.0 log (CFU/g) and aerobic psychrophilic counts reached 8.0 log (CFU/g) (Oms-Oliu et al., 2008). In melon cubes, the cause of off odor was associated with yeast and mold counts above 7.0 log (CFU/g) (Bai et al., 2003).

In the U.S, other than the common sense that no human pathogen should be present in a fresh-cut product, no legislation is currently imposed on the fresh-cut produce industry. In Spain however, the hygienic regulations for processing, distribution and commerce of prepared meals recommend a maximum limit for mesophilic bacteria of 7 log (CFU/g) for meals prepared from raw vegetables (In Real Decreto 3484/2000 as reported by Montero-Calderón et al., 2008).

Optimizing Fresh-cut Mango Quality

Several chemical and/or physical treatments may be applied in synergy with proper handling practices such as washing and sanitizing the whole fruit before processing, use of sharp blades for cutting, removal of free water from the processed product, and maintenance of low

temperature conditions to prolong the shelf life of fresh-cut mango. Namely, treatments with calcium salts, antioxidants and/or enzymatic browning inhibitors, edible coatings, MAP, or any combination of the above treatments have been effectively used to prolong shelf life of fresh-cut mango (González-Aguilar et al., 2007a; Rattanapanone et al, 2001; Plotto et al., 2006).

Chemical treatments

Sanitizers are commonly used in fresh-cut processing operations in order to prevent contamination of food products by maintaining low levels of microorganism in the environment. Washing with chlorinated water, the most widely employed sanitation procedure is accomplished by immersing the product in solutions containing between 50 and 200 $\mu\text{L/L}$ free chlorine during less than 5 min (Ngarmsak et al., 2006; Rico et al., 2007). Even though the application of chlorine is not considered very effective in reducing microbial levels in contaminated tissues, chlorine reduces microbial loads in the water and prevents cross-contamination. In addition, chlorine rinse acts directly on the tissues by inhibiting browning reactions while it also helps remove cellular contents present on the cut surfaces of fruits and vegetables that may promote browning (Brecht et al., 1993). The use of chlorinated water solutions have also been used to reduce the microbial load on fresh-cut mango (Martinez-Ferrer et al., 2002; Ngarmsak et al., 2006). However, there is some controversy about using chlorine as antimicrobial agent due to the possible formation of carcinogenic chlorinated compounds in the rinsing water, namely chloramines and trihalomethanes (Rico et al., 2007). Other sanitizers that have been used to reduce microbial loads in fresh-cut fruits and vegetables is chlorine dioxide (ClO_2), a strong oxidizing and sanitizing agent that has a broad and high biocidal effectiveness and also less affected than chlorine by pH and organic matter (Zhang, 2007). Hydrogen peroxide (H_2O_2), acidified sodium chloride, peroxyacetic acid, and organic acids have also been used to sanitize fresh-cut fruits and vegetables (Brecht et al., 2004; Narciso and Plotto, 2005; Ngarmsak et al.,

2006; Rico et al., 2007). Peroxyacetic acid is the most commonly used sanitizer in commercial fresh-cut processing facilities.

Organic acids (e.g. lactic acid, citric acid, acetic acid, tartaric acid) have been described as having a strong antimicrobial action against psychrophilic and mesophilic microorganism in fresh-cut fruits and vegetables (Rico et al., 2007). The powerful antimicrobial actions of organic acids is attributed to their capacity to reduce external pH disrupt membrane transport and/or permeability, cause anion accumulation, and reduce the internal cellular pH by dissociation of hydrogen ions from the acid fraction (Rico et al., 2007).

Reducing agents, most commonly AA or its isomer erythorbic acid, isoascorbate or sodium erythorbate, are some of the most commonly used agents to reduce or eliminate fresh-cut cut surface discoloration, which is mainly attributed to enzymatic browning, caused by the action of polyphenol oxidase on phenolic compounds (Brecht et al., 2004; Beaulieu and Gorny, 2004). The use of isoascorbic acid has been shown to be more effective than AA or N-acetylcysteine, another reducing agent, in preventing tissue softening, surface browning, and decay on fresh-cut pineapple slices, extending shelf life to 14 d compared to a shelf life of 9 d for the non-treated slices (control) (González-Aguilar et al., 2004).

Calcium and its salts have been used to decrease tissue softening of a great variety of fresh cut fruits (Soliva-Fortuny and Martin-Belloso, 2003; Toivonen and Brummell, 2008; Aguayo et al., 2008). These compounds help maintain cell wall integrity by interacting with pectin to form calcium pectate, and help reduce tissue softening by cross-linking with cell wall and middle lamella pectins (Luna-Guzman et al., 1999; Rico et al., 2007). A combination of calcium chloride, AA and citric acid significantly reduced color deterioration and loss of firmness,

without affecting sensory characteristics of fresh-cut ‘Ataulfo’, ‘Keitt’ and ‘Kent’ mangoes stored at 5 °C (González-Aguilar et al., 2007a).

Edible coatings have also been used as a means to improve whole and fresh-cut fruit product quality. These coatings are thin, edible films, and do not negatively affect the quality attributes of fruits and vegetables (González-Aguilar et al., 2007a). By reducing gas exchange between the product and the environment, edible coatings provide a barrier against external elements and therefore increase shelf life by reducing loss of water, flavor and aroma and by reducing solute migration toward the cuticle (González-Aguilar et al., 2007a). Polysaccharide-based and carnauba wax coatings have been reported to markedly reduce water loss and to extend shelf life of fresh-cut mangoes (Baldwin et al., 1999). However, the necessity of labeling the product as containing “artificial chemical compounds” may be impediments to their use on “natural” fresh-cut products (Brecht et al., 2004).

Physical treatments

Along with good temperature management, the use of ozone, radiation, UV light, and MAP, are physical treatments that can be applied to fresh-cut products in order to extend shelf life. Ozone is a strong antimicrobial agent with high reactivity and penetrability, and spontaneously decomposes to O₂ in air, or to O₂ + H₂O in water (Rico et al., 2007). Low dose gamma irradiation is also very effective in reducing bacterial, parasitic, and protozoan pathogens in raw food (Rico et al., 2007). A maximum irradiation level of 1.0 kGy was approved by the U.S. FDA for use on fruits and vegetables at. Another effective antimicrobial agent is ultraviolet (UV) light, referred to as UV-A, UV-B or UV-C according to the wavelength from shortest to longest, respectively. UV light damages the DNA of microorganisms as well as acting indirectly against spoilage pathogens due to the induction of resistance mechanisms in different fruits and

vegetables (Boynton, 2004). UV-C irradiation was reported to improve the total antioxidant capacity of fresh-cut mango (González-Aguilar et al., 2007a).

Low O₂ and/or elevated CO₂ plus saturated or near-saturated humidity environments generated in MAP have been successfully used to extend fresh-cut produce shelf life, by either reducing product respiration rates and/or reducing ethylene action and biosynthesis, and by reducing browning reactions on cut surfaces, reducing microbial growth, and inhibiting loss of water (Gorny et al., 2002). MAP concepts will be discussed in the following section.

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) is a system designed to maintain a respiring product in a favorable atmosphere, usually incorporating reduced O₂ and elevated CO₂. The modified atmosphere (MA) is created and maintained through the interplay of product respiration and gas permeation through the package (Yam and Lee, 1995; Mir and Beaudry, 2004).

A MA can be created either passively or actively. A passive MAP system is generated by allowing the desired atmosphere to develop naturally as a consequence of the product respiration and the diffusion of gases through the selected film or perforations (Moleyar and Narasimham 1994; Yam and Lee, 1995). In passive MAP systems, the development of a desirable atmosphere composition may take a considerable amount of time (up to several days), depending on the product respiration rate and the void volume within the package (Rodov et al., 2007). On the other hand, in an active MAP system the atmosphere is created rapidly by flushing the headspace of the package with a desired gas mixture, usually consisting of N₂ mixed with O₂ and CO₂ concentrations that are near the anticipated equilibrium concentrations of those gases. In both cases, once the MA is established, the dynamic equilibrium of respiration and permeation maintain the appropriate atmosphere.

MAP and Fresh-cut Fruit

MAP systems in association with low temperature are extensively used to extend shelf life of fresh-cut products by reducing respiration rate, cell wall degradation, water loss, phenolic oxidation, microbial growth, and ethylene biosynthesis and action (Beaudry, 2004; Gorny 2003). Due to the active metabolism of fresh-cut fruits, MAP alters the atmosphere composition surrounding the product, affecting the concentrations of O₂, CO₂, water vapor, and other volatiles compounds that impact the physiology and final quality of the product (Forney, 2007).

MAP Design

Good understanding of the dynamic interactions among the product, the environment, and the package are required in the design of MAP. A design established by trial-and-error will often lead to poor performance and product injury (Yam and Lee, 1995). The design of a useful and efficient MAP system, suitable for a particular fresh-cut product, requires knowledge of the atmosphere combination(s) that will best maintain the quality of the product and extend shelf life without inducing physiological disorders or microbial decay. In order to determine the best atmosphere combination(s) to be used in a MAP system, preliminary controlled atmosphere (CA) experiments are usually conducted in which the product is exposed to different atmosphere and temperature combinations and respiration rate measured throughout a determined length of time . The atmosphere combinations required to obtain a positive or negative effect on the product are dependent upon and vary among commodities and cultivars (Forney, 2007). When the atmosphere combinations that extend product quality while avoiding the onset of fermentative metabolism are established, it is then possible to select the most suitable packaging material that will help maintain the desired MA during marketing.

Respiratory requirements

The tolerance of a specific fresh-cut fruit to reduced O₂ and/or elevated CO₂ concentrations may be evaluated by the onset of fermentative metabolism. The external lower O₂ limit (LOL) (i.e., the lowest O₂ concentration surrounding the product that does not induce fermentation) depends on several factors such as: species, cultivar, maturity, CO₂ concentration, temperature and time (Wills et al., 2001; Brecht et al., 2004). The LOL is usually higher as storage temperature and duration increase (Kader, 2002).

A simple indicator of fermentation is an increase in the respiratory quotient (RQ), which is the ratio between CO₂ production and O₂ consumption rates. It is in general assumed that the normal RQ values range from 0.7 to 1.3 depending on the predominant metabolic substrates (i.e., sugars, organic acids or lipids); however, when fermentative metabolism occurs, the RQ is much greater than 1.0 (Fonseca et al., 2002). Moreover, fermentative metabolism induces the production of acetaldehyde, ethanol, ethyl acetate, and lactate which contribute to the development of off flavors and odors as well as physical injury (Kays 1991; Mattheis and Fellman, 2000).

The tolerance to and physiological effects of elevated CO₂ are highly variable and depend on the commodity, maturity or ripeness stage, and storage temperature. Besides, elevated CO₂ may alter the response of the product to reduced O₂ concentrations since with an increase of CO₂ concentration the tolerance limits to reduced O₂ decrease (Watkins, 2000; Kader, 2002b; Kader and Saltveit, 2003). In some cases, elevated CO₂ may cause discoloration and softening, and induce fermentative metabolism (Mir and Beaudry, 2004). Nevertheless, elevated CO₂ concentration (> 8 to 10 kPa) may inhibit ethylene action and can also effectively inhibit microorganism growth.

Holding fresh-cut slices of 'Tommy Atkins', 'Haden' and 'Palmer' mango in 10 kPa O₂ plus 10 kPa CO₂ at 5 °C retarded browning and softening (Limbanyen et al., 1998). Also, holding 'Tommy Atkins' and 'Kent' mango cubes in 2 or 4 kPa O₂ plus 10 kPa CO₂ extended the shelf life by 1 d at 10°C and 2 d at 5°C, based on shear force, pH, SSC, and color. Those conditions also retarded browning, water soaked appearance, and microbial growth. Table 2 to 3 gives a summary of the effects of different O₂/CO₂ combinations (CA or MAP) on the physiology and quality of different fresh-cut mango cultivars.

MAP and temperature

Temperature is extremely important in MAP design as it strongly affects the physiology of the fresh-cut fruit and also affects the permeability properties of the package. Low temperature and MAP work in concert to maintain freshness, extend shelf life, ensure safety, and promote marketability of fresh-cut fruit. Unfortunately, temperature abuses during shipping, storage, and retail display are very common (Leblanc et al., 1996; Gorny, 2003, Nunes et al., 2009).

Consequently, an increase in temperature during handling of products in MAP will cause an increase in the respiration rate of the product at that occurs at a faster rate than the increase in permeation of the package, resulting in depletion of O₂ and increase of CO₂ that may reach injurious levels (Jacxsens et al., 2002). Thus, a film that produces a favorable atmosphere at the optimal temperature for a particular fresh-cut product may, if exposed to higher temperatures, cause the development of an anaerobic atmosphere (low O₂ and high CO₂) inside the package, leading to metabolic disorders and fermentative metabolism, with possible growth of anaerobic or facultative anaerobic pathogens that can compromise product safety (Mahajan et al., 2007).

The development of high humidity levels inside the package can be another problem associated with MAP and usually results from exposure of packages to temperature fluctuations during handling. Fluctuating temperature favors water condensation on the film and on the

product contained within the package when the temperature drops below the dew point temperature within the package, promoting the development of decay and also blocking O₂ diffusion into the tissues and through the film and as a result causing product fermentation (Brecht et al., 2003). Repeated temperature fluctuations above and below the in-package dew point temperature promote product drying by creating a cycle of water vapor loss from the product followed by water condensation.

To mitigate MAP-temperature problems several methods can be used. The choice of a polymer film with a high temperature sensitivity factor for O₂ transmission can be one alternative, or otherwise the development of a package system that senses either the environment or the physiological status of the enclosed product and responds by increasing the permeability to O₂ can be another alternative. A third approach, used by many manufacturers as the simplest solution, is a MAP system designed to function (i.e., avoid product fermentative metabolism) at the highest temperature typically encountered during distribution and retail display. (Silva et al., 1999; Beaudry, 2000; Mir and Beaudry, 2004).

Permeability characteristics

The biggest challenge when designing a MAP system is the choice of a packaging film with appropriate O₂ and CO₂ transmission rates (OTR and CDTR respectively) that will match the product respiratory requirements. The gas transmission rates of the film are a very important factor, because the respiration of the product contained within the package creates the gas gradients across the film barrier, which in turn provide the driving force for the gasses to move into and out of the package (Mir and Beaudry, 2004). The gas transmission rates are, however, dependent on several factors such as package construction characteristics (polymer composition, film thickness, and layer ratio); optimal target atmosphere (O₂ consumption rate) and

temperature; volume of product: film surface area ratio, package void volume, printing, and anti-fog coating (Lange, 2000).

Many mathematical models have been developed to predict the equilibrium atmospheres inside MAP and help in the package system design (Tanner et al., 2001; Fonseca et al., 2002). However, these models cannot fully account for the variability in product respiration rates that may occur during handling and storage, variations in atmosphere composition, and biological variations (Fonseca et al., 2002; Forney, 2007). Nevertheless, these models use the principles of O₂ and CO₂ mass balances to predict the interactions among the respiration of the product, the permeability of the package, and the environment (Yam and Lee, 1995). Basically, the rate at which O₂ or CO₂ concentrations change inside the package is equal to the rate of O₂ or CO₂ permeating into the package and the rate at which O₂ and CO₂ are consumed or generated by respiration. The mass balance equations for O₂ and CO₂, which are useful in describing the process of passive atmosphere modification during exposure of the MAP system to temperature fluctuations (i.e., describing an unsteady state), are first order linear differential equations (Yam and Lee, 1995):

$$([M_{O_2} PV] / 100RT) (d[O_2]_i / dt) = (S P_{O_2} / L) ([O_2]_o - [O_2]_i) P_{atm} - W R_{O_2} \quad (2.1)$$

$$([M_{CO_2} PV] / 100RT) (d[CO_2]_i / dt) = (S P_{CO_2} / L) ([CO_2]_i - [CO_2]_o) P_{atm} - W R_{CO_2} \quad (2.2)$$

where, M_{O₂} and M_{CO₂} are the molecular weight of O₂ (0.032 kg/Mole) and CO₂ (0.044 kg/Mole); *P*, the pressure in the package; *V*, the free volume in package (mL); *R*, the gas constant (8.314 J/mol K); *T*, the absolute temperature (°K); *S*, the package surface area (m²); *P*_{O₂} and *P*_{CO₂}, the permeability to O₂ or CO₂ (mg mil/m² h atm); *L*, the thickness of the film (mm); [O₂] and [CO₂], the % O₂ or CO₂ concentrations; *P*_{atm}, the pressure of 1 atmosphere; *W*, the product weight (kg)

and R_{O_2} or R_{CO_2} , the rate of O_2 consumption or CO_2 evolution ($mg/kg \cdot h$) and with the subscripts “i” and “o” that denote the inside and outside of the package.

When a steady state or equilibrium condition inside the package is reached, meaning that the CO_2 evolution rate equals the efflux rate of CO_2 through the package, and the O_2 consumption rate equals the influx rate of O_2 through the package, usually occurring within 2 d (Yam and Lee, 1995), the equations 2.1 and 2.2 are reduced to the steady-state equations:

$$W R_{O_2} = (S P_{O_2} / L) ([O_2]_o - [O_2]_i) P_{atm} \quad (2.3)$$

$$W R_{CO_2} = (S P_{CO_2} / L) ([CO_2]_i - [CO_2]_o) P_{atm} \quad (2.4)$$

These two last equations can be used as preliminary design equations for a MAP system. In fact, when the product and the temperature are selected, the required permeabilities P_{O_2} and P_{CO_2} , can be determined, since from the eleven variables in equations (2.1) and (2.2), six variables are already known. That is, R_{O_2} , R_{CO_2} were determined *a priori* by CA experiments; $[O_2]_i$ and $[CO_2]_i$ are assumed to be the optimum O_2 and CO_2 concentrations for the product at a specific temperature; $[O_2]_o$ and $[CO_2]_o$ are 21% and 0.03% respectively; the weight (W), the surface (S) and the thickness (L) of the film can be specified arbitrarily within practical limits.

Several types of polymeric films with different permeability characteristics are available for MAP, but several limitations must be considered. For example, the CDTR for most available films are 2 to 6 times greater than the OTR, producing an atmosphere that is low in O_2 and CO_2 (Forney, 2007). On the other hand, perforated films have O_2 and CO_2 exchange rates of approximately 1:1 which is desirable when high CO_2 concentrations are required. Also, the permeability characteristics of the film may be affected by time, temperature, and relative humidity. For example, the permeability of films increases when temperature increases, while the gas diffusion through perforations is relatively insensitive to temperature changes within the

physiological range (Mir and Beaudry, 2004). Moreover, the marketability of fresh-cut products also requires that the film provide good visual characteristics (i.e., it must be printable, clear, and tear resistant).

To address some of the limitations of using non-perforated or perforated films for MAP, active packages are being developed (Forney, 2007). Some of them are designed to respond to environmental changes (i.e., temperature, atmosphere composition) or to physiological changes in the product such as evolution of volatiles (i.e., ethanol and ethylene). However, the cost associated with such technologies must be taken into consideration when selecting the type of MAP system according to the market value of the specific fresh-cut product.

Table 2-1. Hot water treatments as prescribed by USDA-APHIS for heat disinfestations of mango fruit based on their origin, shape, and weight.

Origin of fruit	Fruit shape	Fruit weight (grams)	Dip time (minutes)
Puerto Rico, US Virgin Islands, or West Indies	Flat, elongated varieties ¹	Up to 400	65
		400 to 570	75
	Rounded varieties ²	Up to 500	75
		500 to 700	90
		701 to 900	110
Mexico or Central America (north of and including Costa Rica)	Flat, elongated varieties ¹	Up to 375	65
		400 to 570	75
	Rounded varieties ²	Up to 500	75
		500 to 700	90
		701 to 900	110
Panama, South America or West Indies islands of Aruba, Bonaire, Curacao, Margarita, Tortuga, or Trinidad and Tobago	Flat, elongated varieties ¹	Up to 375	65
		375 to 570	75
	Rounded varieties ²	Up to 425	75
		425 to 650	90

¹Cultivars: 'Ataulfo', 'Carabao', 'Carrot', 'Frances', 'Irwin', 'Manila', 'Zill'.

²Cultivars: 'Haden', 'Keitt', 'Kent', 'Tommy Atkins'.

Table 2-2. Symptoms of heat injury in selected mango cultivars

Mango cultivar	Heat injury	Heat treatment	Reference
'Carabao'	Internal breakdown in inner mesocarp of ripe fruit; white, starchy, tough lesions, fermented odor	VHT 46 °C for 10 min	Esguerra et al. (1990)
'Keitt'	Internal breakdown and internal cavities formed near the seed surrounded by hard unripe tissue; development of modified atmosphere in the center of the fruit leading to off flavor development	VHT 46 °C for 3 to 4 h or VHT 48 °C for 5h	Mitcham and McDonald (1993)
'Kensington'	Uneven skin color development with ripening; skin scalding; starch retention in the form of layers and spots in ripe fruit; internal cavities	HWT 48 °C for 7.5 to 30 min	Jacobi and Wong (1992)
'Kensington'	Starch regions retained in ripened mesocarp; internal cavities	HWT 47 °C for 25 min	Joyce et al. (1993)
'Kensington', 'Irwin', 'Haden', 'Tommy Atkins', 'Strawberry'	Skin scalding	HWT 47 °C for 25 min	Smith and Chin (1989)
'Tommy Atkins'	Peel pitting	FHAT 51.5 °C for 125 min	Miller and McDonald. (1991)

WHT: hot water treatment; VHT: vapor heat treatment; FHAT: forced hot air treatment

Table 2-3. Reported effects of controlled atmospheres and modified atmosphere packaging on fresh-cut mango physiology and quality

Mango cultivars	[O ₂]*	[CO ₂]*	CA or MAP	Storage T°	Effects	References
'Kent'; and 'Tommy Atkins' (cubes)	4 and 2%	10 %	CA	5 and 10 °C	Extended shelf life 1 d at 10°C and 2 d at 5°C, based on shear force, pH, SSC and color Retarded browning, water soaked appearance, and microbial growth CA was beneficial in maintaining quality, but temperature was found to be more effective than CA.	Rattanapanone et al. 2001
'Carabao' and 'Nam Dok Mai' (cubes)	0.5, 1 and 2%	Not tested	CA	1, 5 and 13 °C	Beneficial to maintain the quality of Carabao mango cubes stored at 5 or 13°C. Extended shelf life of Nam Dok Mai by 1 d at 1, 5 and 13°C In both cases retarded browning discoloration and water soaking appearance	Poubol and Izumi, 2005a
	Air	3, 5 and 10%	CA	5 and 13 °C	Extended shelf life by 3d at 5°C and 1d at 13°C for Carabao and 1d at 5°C for Nam Dokmai without deleterious effects on respiration rates, ethanol content, texture, L-ascorbic acid and bacterial count 10% CO ₂ is recommended to reduce bacterial population and bacterial diversity when storage temperature abuse occurred. Longest shelf life (25 d at 5°C) compared to 100% O ₂ , vacuum packaging and air control. Microbial growth was inhibited, no anaerobic respiration detected	
'Keitt' (cubes)	4%	10%	MAP	5 °C	With 2.5% O ₂ : inhibition of tissue darkening and development of "glassy" appearance seen at normal O ₂ levels Enhanced CO ₂ had little impact on general appearance Weight loss tended to be slightly higher at 2.5% O ₂ than in 21% (dryer air flow)	Martinez-Ferrer et al., 2002
'Kensington' (slices)	2.5 and 21%	0, 5, 10, 20 and 40 % (overall 10 combinations)	CA	3 °C	With 2.5% O ₂ : inhibition of tissue darkening and development of "glassy" appearance seen at normal O ₂ levels Enhanced CO ₂ had little impact on general appearance Weight loss tended to be slightly higher at 2.5% O ₂ than in 21% (dryer air flow)	Souza et al., 2006
'Tommy Atkins', 'Haden' and 'Palmer' (slices)	10%	10%	CA	5 °C	Retarded softening and browning	Limbanyen et al., 1998

* Reduced O₂ and/or elevated CO₂ atmospheres were balanced with nitrogen.

CHAPTER 3 OPTIMAL RIPENESS STAGE FOR PROCESSING 'KENT' MANGO INTO FRESH-CUT SLICES

Introduction

Maximum shelf life and best eating quality are both extremely important attributes for a successful commercialization of fresh-cut fruits, and are greatly influenced by the initial ripeness stage of the fruit as well as by the cutting procedures (Gorny et al. 1999; Allong et al., 2001). Within the fresh-cut industry, the establishment of the end of shelf life has largely been based on appearance, neglecting flavor and texture (Beaulieu and Gorny, 2004). In order to maximize shelf life, firmer and less ripe fruit are usually processed due to their better firmness retention and minimal change in appearance during handling compared with softer, riper fruit (Hodges and Toivonen, 2008). However, less ripe fruit have normally not attained optimal aroma, sweetness, texture, and/or color that is appealing to the consumer, which can be detrimental for the commercialization of a relatively unfamiliar tropical fresh-cut fruit such as mango.

Because both physiological and metabolic activities change during ripening, fruit of different ripeness stages respond differently to peeling and slicing (Allong et al., 2001). Several studies have shown that the more advanced the stage of ripeness the more susceptible the fruit is to wounding, hence to fresh-cut processing (Brecht, 1995; Watada and Qi, 1999; Gorny et al., 2000; Soliva-Fortuny and Martín-Belloso, 2003; Beirão-da-Costa et al., 2006). Moreover, during ripening, changes in the aroma volatiles profile also occur. For example, in 'Palmer' and 'Keitt' mangoes, terpenes were present in higher concentrations in firm-ripe fruit compared with soft-ripe fruit, which in turn had higher contents of esters and alcohols, mainly ethanol (Beaulieu et Lea, 2003).

Consumers judge the quality of a fresh-cut fruit product when making a purchase decision based on appearance and freshness at the time of purchase. However, repeated purchases of the

same product will depend upon consumer satisfaction in terms of texture and flavor (Rico et al., 2007). Therefore, selection of a cultivar with inherently excellent quality potential and selection of an optimal ripeness stage for fresh-cut processing, based on appearance, sensory, and compositional quality are a key decisions for successful fresh-cut fruit product marketability.

Commonly, fruit firmness, peel color, and SSC are the most common criteria to measure mango ripeness stage for fresh-cut processing (Allong et al., 2000; Tovar et al., 2001; Beaulieu et Lea, 2003; Gil et al., 2006; Riviera-López et al., 2005; González-Aguilar et a., 2007a).

However, as seen in the previous chapter, a wide range of physiological changes occur during mango ripening, which affects the eating quality. For example, the change in the relative sweetness (sugars) and tartness (acids) of the fruit with ripening is an important flavor attribute for mango (Brecht et al., 2004). The ratio of sugars to acids is normally considered a good indicator of sweetness perception by the consumer. In general, the higher the ratio, the sweeter the slices would be perceived to be. This aspect of flavor quality is determined by measuring the soluble solids content (SSC) of the juice with a refractometer and the acidity of the juice by titration, and is expressed as the SSC/titratable acidity (SSC/TA) ratio.

The aim of this study was to determine the optimal ripeness stage for processing and marketing ‘Kent’ mango into a high quality fresh-cut product, with maximum shelf life based on appearance, subjective visual and aroma quality, and composition.

Materials and Methods

Fruit Source and Initial Selection

This study was conducted twice [Experiment 1 (E1) and Experiment 2 (E2)] during the Peruvian ‘Kent’ mango season (January-February 2008). For each experiment, 210 mature green ‘Kent’ mangos size 9 (E1) or 8 (E2), were bought from a local market in Gainesville, Florida

(E1) or received directly from a wholesaler in Miami, and shipped by refrigerated truck to the Postharvest Laboratory at the University of Florida in Gainesville (E2).

Upon reception, all mangoes were stored at 20 °C and the fruit firmness was measured daily until the firmness distribution of 40 fruit randomly sampled from the lot reached a mean of approximately 35 N (ripeness stage A), 30 N (ripeness stage B), or 25 N (ripeness stage C) (Figure 3-1). Firmness was measured nondestructively using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a flat plate probe (5-cm diameter) and equipped with a 50-kg load cell. After establishing zero force contact between the probe and the equatorial region of the fruit, the probe was driven with a crosshead speed of 50 mm /min, and the force was recorded at 2.5 mm deformation.

When the 40 randomly sampled mangoes reached one of the desired firmness values (ripeness stage A, B or C), a total of 80 mangos were randomly sampled from the ripening room, and for further selection a number was assigned to each mango. Firmness of all 80 fruit was initially measured following the same procedure described above. Then, a 5.0-mm deep slice was removed from the equatorial side of the mango using a mandolin slicer, in order to measure first the flesh color using a reflectance colorimeter (Minolta CR 200b, Minolta Corp., Ramsey, NJ) and subsequently to measure the total SSC of the juice squeezed from the slice using a digital refractometer (Palette PR-101, 0 to 45 °Brix, Atago Co. LTD, Tokyo, Japan).

From those 80 fruit, 36 mangoes with comparable firmness near the sample mean were selected, as determined by the normal distribution plot using JMP[®] (JMP-SAS software 7.0, Cary, NC) and stored overnight at 5 °C to be processed into fresh-cut slices the next morning. The remaining 44 fruit were discarded. The same process was repeated until the three desired

ripeness stages were obtained and none of the original fruit sample remained. Figure 3-2 illustrates the selection process of the fruit designated as ripeness stage A in E2.

Fresh-cut Processing

The mangoes were held overnight in a refrigerated and sanitized room at 5 °C. Before being peeled, mangoes received a 3-min, 100 µL/L chlorinated 5 °C water bath, adjusted to pH 7 with 2N citric acid solution. After peeling, mangoes were submerged in another 100 µL/L chlorinated, 5 °C, pH 7 water bath before being drained and cut into slices. Each mango for fresh-cut was halved and cut into 8 slices. All mango slices from mangoes from the same treatment were pooled together and randomized before being distributed into containers made of polyethylene terephthalate (PETE). The leak free snap-on cover was pierced with a 1.5-cm diameter hole that was filled with a cotton ball to both assure good air circulation and avoid microbial contamination. Whole fruit controls and a total of 8 random slices per container were stored at 5 °C for 10 d.

Visual Analysis

The visual quality of each sample of fresh-cut mango slices was assessed on days 0, 2, 5, 7 and 10 at 5 °C using a 9-point visual rating scales for overall color, edge tissue damage, spoilage, aroma, and desiccation with higher numbers corresponding to better quality as previously reported by Beaulieu and Lea (2003) (Table 3-1). All visual evaluations were performed by the same trained person.

Respiration Rate Measurements

Four containers of fresh-cut and four whole fruit for each treatment were all individually sealed for 1 to 2 h in 2-L plastic containers prior to sampling for respiration determinations. A 0.5-mL headspace sample was withdrawn by syringe through a rubber septum, initially and after sealing, and carbon dioxide concentration was determined using a Gow-Mac (Series 580, Bridge

Water, N.J.) gas chromatograph (GC) equipped with a thermal conductivity detector (TCD) and a 1219 x 3.18 mm, 80/100 mesh Porapak Q column. The detector and injector were operated at ambient conditions (26 to 27 °C), the oven temperature was at 40 °C, and the carrier gas (helium) flow rate was 30 mL/min at 275.8 kPa. Respiration rate measurements were conducted using the same samples on days 0, 2, 4 and 8 at 5 °C for H1 and on days 0, 3, 4, 6 and 8 at 5 °C for H2.

Conductivity Analysis - Electrolyte Leakage

Twelve mesocarp tissue plugs (5 mm diameter × 10 mm) per 8-slice sample were excised from fresh-cut slices using a No. 5 brass cork borer. The mesocarp plugs were cleaned of damaged cells by rinsing gently with deionized water before being incubated in 30 mL of 0.7 mol/L isotonic mannitol in water at room temperature for 3 h. The electrical conductivity of the solutions was measured using an YSI Conductivity Instrument (YSI Inc., Yellow Springs, OH). Total electrolytes were determined after freezing at -20 °C, thawing, and re-warming to room temperature. Three measurements per sample were taken. Electrolyte leakage was expressed as a percent of the conductivity of total tissue electrolytes.

Firmness Evaluation

Firmness of fresh-cut slices was measured using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a 1-cm diameter convex probe, and equipped with a 50-kg load cell. After establishing zero force contact between the probe and the largest flat side of each slice, the probe was driven with a crosshead speed of 50 mm/min. The force was recorded at 2.5 mm deformation. The measurements were made on the cut surface of four fresh-cut slices per sample. The results were reported in Newtons ($N = m/kg \cdot s^2$).

Flesh Color Measurements

Superficial flesh color measurements (L^*, a^*, b^*) were taken with a reflectance colorimeter (Minolta CR 200b, Minolta Corp., Ramsey, NJ) on the cut surface of mango slices. There were

10 measurements made per treatment from 10 slices from four containers. Numerical values of a^* and b^* were converted into hue angle ($H^\circ = \tan^{-1}b^*/a^*$) (Francis, 1980).

Compositional Measurements

Samples destined for compositional measurements were homogenized, and kept frozen at -20 °C in air-tight, zipper-lock, plastic freezer bags until analysis.

pH, titratable acidity and soluble solids content

Each individual sample replicate was thawed, and a 50-g aliquot of the tissue slurry was centrifuged at $17,600 \times g$ for 25 min. The clear juice was decanted from the centrifuge tubes and the pH and TA were determined using an automatic titrimer (Metrohm Ion Analysis Ltd, model 719 S Titrino, Switzerland). Aliquots (6.00 g) of mango juice were diluted with 50 mL distilled water and the TA determined by titration with 0.1 N sodium hydroxide (NaOH) to an end point of pH 8.2. The TA was expressed as percent citric acid. The SSC of the resulting clear juice samples was determined with an Abbe refractometer (Cambridge Instruments, Inc., Buffalo, NY) and expressed as percent juice fresh weight.

Total ascorbic acid

For each sample, 2.5 g of homogenized mango tissue were mixed with 50 mL of a mixture of 6% metaphosphoric acid and 2N acetic acid. Samples were kept frozen in glass containers at -20 °C until analysis. After thawing, the fruit-acid mixture was centrifuged for 20 min at $17,600 \times g$. The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of total ascorbic acid (TAA) was calculated from absorbance measured at 540 nm using a standard curve prepared from a serial dilution of an ascorbic acid standard solution (Sigma-Aldrich Co., St. Louis, MO). Concentration of ascorbic acid was expressed in terms of fresh weight.

Volatiles

Volatile samples were prepared by combining 1.5 g of mango homogenate with 1.5 g of distilled water in a 10-mL gas chromatography vial, crimp-capped and flash frozen in liquid nitrogen. The samples were stored at -20 °C before analysis. The headspace analysis was conducted using an Agilent 6890N GC equipped with a flame ionization detector (FID) and a 0.53mm×30m, 1.0µm film thickness, polar Stabilwax column. Volatiles were quantified using calibration curves obtained from deodorized mango homogenate, where volatiles are first removed by rotary evaporation (Malundo et al., 1997; Plotto et al., 2006), then spiked with five levels of authentic standards (Sigma-Aldrich). Sixteen aroma volatiles were measured and quantified: acetaldehyde, hexanal, acetone, methanol, ethanol, α -pinene, β -pinene, limonene, *p*-cymene, α -copaene, 3-carene, myrcene, terpinolene, caryophyllene, ethyl acetate, ethyl butyrate.

Statistical Analysis

A completely randomized design was used in this study comprising the evaluation or analysis of composite samples of 8 slices from 4 replicated containers per treatment and sampling time. Color and firmness measurements were, however, made on 16 slices taken from 4 replicated containers per treatment and sampling time. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. Statistical analysis was performed using the PC-SAS software package (SAS-Institute, 1985). Analysis of variance (ANOVA), using the General Linear Model, was conducted to identify significant main effects due to experiments (E1, E2), ripeness stages (A, B, C) and storage duration(0, 2, 4, 6, 8, 10 d). Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level.

Results

Initial Ripeness Stage Selections

Initial texture measurements of the whole mango fruit upon arrival at the laboratory showed that fruit from the first experiment (E1) were less firm (62.4 ± 3.0 N) than those from the second experiment (E2) (96.8 ± 5.8 N) (Figure 3-1). After approximately 4, 6 and 8 d at 20°C mangoes from both experiments reached the desired firmness for ripeness stages A, B and C, respectively.

No significant correlation was found between the firmness of whole fruit and flesh color or SSC (data not shown). In this study, the SSC of mangos from E1 was significantly lower than that of fruit from E2 and the flesh color expressed as hue angle was not markedly different for each ripeness stage (Table 3-2).

Subjective Evaluation

It is important to mention that the limit of marketability of the fresh-cut mango was established when one or more of the quality attributes evaluated reached a score of 5. Although at this limit the fresh-cut mango was considered unsuitable for retail sale, with partial trimming it could still be considered edible, depending on consumer preferences.

Storage duration and ripeness stage had significant effects on the visual quality (ANOVA table not shown). The subjective scores attributed to mango slices from both experiments decreased consistently during storage regardless of the ripeness stage, as shown in Figure 3-3, which presents the changes in visual quality of the fresh-cut slices at the different ripeness stages during storage at 5 °C.

Mango slices from fruit of ripeness stage A had a shelf life of 10 d at 5°C (Figure 3-4). In both experiments, the visual quality of the mango slices was limited by a progressive drying of the slice surface and a detectable off odor. In E1, the shelf life was also limited by the overall

color as mango slices showed a pale discoloration or bleaching, while in E2 signs of spoilage also limited the product marketability after 10 d of storage at 5°C. The shelf life of mango slices from fruit of ripeness stage B was 7 d and was also limited by progressive drying of the slice surface and a detectable off odor. Additionally, in E2, the shelf life was limited by edge tissue damage, in which the slices became slightly soggy and showed a darker color. Mango slices from fruit of ripeness stage C had the shortest shelf life (5 d). The quality of the stage C slices was mainly limited by obvious edge tissue damage as well as slimy surfaces on some of the mango slices sign of spoilage. In addition, in E1 the shelf life of mango slices was limited by darkening of the color, overripe appearance, and detectable off odor.

Respiration Rate Measurements

Overall, experiments (E1 or E2) and ripeness stages (A, B, or C) had no significant effect on the respiration rate (RR) of the fresh-cut mangoes (Table 3-3). The RR decreased during storage with the highest rate measured on day 0 and the lowest on days 5 and 7 (Figure 3-5). The significant interaction between E (experiments) and R (ripeness stages) was due to higher RR measured in slices from ripeness stage A and C in E1, compared to E2, while slices of ripeness stage B had lower RR in E1 compared to E2.

Moreover, the significant interaction between E and storage days (D) resulted from the overall higher initial RR (on days 0 and 2) in E1 compared to E2 (all ripeness stages included), whereas for the rest of the storage duration E2 had in general higher RR than E1. Also, the R×D interaction indicates that the RR of fresh-cut mango slices from the different ripeness stages varied within the storage. On day 0, higher RR were measured in stage B slices in E2 compared to stages C and A (lowest RR), while for days 5, 7 and 10, stage B mango slices had lower RR compared to A (higher RR followed by stage C).

Electrolyte Leakage

The EL levels of mango slices varied significantly between the experiments and ripeness stages, and during storage (Table 3-3). In general, the EL increased with storage duration. Mango slices from E2 had higher EL values than those from E1 (Figure 3-5). In E2, the slices of ripeness stage C had higher or equal EL than stage B, which had higher levels than slices of stage A ($C \geq B > A$). The significant interaction between E and R was attributable to the fact that no significant differences in the EL levels among the ripeness stages were noticed in E1. However, in E2 lower EL levels were found in slices of ripeness stage A compared to similar, higher EL levels in slices of mangoes from stages B and C.

Firmness

The firmness of mango slices varied significantly between the experiments and ripeness stages, and during storage (Table 3-3). The overall firmness of mango slices was higher in E2 than in E1, and slices from ripeness stage A were firmer than those from stages B and C (Figure 3-5). In general, firmness slightly decreased from days 0 to 5, and then remained quite constant for the rest of the storage duration. The significant interaction between E and R can be explained by the fact that firmness of slices from ripeness stages B and C was higher in E2 than E1, but slices from ripeness stage A were firmer in E1 than in E2.

Flesh Color

In this study, the hue angle value measured at the surface of the mango slices varied significantly between the experiments, the ripeness stages, and during storage (Table 3-3). For both experiments, mango slices from ripeness stage A had higher hue angle values than slices from the other ripeness stages, indicating that the Stage A slices were more yellow (Figure 3-6). In general, hue angles of mango slices decreased during storage at 5 °C. The significant interactions between E and R were due to the higher hue angle value for the slices of ripeness

stage A in E1 compared to E2, while similar hues were measured for stages B and C among the experiments. Moreover, during storage, slices of mangoes from ripeness stages A, B, and C maintained distinctly different hue values, except on day 2 for E2, when slices of ripeness stages A and B had similar hues, which may explain the general significant interaction between R and D (Table 3-3).

Lightness of mango slices varied significantly between the experiments and ripeness stages (Table 3-3). In general, slices of ripeness stage C showed a rapid decrease in L* value during storage compared with the other ripeness stages (Figure 3-6). On the other hand, L* value of slices from ripeness stage B, remained quite constant throughout storage, while in E2 slices from ripeness stage A showed a slight increase in lightness after 7 d, which was associated with the bleaching effect observed during the visual subjective evaluations (Figure 3-5).

Fruit Composition

pH and soluble solids content / titratable acidity ratio

Mango slice pH varied significantly between the experiments and ripeness stages, and during storage (Table 3-3). Slices of mangoes from E1 had higher pH than those from E2 and in general, as ripening progressed pH slightly increased (Figure 3-7). Slices of ripeness stage A had the highest pH and stage C the lowest. Larger differences in pH within the ripeness stages were observed in E1 than in E2. Moreover, slices of ripeness stage A had higher pH in E2 than E1, while for the other stages, the pH was higher in E1 than in E2, explaining the significant interaction between E and R.

In this study, the SSC/TA ratio varied significantly between the ripeness stages and during storage (Table 3-3, Figure 3-7). Compared to mango slices from ripeness stage B, slices from ripeness stage C had higher SSC/TA ratio, while those from stage A had lower SSC/TA. For all the ripeness stages, the SSC/TA ratio tended to increase during storage as TA declined while

SSC changed little (data not shown), indicating that organic acids were probably preferentially used as the substrate for respiration.

Total ascorbic acid

The TAA content of mango slices varied significantly between the experiments and ripeness stages, and during storage (Table 3-3). In general, TAA content increased during storage, but was higher in mango slices from E2 than E1 (Figure 3-7). However, when the experiments were analyzed separately, no significant effect of ripeness stage or storage duration was observed in E1, whereas in E2, slices from ripeness stage C had significantly higher TAA than slices from ripeness stages A and B. Moreover, in E2, only the slices from ripeness stage A showed a slight increase in TAA during storage at 5°C, while no significant change in TAA was observed in the slices from riper fruit (ripeness stage C).

Volatiles

Overall, no significant differences between experiments (and/or ripeness stages and/or during storage) were observed for methanol, limonene, ρ -cymene and caryophyllene (data not shown). Figures 3-8 to 3-11 present the changes in volatile content for all volatiles that were affected by one or more of the main effects of this study during storage at 5 °C.

In general, higher contents of hexanal, acetone, 3-carene, and ethyl acetate were measured in E1, while in E2 higher contents of acetaldehyde, ethanol, α -pinene, myrcene, and α -terpinolene were measured.

Mango ripeness stage had a significant effect on the concentration of most of the volatiles measured (Table 3-4). Ripeness stage A had higher contents of hexanal, acetone, β -pinene, 3-carene, α -copaene, ethyl butyrate, and ethyl acetate compared to similar, lower levels in ripeness stages B and C. Acetaldehyde content increased with ripening, with higher levels found in ripeness stage C and the lowest in A. Ethanol content was highest in ripeness stage C, and was of

comparable, lower levels in A and B. Higher concentrations of α -terpinolene were measured in slices of ripeness stages B and C than in stage A. Moreover, the concentrations of α -pinene and myrcene were higher in ripeness stage B and lower in stage A.

The storage duration also affected the concentration of some volatiles (Table 5-3). Overall, acetaldehyde and ethanol increased during storage at 5°C, while hexanal, acetone, and ethyl butyrate were significantly lower on day 10 than earlier in storage. The content of α -copaene decreased in E1 from day 0 to day 2, but remained constant thereafter, while lower α -copaene was measured in E2 on day 2 (significant interaction E×D) (Table 5-3).

Discussion

Initial Ripeness Stage Selection

The initial mango ripeness stage selection criterion was established based on the nondestructive aspects of the method used as well as its consistency and reliability among the different lots of fruit. Therefore, whole fruit firmness was the method preferred over SSC or flesh color (hue angle). Previous studies have suggested the use of SSC alone or in combination with flesh firmness as the best method to establish the initial ripeness stage for processing of fresh-cut mangoes (Allong et al., 2000; Beaulieu and Lea, 2003). However, in this study, a significant difference in the SSC and in the hue angle of fruit between experiments was observed, whereas little or no significant difference in the SSC was measured between the different ripeness (i.e., firmness) stages (Table 3-2). The difference in the SSC and hue angle between experiments may be attributable to the different origin of each fruit lot. In fact, it is known that fruit quality and composition varies greatly among different origins and cultivation practices (Kays, 1991). In E1, the higher SSC content measured in mango slices from fruit of ripeness stage A may be attributable to the fact that, when extracting the juice from the peel side

excised from the fruit, cell residues and potentially residual starch may have influenced and increased the SSC measurements.

Thus, this study has shown that it is more accurate to use firmness measurements as a way to select a uniform fruit sample from different batches rather than to select ripeness stages based on SSC or flesh color.

Ripeness Stages and Fresh-cut Quality

The ripeness stage of the whole fruit before processing into slices significantly affected the duration of the shelf life of the fresh-cut mango slices. For slices from fruit of ripeness stages A and B, the visual quality was limited by progressive drying of the surface and detectable off odor, while for slices from fruit of ripeness stage C, texture became softer and led rapidly to obvious edge damage and spoilage. Therefore, the shelf life was limited to 10, 7, and 5 d for ripeness stages A, B and C, respectively. Similar results were previously reported in the literature. For example, Beaulieu and Lea (2003) showed that the shelf life of soft-ripe ‘Keitt’ and ‘Palmer’ mango cubes was limited by poor texture and mushy tissue, followed by loss of aroma and general discoloration, while the shelf life of the firm-ripe cubes was limited by development of off odor and desiccation. Gorny et al. (1998) also reported shorter shelf life for overripe fresh-cut peaches and nectarines compared to less ripe fruit based on visual quality, with the overripe fruit developing darker color and retaining less visible structural integrity and general visual appeal than mature-green fruit.

The initial ripeness stage of the fruit used for fresh-cut processing is a critical factor as it may impact several metabolic and physiologic activities such as respiration rate and ethylene production, and consequently changes in the overall quality of fresh-cut products, such as changes in appearance, color and texture (Soliva-Fortuny et al., 2004). However, in this study, initial ripeness stage of the whole fruit had no significant effect on the RR of the fresh-cut mango

slices. All treatments showed high RR on day 0, probably due to the wound response, but then RR decreased significantly on day 2, remaining constant for the rest of the storage duration. These results are in agreement with those reported by Allong et al (2001), in which a significant decrease in RR was measured for firm-ripe and soft-ripe 'Julie' and 'Graham' mango slices after 12 h of storage at 5°C and remain steady for the rest of the storage duration.

The ripeness stage of the whole fruit had a significant effect on the EL, slice firmness, flesh color, pH, SSC/TA ratio, TAA, and on several aroma volatiles compounds measured. The EL levels in fresh-cut slices increased with ripening, which parallels the changes in cell membrane integrity and permeability that occur as a result of fruit ripening and/or tissue injury (; Nyanjage et al., 1999). Initial slice firmness was significantly different between the ripeness stages and a slight decrease in firmness was measured during storage of mango slices from different ripeness stages. The flesh color also varied with the stage of fruit ripeness. Slices from stage C (i.e., more ripe) fruit had a more yellow-orange color than the less ripe fruit (A and B), which were more yellow, probably due to increased carotenoid content as the fruit ripened (Moore, 2003; Yashoda et al., 2006). The 'bleaching' effect observed on the slices of ripeness stage A may be attributable to surface desiccation (Watada and Qi, 1999). Besides, because the slices from fruit of ripeness stage A were not initially as juicy as the slices from the other, more advanced, ripeness stages, they lost their glossiness and color more rapidly.

In this study, the pH and the SSC/TA ratio of the mango slices increased with ripening as previously reported by Medlicott and Thompson (1985), Sharaf et al. (1989), and Allong et al, (2000), which suggests that mango slices processed at ripeness stage C, with higher SSC/TA ratio and higher pH, would be perceived as sweeter than slices from ripeness stage A, and thus, would initially be more desirable in terms of eating quality. The lack of significance between the

ripeness stages and between experiments regarding TAA measurements, suggests that this parameter is not suitable for ripeness stage differentiation.

Ripeness Stages and Aroma Volatiles

Initial aroma volatile differences were observed between the experiments E1 and E2. On day 0, the amount of acetaldehyde, ethanol, α -pinene, α -terpinolene, and limonene were higher in fruit from E2 than from E1 (Figure 3-8, 3-9, 3-10). When those volatiles were analyzed within each experiment, only acetaldehyde (Figure 3-8) and α -terpinolene (Figure 3-10) showed a significant difference between the different ripeness stages. In fact, in both experiments higher acetaldehyde content was measured in slices from fruit of ripeness stage C than in the other stages. On the other hand, in E1, α -terpinolene concentration was significantly lower in slices from fruit of ripeness stage A than in stages B and C, while in E2 no significant differences were observed in the α -terpinolene content.

Overall, slices of mango from ripeness stage A had higher contents of ketone, terpenes, and esters, mainly characterized by higher contents of acetone, 3-carene, and ethyl acetate, respectively. Slices from fruit of ripeness stage C showed the highest content of alcohols and aldehydes, mainly ethanol and acetaldehyde. Slices of fruit from ripeness stage B had an intermediate concentration of aldehydes compared to stages A and C; similar concentration of alcohols as A; similar content of ketones and esters as C, and lower or equal amount of terpenes than ripeness stage C. Such results are in accordance with the findings of Beaulieu et Lea (2003), in which cubes from soft-ripe mangos had higher content of ethanol and aldehydes than firm-ripe cubes, which in contrast had the highest content of terpenes, with 3-carene being the dominant aroma volatile.

Aroma volatile compounds are the major constituents of fruit aroma, which in turn have a great influence on consumer perception and preference and, thus, are important in defining fruit

quality. In this study, the high content of ketone (acetone) and terpenes combined with the lower pH and SSC/TA ratio, may have given the mango slices from fruit of ripeness stage A more acidic, green, and piney flavor compared with the other ripeness stages (Beaulieu et Lea, 2003). On the other hand, even if the slices processed at ripeness stage C may have been perceived as tasting sweeter and less acidic than the other ripeness stages, the high ethanol and acetaldehyde contents that accumulated during storage may lead to a fermented aroma that might not be appealing to consumers. Therefore, it is likely that slices processed from fruit of ripeness stage B, which had lower terpene content than slices processed at ripeness stage A, and lower alcohol content than ripeness stage C, and had an intermediate SSC/TA ratio, possess the best aroma that may reflect the optimal eating quality of 'Kent' mango fruit.

Conclusion

This study determined the optimal initial ripeness stage of the whole fruit for processing 'Kent' mangoes into fresh-cut slices. Selection of the initial ripeness stage was based on whole fruit firmness, which was more reliable than the use of flesh color or SSC. The maximum shelf life based on subjective visual evaluation was 10, 7, and 5 d for ripeness stages A (35 N), B (30N) and C (25 N), respectively.

Consumers judge the quality of fresh-cut fruit on the basis of appearance and freshness at the time of purchase. But repeated purchases depend upon the consumer's satisfaction in terms of texture, flavor, and aroma (Rico et al., 2007). Therefore, a ripeness stage equal to an initial firmness of 30 N would be the recommended stage for processing 'Kent' mangoes into fresh-cut slices in order to assure maintenance of the best possible overall quality and maximum shelf life under refrigerated conditions. At that ripeness stage, a maximum shelf life of 7 d can be expected if the product is stored under refrigerated conditions and kept at 5°C. Moreover, the product

would have an intermediate firmness, pH, and SSC/TA ratio, and a well balanced aroma volatile profile.

Table 3-1. Visual quality rating scale for fresh-cut mango slices.

Quality attributes	Subjective score ^a				
	9	7	5 ^b	3	1
Overall color (loss of yellow or change to orange color)	Very fresh and “normal” appearing (per variety). (Tree-ripe)	Slightly visible loss of bright yellow/orange color	Visibly more pale color and slightly pale flesh	Obvious pale or whitish discoloration	Severely pale “washed-out” appearance
Edge tissue damage, vein browning	None, very fresh and normal appearance; no visible veins.	Small % visible vein browning	Edges slightly soggy or water-soaked with darker color, or darkening of veins; slight texture loss	Obvious edge damage, like compression bruising; veins markedly browning; gooey appearance	Severe edge damage with obvious water-soaking or associated soggy appearance; brown veins
Spoilage	None	Minor; perhaps increased spore counts, but via lab testing	Noticeable by trained person, but most consumers may not observe	Slimy surfaces on some pieces with a slightly “gooey” appearance	Obvious mold, or slimy surfaces and “gooey” pieces (bacterial)
Aroma	Normal, characteristic, fresh mango (peachy, coconut, almond, caramel)	Normal to perhaps slightly “flat” or “off” to a trained person (piney, green mango/woody)	Detectable “off odor” (i.e. when package opened, but dissipates); still edible	Off odors moderate (slightly anaerobic), becoming offensive	Off odors strong. The product is “fermented-like” (musty)
Desiccation	None; very fresh with a wet glean	Slightly visible water loss on edges, but only to a trained person	Progressive drying on cube edges, often undetected by consumers	Little to no surface glean, slightly dehydrated surfaces	Severe, tissue drying, similar to blush on sliced carrots

(^a) Generally: 9, excellent; 7, very good; 5, limit, good; 3, fair, absolute limit for household use with trimming and/ or loss; 1, poor, inedible. (^b) Five is the minimum subjective score (limit) for marketing any product

Table 3-2. Mean of whole fruit firmness, flesh soluble solids content, and flesh hue angle values for whole mango fruit at different ripeness stages.

Experiment	Ripeness stage	Firmness (N)	SSC [†] (%)	Hue angle [†] (H°)
E1	A	36.13 a	15.81 a	92.26 a
	B	30.39 b	14.37 b	90.94 b
	C	25.02 c	14.12 b	90.40 b
E2	A	35.49 a	18.18 a	90.47ab
	B	30.30 b	18.00 a	90.69 a
	C	25.01 c	17.44 a	89.21 b

[†]Significant difference between the experiments (P<0.01);

95

Table 3-3. ANOVA table - Quality parameters for fresh-cut 'Kent' mango.

Source of variations	d.f.	F-value							
		RR (mg/kg·h)	EL (% of total)	Firmness (N)	Hue angle (H°)	Lightness (L*)	pH	SSC/TA	TAA (mg/100 fruit tissue)
E	1	1.71 ns	133.92 ***	8.66**	4.67*	4.61 ns	39.33***	3.76 ns	38.53***
R	2	0.68 ns	5.06 **	139.55***	61.94***	13.99***	997.37***	209.42***	3.82*
D	4	275.47 ***	10.80 ***	10.35***	23.52***	15.40***	11.18***	8.34***	3.42*
E×R	2	30.28***	6.94 **	7.04**	4.83**	3.75 ns	214.33***	22.98***	5.08**
E×D	4	8.03***	0.44 ns	1.64 ns	0.81 ns	1.95 ns	2.62*	1.67 ns	0.63 ns
R×D	8	12.17***	1.89 ns	1.04 ns	4.26***	12.15***	0.52 ns	1.35 ns	0.58 ns
E×R×D	8	17.00***	1.20 ns	2.07*	0.56 ns	1.31 ns	2.58 ns	2.43*	0.53 ns

Mangoes from both experiments (E) were processed at ripeness stage (R) A, B or C, and analyzed on days 0, 2, 5, 7 or 10 during storage at 5°C (D); ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 3-4. ANOVA table - Volatile compounds and categories for fresh-cut 'Kent' mango.

Source of variations	d.f.	F-value										
		Acetaldehyde ($\mu\text{L/L}$)	Hexanal ($\mu\text{L/L}$)	Acetone ($\mu\text{L/L}$)	Ethanol ($\mu\text{L/L}$)	α -pinene ($\mu\text{L/L}$)	β -Carene ($\mu\text{L/L}$)	Myrcene ($\mu\text{L/L}$)	α -terpinolene ($\mu\text{L/L}$)	α -copaene ($\mu\text{L/L}$)	Ethyl acetate ($\mu\text{L/L}$)	Ethyl butyrate ($\mu\text{L/L}$)
E	1	102.99***	5.29*	8.01**	19.38***	32.09***	26.34***	19.25***	28.11***	1.02 ns	14.36**	0.09 ns
R	2	49.29***	60.18***	48.53***	25.11***	2.49*	4.01*	2.12 ns	12.79***	2.24 ns	45.09***	9.82**
D	4	1.34*	2.84*	4.50**	1.60 ns	0.53 ns	0.43 ns	0.35 ns	0.47 ns	5.64**	0.66 ns	2.79*
E×R	2	2.33 ns	11.74**	9.29**	2.45 ns	2.19 ns	1.22 ns	1.53 ns	0.90 ns	2.08 ns	13.02***	3.84*
E×D	4	1.35 ns	1.48 ns	0.82 ns	0.14 ns	0.14 ns	0.32 ns	0.47 ns	0.35 ns	2.63*	0.86 ns	0.51 ns
R×D	8	1.16 ns	1.94 ns	1.33 ns	1.34 ns	0.40 ns	0.40 ns	0.39 ns	0.32 ns	3.10**	0.78 ns	1.25 ns
E×R×D	8	1.25 ns	2.33*	1.54 ns	0.89 ns	0.72 ns	0.75 ns	0.62 ns	0.97 ns	1.74 ns	2.02 ns	1.87 ns

Mangoes from both experiments (E) were processed at ripeness stage A, B or C (R) and analyzed on days 0, 2, 5, 7 or 10 during storage at 5°C (D); ns, *, **, or *** = non-significant or significant at $P < 0.05$, 0.01, or 0.001, respectively

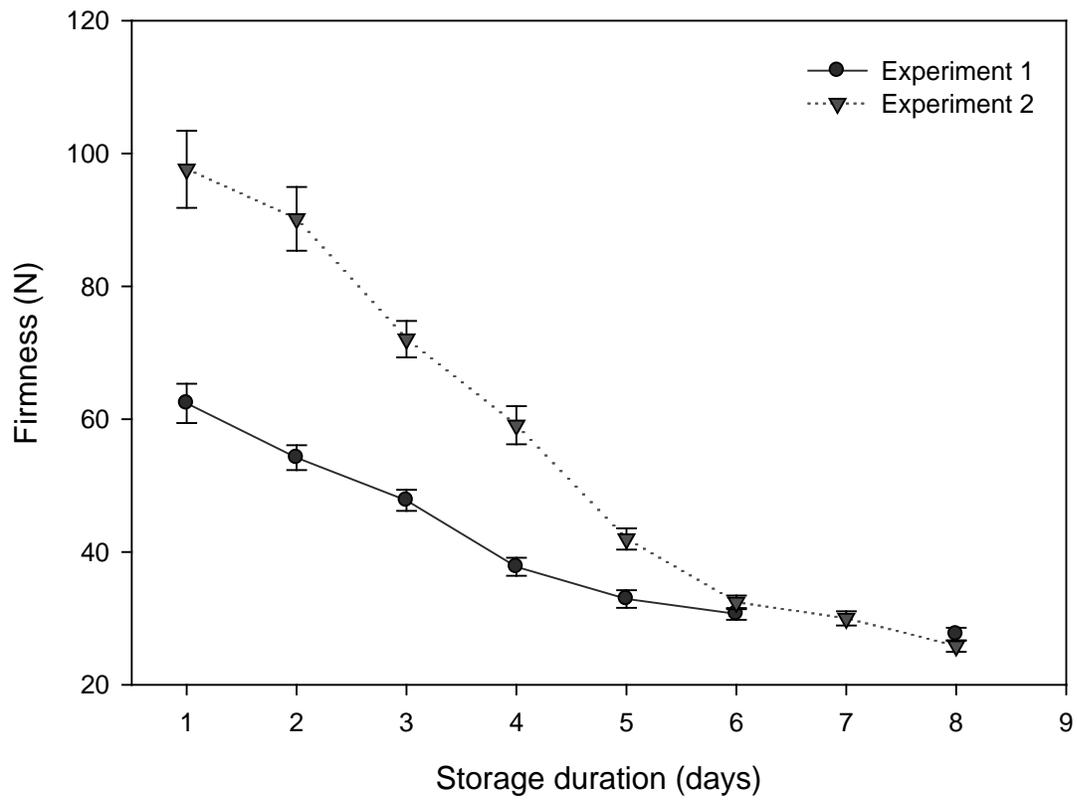
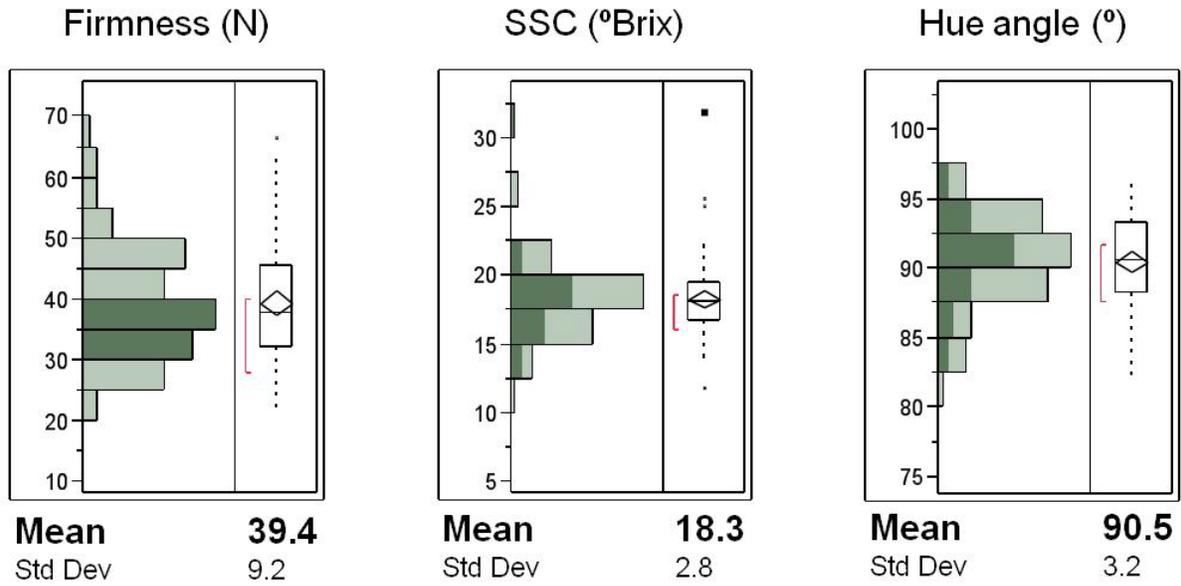
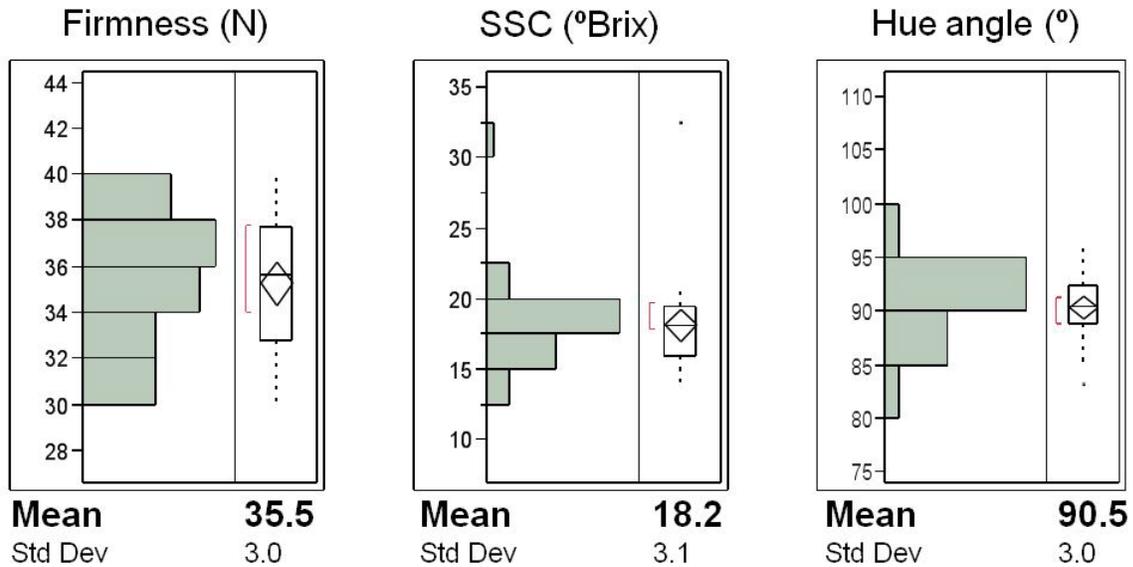


Figure 3-1. Changes in the firmness of whole mango fruit during ripening at 20 °C.



A



B

Figure 3-2. Initial fruit selection for ripeness stage A (experiment 2). (A) Distribution of firmness, SSC, and hue angle values of 80 mangoes after ripening at 20°C. The shaded zone indicates mangoes with targeted firmness and their corresponding SSC and hue angle values. (B) Distribution of firmness, SSC, and hue angle of the 36 fruit selected for fresh-cut processing.

Storage duration



Figure 3-3. Changes in the appearance of fresh-cut 'Kent' mango slices from ripeness stages A, B, and C during storage for 7 or 10 days at 5°C.

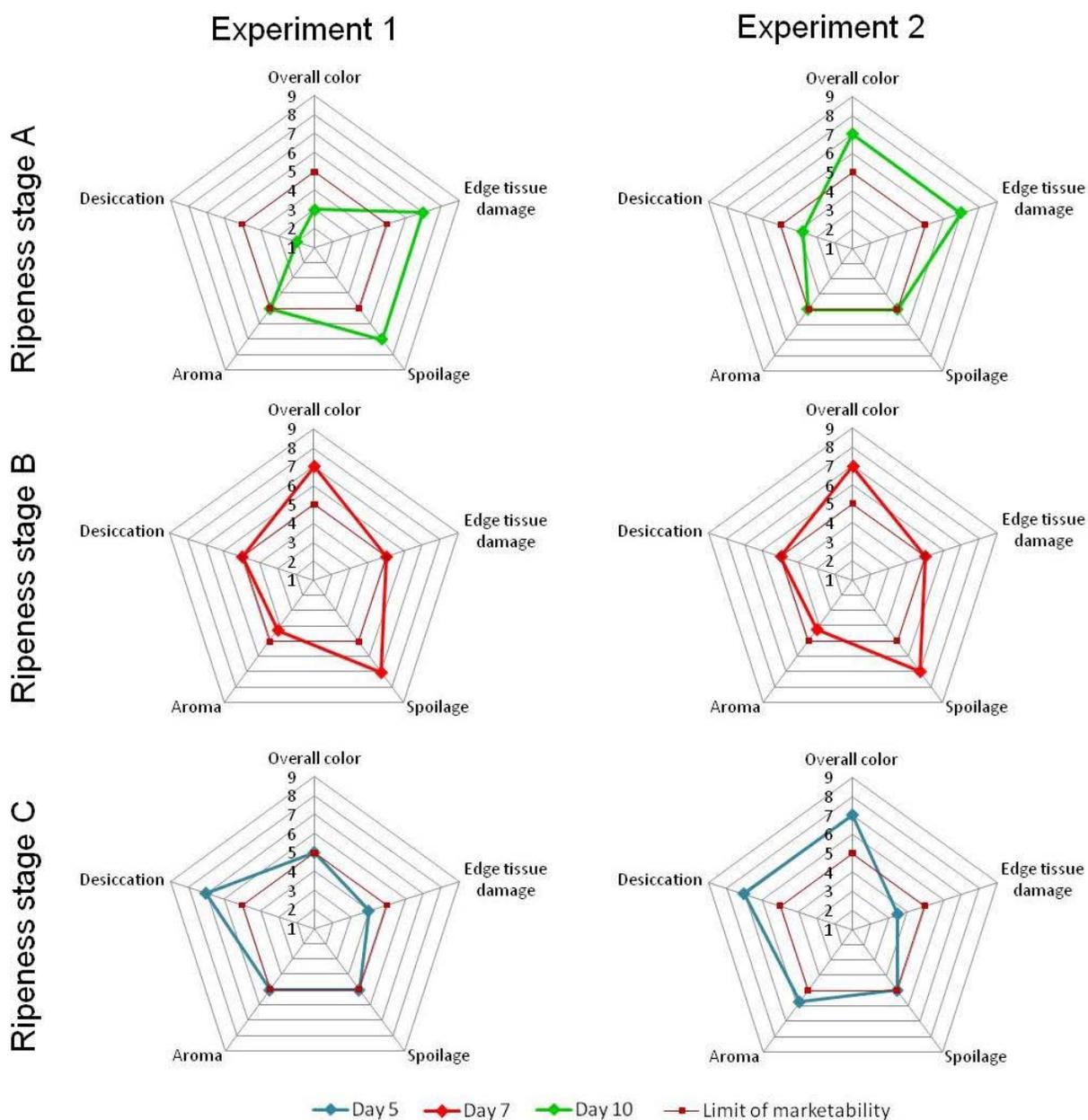


Figure 3-4. Subjective quality scores at the end of the shelf life for each ripeness stage (A, B, and C) after storage at 5°C; where: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1 = poor, inedible. Rating of 5 is the minimum subjective score for marketing any product.

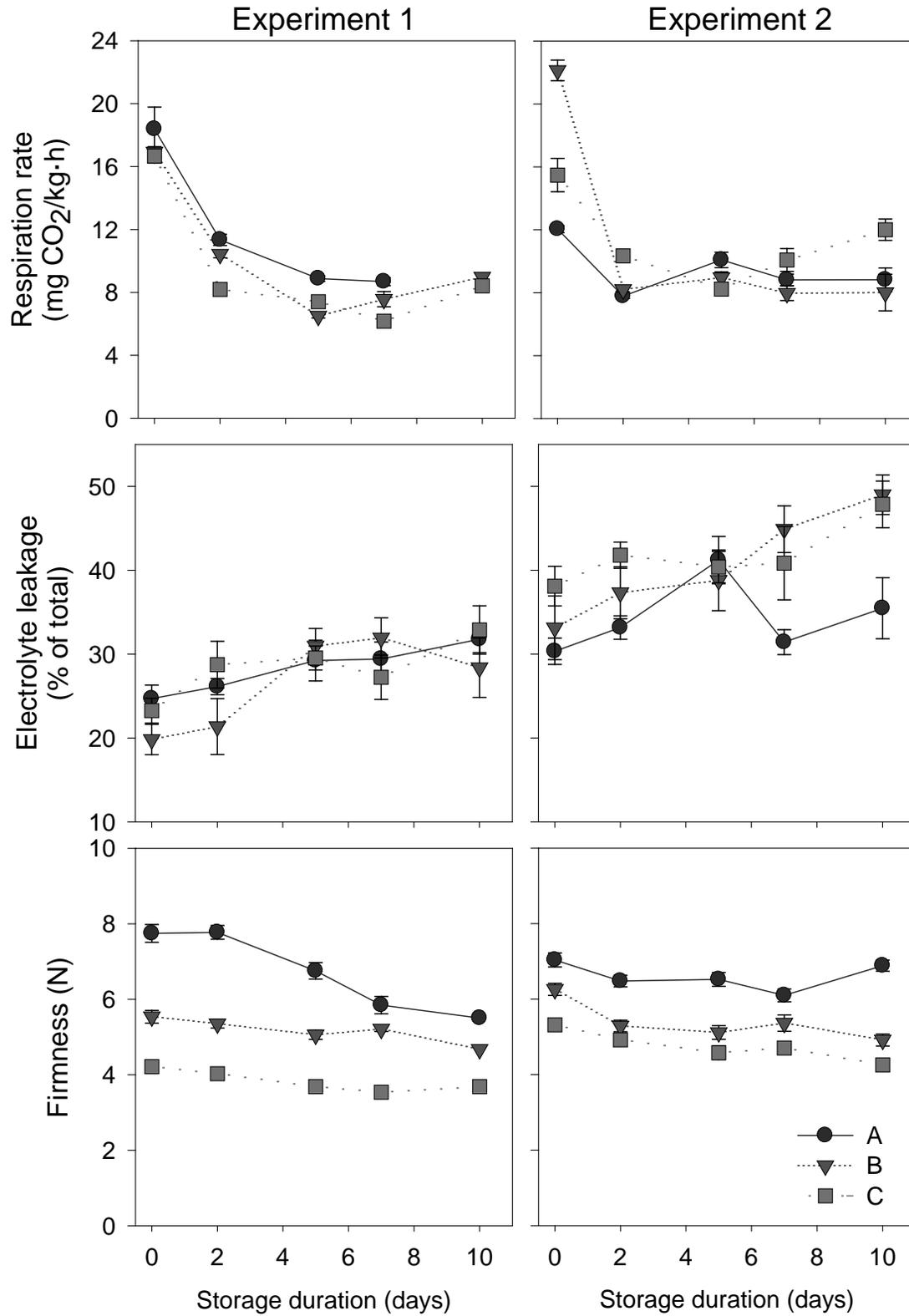


Figure 3-5. Changes in RR, EL, and firmness during storage at 5°C of fresh-cut 'Kent' mango slices that were processed from whole fruit at ripeness stages A, B or C.

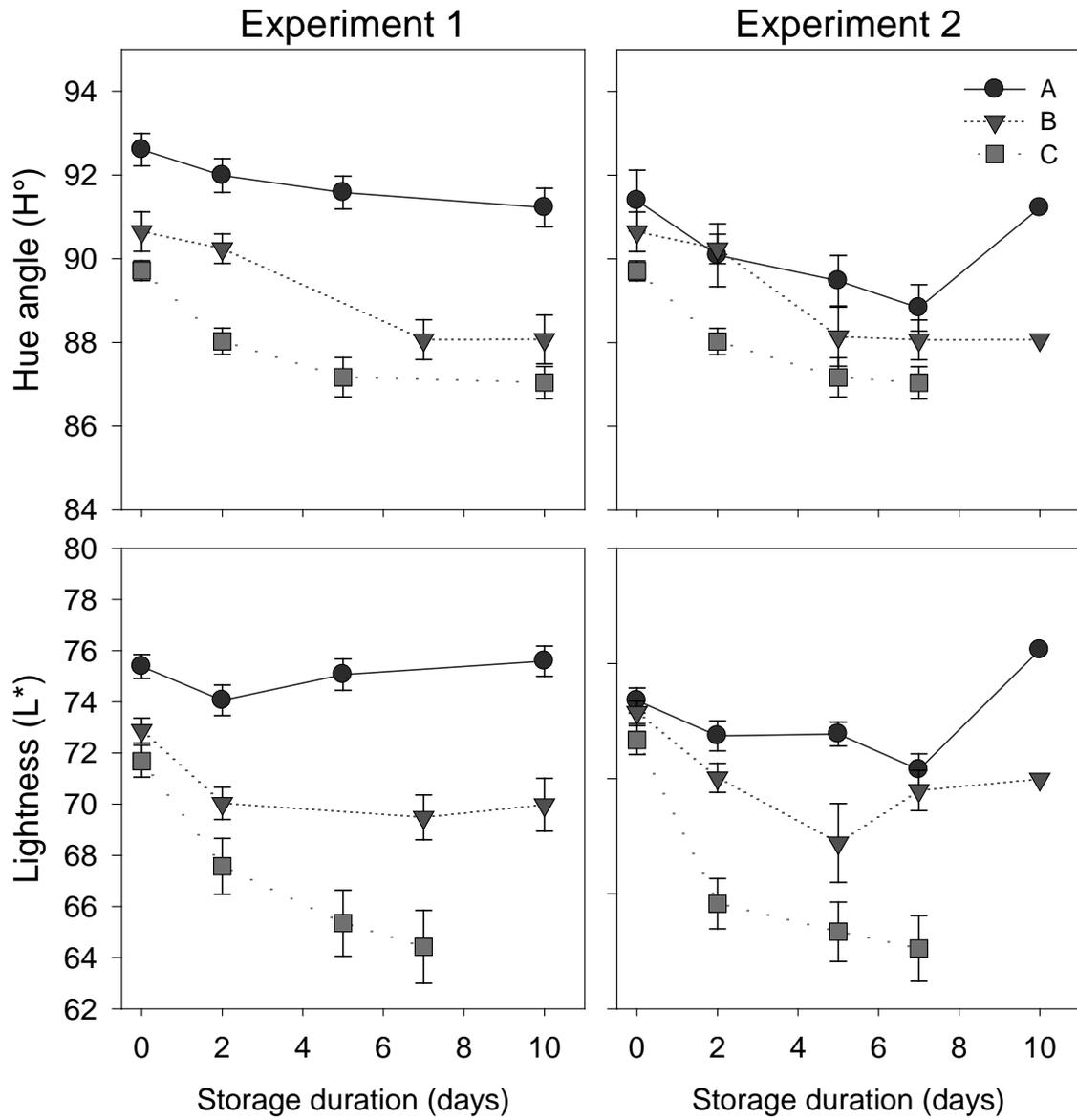


Figure 3-6. Changes in the flesh color (hue angle and lightness) during storage at 5°C in fresh-cut 'Kent' mango slices processed from whole fruit at ripeness stages A, B or C.

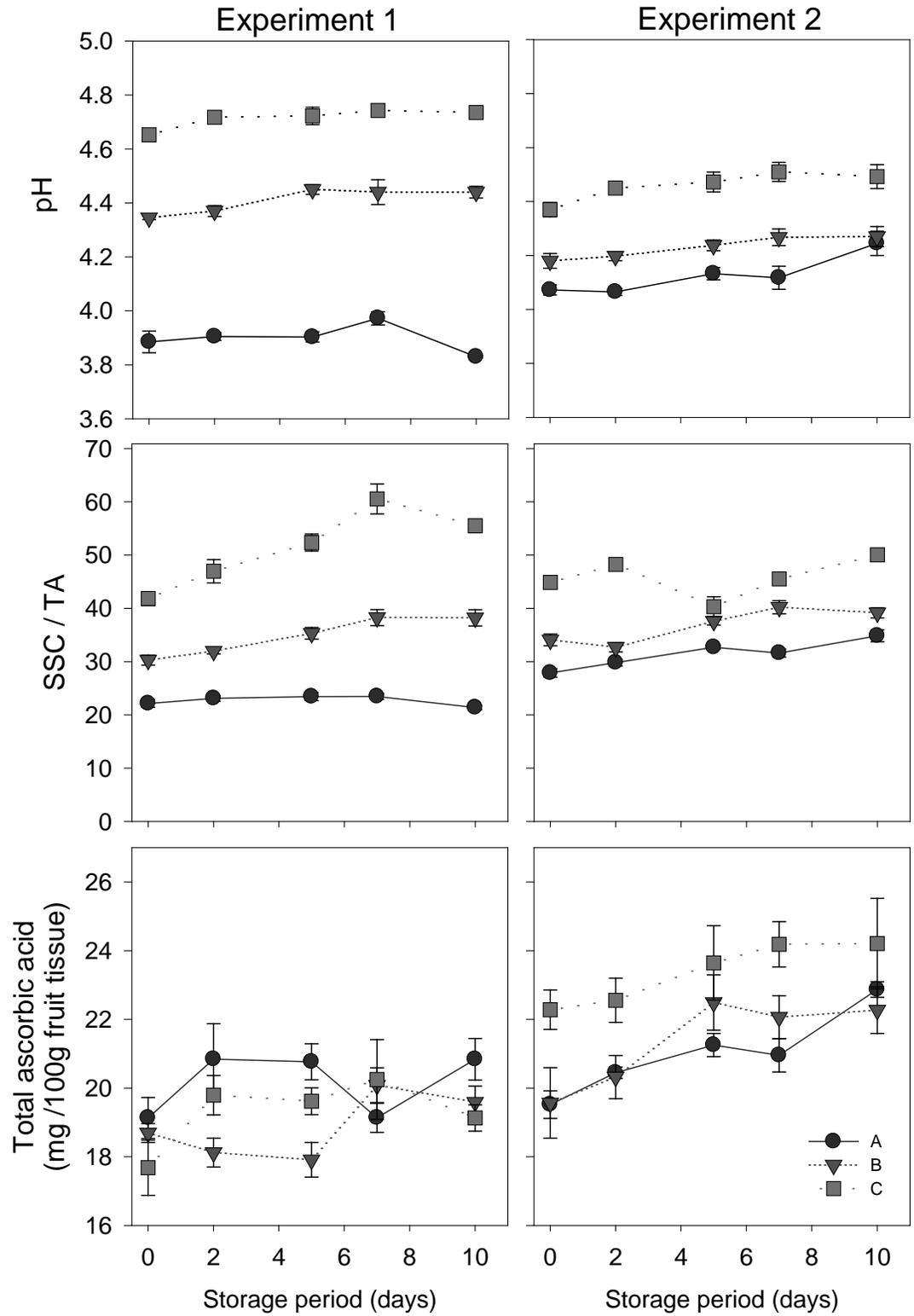


Figure 3-7. Changes in the pH, SSC/TA ratio, and TAA during storage at 5° in fresh-cut ‘Kent’ mango slices processed from whole fruit at ripeness stages A, B or C.

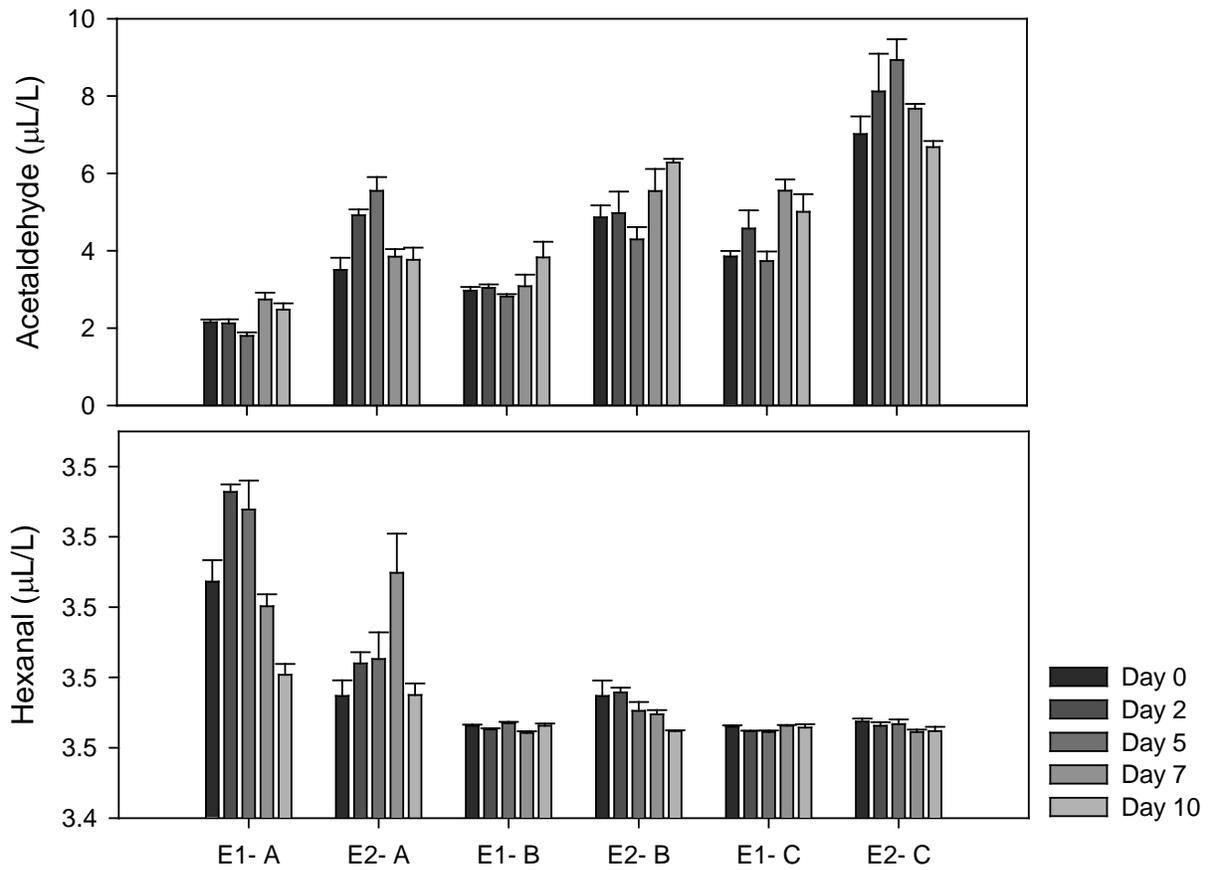


Figure 3-8 Changes in aldehydes during storage at 5°C in fresh-cut 'Kent' mango slices processed from whole fruit at ripeness stages A, B or C for experiments 1 (E1) and 2 (E2.)

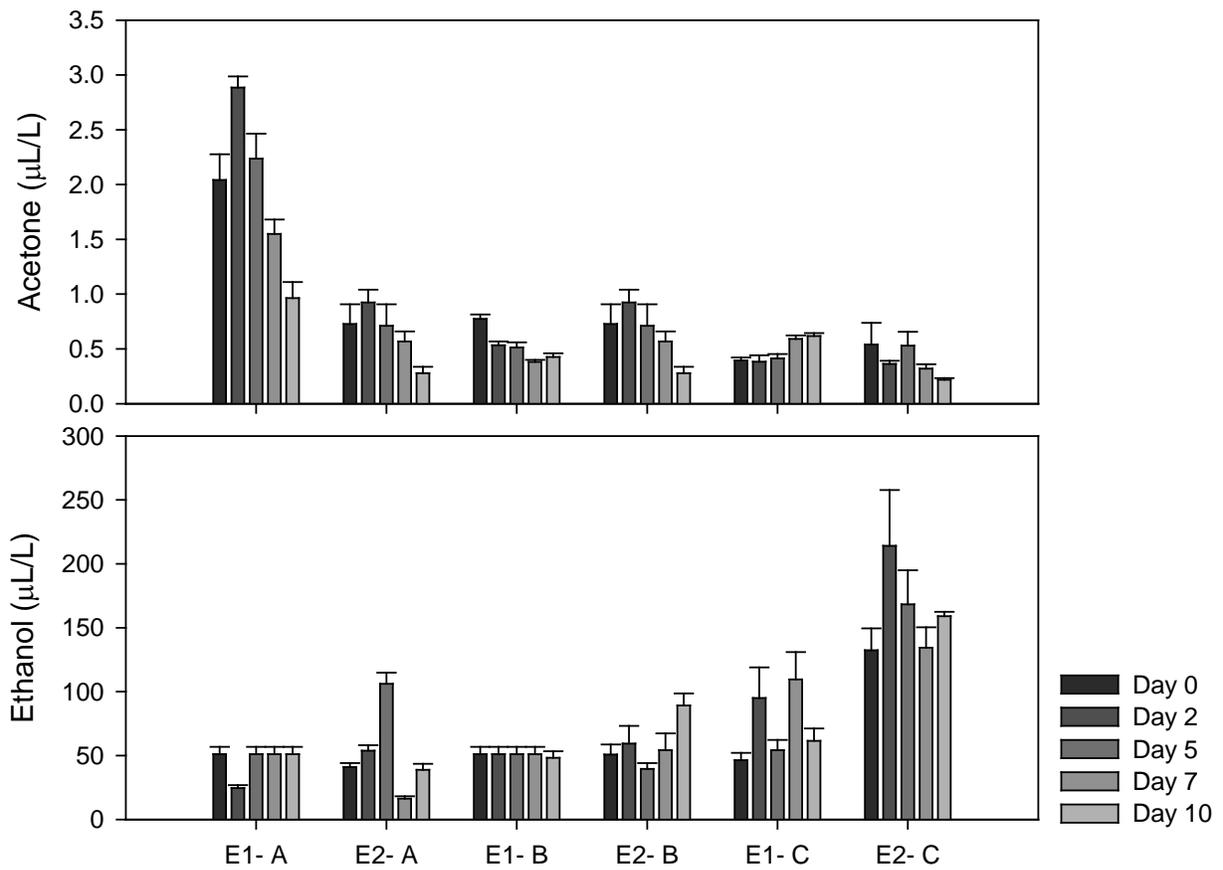


Figure 3-9 Changes in ketone (acetone) and alcohol (ethanol) during storage at 5°C in fresh-cut ‘Kent’ mango slices processed from whole fruit at ripeness stages A, B or C for experiments 1 (E1) and 2 (E2.)

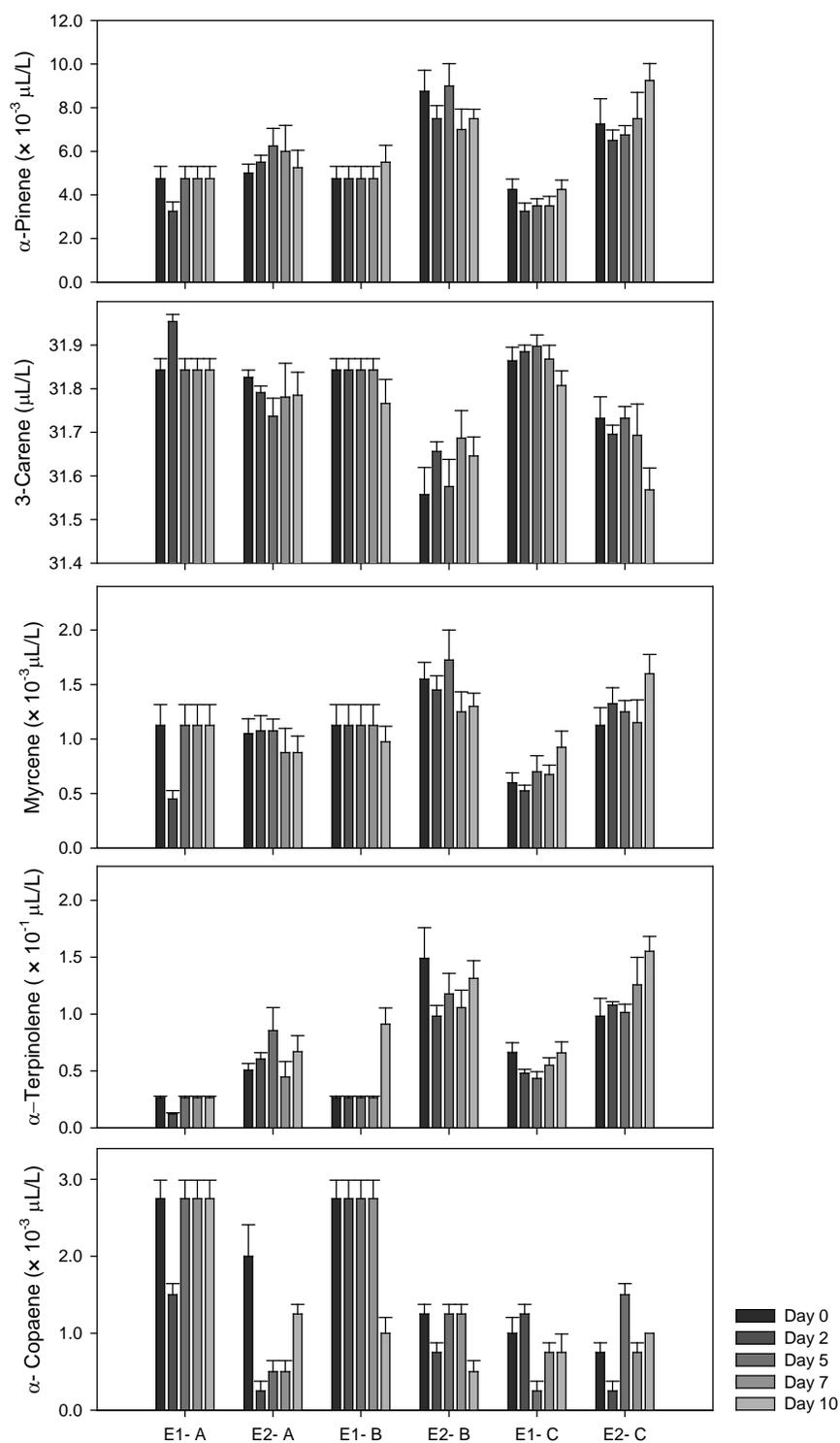


Figure 3-10 Changes in terpenes during storage at 5°C in fresh-cut ‘Kent’ mango slices processed from whole fruit at ripeness stages A, B or C for experiments 1 (E1) and 2 (E2).

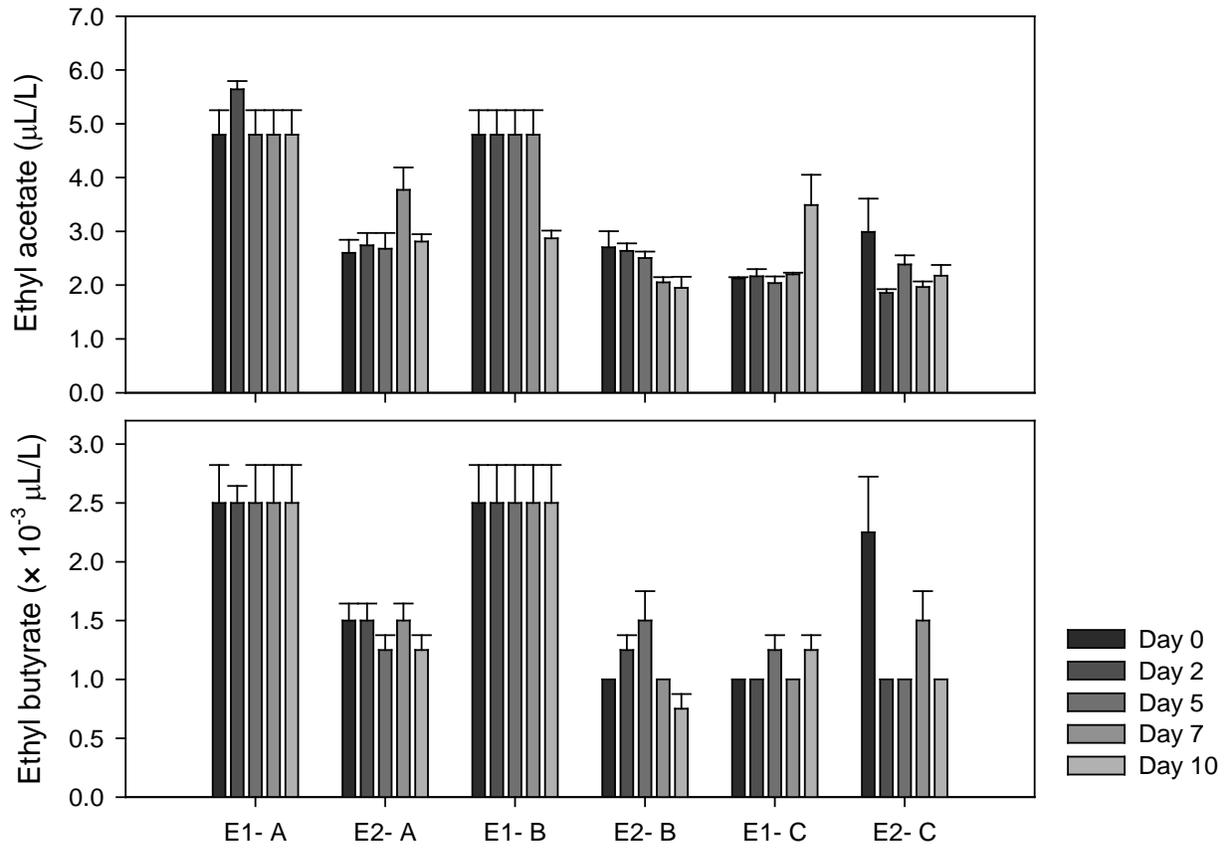


Figure 3-11 Changes in esters during storage at 5°C in fresh-cut ‘Kent’ mango slices processed from whole fruit at ripeness stages A, B or C for experiments 1 (E1) and 2 (E2.)

CHAPTER 4
QUALITY OF FRESH-CUT 'KENT' MANGO SLICES PREPARED FROM HOT WATER
OR NON HOT WATER TREATED FRUIT.

Introduction

The convenience and quality of fresh-cut fruit are factors in their increasing popularity in the food supply and so is the demand for various fresh-cut tropical and subtropical fruits. Mango, one of the most important tropical fruits in the world and currently ranked fifth in total world production among fruit crops (FAO, 2007), is considered to be a fruit with good potential for marketing as a fresh-cut product. However, little is known about mango physiology and shelf life when processed into fresh-cut slices or chunks, and less information exists regarding fresh-cut mango flavor quality (Beaulieu et Lea, 2003) in order to commercialize a high quality product with acceptable shelf life for marketing.

For all mangoes entering the United States, a quarantine heat treatment consisting of exposure to 46 °C water for 65 to 110 min (depending on cultivar and fruit size) is mandated by USDA-APHIS (USDA-APHIS, 2005; Schedule T102-a). It is known that heat treatments may have positive effects on fruit quality such as extending storability and marketing by inhibiting ripening processes, inhibiting decay, or inducing resistance to chilling injury (CI) and altering the volatile profile of whole fruit (Lurie, 1998; Paull and Chen, 2000; Fallik, 2004). However, the APHIS heat treatment can also cause heat injury to develop in mangoes, at both external and internal levels. Heat treatments were reported to accelerate ripening in mango varieties such as 'Keitt' (Jacobi et Giles, 1997) and 'Tommy Atkins' (Talcott et al., 2005). Accelerated water loss and failure to achieve the desired peel color are also common in heat injured fruit (Joyce et al., 1993). Moreover, internal injury includes poor color development, abnormal softening, lack of starch breakdown, and development of internal cavities. In addition, heat-injured fruit can fail to color and can either soften quickly or show abnormal softening in which some areas of the flesh

remain hard while others soften (Lurie, 1998, Jacobi et al., 2001). Therefore, the use of heat treated mangoes for fresh-cut processing may compromise the composition and or the sensory quality of the product.

This study addresses the effects of the USDA-APHIS hot water (HW) quarantine treatment on the visual, and compositional quality factors, aroma volatile production, respiration rate, and electrolyte leakage of fresh-cut ‘Kent’ mango slices during subsequent storage at 5 °C for 10 d. To the best of our knowledge, this is the first report to address the direct effect of quarantine heat treatments on fresh-cut mango quality and shelf life. A previous report by Plotto et al. (2006) involved treatment of mango with ethanol vapor prior to fresh-cut processing and involved a 4 or 7 d period at 20 °C between heat treatment and ethanol treatment/processing.

Materials and Methods

Plant Material

This study was conducted twice during two Florida harvest seasons. Mangoes (cv. Kent) were obtained from a commercial operation in Homestead, Florida [first harvest (H1), July 2006] and from the University of Florida Tropical Research and Education Center in Homestead, Florida [second harvest (H2), July 2007].

Fruit were removed from the field with minimal delay after harvest and transported to the postharvest laboratory in Gainesville, Florida, within approximately 6 h. Mangoes were selected based on uniformity of size, color, and freedom from defects. Half of the fruit received the quarantine hot water (+HW) treatment following the USDA treatment schedule (USDA-APHIS, 2002; Schedule T102-a). Mangoes were immersed in water at 46 °C for 90 min or 75 min for fruit with weights greater than 500 g or less than 500 g, respectively. The other half of the mangoes (-HW) were used as a control and were immersed in water at room temperature (24 °C) for 2 min to remove sap on the skin. Following the HW treatment, all treated fruit were

left for about 90 min at room temperature to cool down and dry before being transferred to a 20 °C temperature controlled room for a 24-h ethylene treatment (100 µL/L).

Following ethylene treatment, the fruit were allowed to ripen at 20 °C until the desired ripeness stage was attained as determined by flesh firmness that yielded to gentle hand pressure (3-4 d after ethylene treatment), which resulted in slices with average initial firmness of 33.0 ± 4.5 N (H1) or 29.2 ± 3.8 N (H2). The ripe mangoes were held overnight in a refrigerated and sanitized room at 5 °C. Half of the fruit from each treatment (+HW or -HW) were processed into fresh-cut slices while the other half were left whole (control) as described in Chapter 3. Whole fruit controls and a total of 8 mixed slices per container were stored at 5 °C for 10 d. Four whole fruit and four containers of fresh-cut slices per treatment were used for analyses at each sampling time. Prior to analysis, the whole fruit were processed into fresh-cut slices.

Visual Quality Evaluation and Measurement of Flesh Color, Respiration Rate, Electrolyte Leakage, and Composition, Including Volatiles

'Kent' mangoes were evaluated for visual quality, and the flesh color, respiration rate (RR), electrolyte leakage (EL) and composition of the tissue, including volatiles, were measured as described in Chapter 3.

Firmness Evaluation

In H2, firmness was measured using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a flat plate probe (5-cm diameter) and equipped with a 50-kg load cell. The non-destructive measurements were made on four fresh-cut slices per sample, positioning the probe over the largest flat side of each slice, after establishing zero force contact between the probe and the equatorial region of the fruit, the probe was driven with a crosshead speed of 50 mm min⁻¹. The force was recorded at 2.5 mm deformation. The results were reported in newtons (m·kg/s²).

Statistical Analysis

A completely randomized design was used for this study with evaluation or analysis of composite samples of 8 slices from four replicate containers per treatment and sampling time, except that 10 color measurements were made on 10 slices taken from 4 containers per treatment and sampling time. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. Statistical analysis was performed using the PC-SAS software package (SAS-Institute, 1985). Analysis of variance (ANOVA), using the General Linear Model, was conducted to identify significant main effects due to storage time, fresh-cut versus whole, and heat treatments. Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. The seasons of harvest (H1 and H2) were found to have significantly different effects for all treatments evaluated, and were therefore analyzed separately.

Results and Discussion

Subjective Visual Quality

Storage time had a significant effect on the visual quality of fresh-cut mango slices stored at 5°C (Table 4-1). During storage, the visual quality of fresh-cut ‘Kent’ mango slices from both harvests decreased consistently (Figure 4-3-1, 2). In H1, the shelf life of fresh-cut mango slices was limited by edge tissue damage, characterized by edges that were slightly soggy or water-soaked with darker color, veins markedly browning, and a gooey appearance, while the limiting factor of marketability in H2 was desiccation, characterized by a progressive drying of the slice edges with little to no surface gleam, and slightly dehydrated surfaces. The shelf life of fresh-cut slices at 5 °C was, for both harvests, limited to 5 d. Similarly, Beaulieu and Lea (2003) reported that shelf life of fresh-cut mango cubes from soft-ripe mangoes was limited to 7 d when stored at 4 °C and the most critical factor reducing quality was edge or tissue damage, resulting in mushy

tissue and poor texture, followed by aroma loss and general discoloration. Different shelf-lives for fresh-cut mango have been reported in the literature: Rattanapanone et al (2001) reported that the marketable period of fresh-cut ‘Tommy Atkins’ and ‘Kent’ mango cubes was 3 to 5 d at 10 °C and 5 to 8 d at 5 °C and was limited by watery condition, discoloration, and loss of fresh appearance of the mango cubes. In another study, Gil et al. (2006) observed that fresh-cut ‘‘Aaulfo’ mango cubes maintained good visual quality up to 9 d of storage at 5 °C. However, the shelf life of ‘Nam Dokmai’ mango cubes was 2 d at 5 °C and 1 d at 13 °C, and was limited by browning and water soaking appearance on the cut surfaces (Poubol and Izumi, 2005a, b). As pointed out by Allong et al. (2001), the variability in shelf life is mostly cultivar and maturity dependent, since mango fruit at different stages of ripeness may have different responses to fruit preparation (slicing), and may vary in physiological and metabolic activity.

Furthermore, in this study, no significant difference in visual quality s was noticed between slices from +HW or –HW treated fruit. This observation is in agreement with Plotto et al. (2006), who reported no significant difference between +HW and –HW fresh-cut ‘Kent’ mango slices after 0 and 6 d of storage at 7 °C, based on sensory descriptors (overall preference, firmness and mango flavor) evaluated by a panel of 16 to 18 members.

Respiration Rate

Respiration rates were significantly affected by the storage period for both harvests (Table 4-2). However, no common trend was observed between the harvests (Figure 4-3). In H2, the CO₂ production of fresh-cut slices was higher than the corresponding whole fruit, which was not observed in H1. It is known that the increase in the RR of fresh-cut compared with the intact product can range from only a few percent for green beans, grapes and zucchini to over 100% for kiwifruit and lettuce (Watada et al., 1996). The significant increase in RR of fresh-cut slices at the end of the storage period (day 8), for both harvests, may be due to an increase in microbial

population on the cut surface since the spoilage on day 7 was noticeable by a trained person (Figure 4-1, 2). However since no microbial testing was performed during this study no conclusion may be drawn.

The HW treatment had a significant effect on the RR only in H2 (Table 4-2), where +HW fruit had higher RR than –HW fruit. The difference was marked on day 0 and 4 (Figure 4-3). Inconsistent RR data for various fresh-cut mangoes was previously reported in the literature. It is difficult to determine if the respiration patterns in fresh-cut mangoes are due to cultivar variation, heat-treatment, browning inhibition treatments (Beaulieu and Lea, 2003), or due to the cutting shape and the ripeness stage at the time of cutting (Allong et al., 2001; Riviera-Lopez et al., 2005). However, since in H2 the *F*-value for the type of fruit (fresh-cut vs. whole) was much higher than the *F*-value for the storage period and the HW treatment, indicating a higher influence of the fruit sample on the RR, and that no HW effect was present in H1, it is likely that the HW treatment does not have a specific effect on the RR of fresh-cut ‘Kent’ mango slices stored at 5 °C beyond the immediate effect while the whole fruit temperature is elevated during treatment.

Electrolyte Leakage

Electrolyte leakage (EL) is an indicator of loss of cell membrane integrity attributed to ripening, and any damage that can arise from stress or mechanical injury (Nyanjage et al., 1999). The stage of fruit ripeness, duration of exposure to heat treatment, storage temperature, and their interactions may influence levels of EL (Nyanjage et al., 1999). Both leakage and RR depend on fruit tissue integrity, and increase in these parameters should be expected at the end of ripening or when the fruit is exposed to severe stress conditions (e.g. cutting/processing and/or exposed to high or low temperatures) (Vicente et al., 2006).

In this study, higher EL was measured on fresh-cut slices that were stored for a few days before analysis compared to the whole fruit that were cut at the moment of analysis (Table 4-2). High initial EL was most probably a reflection of the relatively advanced ripeness of the fruit at the time of processing. The overall levels of EL did decrease slightly through the 10-d storage period for both harvests, although most of the changes occurred after the slices had passed the marketable period. This decrease could be attributable to further ripening, as indicated by an increase in soluble solids content (SSC; Figure 4-6), that may have led to higher osmotic potential and thereby reduced EL (Nyanjage et al., 1999).

In general, no HW effect was noticed for either harvest during the marketable period, although a significant difference was found on day 0 for H2 (Figure 4-3), where the EL of -HW treated fruit was higher than that of +HW treated fruit, however the trend did not extend to the rest of the storage period.

Firmness

Firmness decreased during storage with greater firmness losses occurring for the fresh-cut slices than for the whole fruit (Table 4-2). In this study, all of the fresh-cut slices were processed a few hours later than the initial whole fruit samples were cut, and then the firmness of all of the sample replicates was measured, which may have contributed to the initial lower firmness (day 0) of fresh-cut slices compared with whole fruit. There was no HW effect on firmness. This observation is contrary to what was found by Jacobi and Giles (1997) who reported that untreated fruit were firmer than vapor heat- (VHT) or HW-treated mangoes, both after storage at 10 °C for 5 d, followed by 22 °C for 5 d, and at the eating ripe stage after some additional days at 22 °C.

Flesh Color

For fresh-cut mangoes, a decrease in L* value may be an indicator of flesh browning, and a decrease in hue angle indicates that flesh turns from yellow to orange-red. In this study, the flesh lightness (L* value) decreased with storage time for the fresh-cut slices, indicating a darkening of the surface color compared with the whole fruit, for which the flesh lightness tended to increase during storage (Figure 4-4). This increase in lightness could be attributable to a loss of green color that occurred prior to a rise in yellow-orange as indicated by an increase in a* value, which followed a similar pattern to the L* value during storage (data not shown).

Hue angle did not follow any specific trend (increase or decrease) even though a significant difference due to storage period was found, possibly due to slice color variations within sample replicates related to initial fruit-to-fruit variability. In this study, no difference in L* value among the HW treatments was noticed, but +HW-treated fruit had higher hue angle values than –HW-treated fruit. This was the opposite of results reported by Jacobi and Giles (1997) for ‘Kensington’ mangoes, in which heat treatment caused a higher lightness and a lower hue angle to develop during ripening. However, Kim et al. (2007) reported no differences in color values between HW-treated and control fresh-cut ‘Tommy Atkins’ mango slices.

Fruit Composition

pH, titratable acidity, soluble solids content

The pH increased significantly throughout the storage period for all treatments and both harvests (Table 4-3; Figure 4-5). Although there was a statistically significant effect of storage time on pH, the pH changes were so small (< 0.2 units) that it would be practically impossible to detect such differences between fruit by taste evaluations. Therefore, pH changes through time for either fresh-cut slices or whole fruit were not considered different. It has been previously reported that there were no significant changes in pH during the storage of fresh-cut mangoes

(Paull and Chen, 2000; Gil et al., 2006; González-Aguilar et al., 2007a). In addition, it has been reported for fresh-cut cantaloupe, that a biochemical parameter such as pH cannot be used as an indicator of quality because it does not change significantly from amounts present in the freshly cut fruit when stored at 4 °C for a period of 2 wk (Lamikanra and Richard, 2002). No significant trend for pH was found in the fruit in terms of HW treatment or whole versus fresh-cut (Table 4-3).

Gil et al. (2006) reported no significant changes in titratable acidity (TA) during storage of fresh-cut 'Ataulfo' mango cubes at 5 °C. Moreover, it was shown that TA of whole mangoes (c.v. Haden and Kent) decreased with ripening at 24 °C, but increased at 13 °C, and changed only slightly at 5 °C (Tovar et al., 2001). In the present study, however, the acidity of fresh-cut and whole mango decreased slightly during storage for both H1 and H2 (Figure 4-5). The overall TA was significantly affected by the HW treatment in H1, where -HW had a higher TA value than the +HW-treated fruit. This difference was significant at day 0 and 7 (Figure 4-5). These findings are in accordance to those reported by Paull and Chen (2000), in which TA was reduced in heat-treated nectarines and strawberries. The significant interaction between HW and fresh-cut processing reflects treatment differences that occurred after the marketability was compromised. However, since no difference due to HW treatment was observed in H2, no conclusion can be drawn as to whether the HW treatment had a significant impact on TA of fresh-cut slices or whole mangoes.

The SSC increased slightly (Table 4-3, Figure 4-6) during storage in H1, indicating that the fruit may have continued to ripen during storage with residual starch converted into sugars. No SSC change was observed in H2. Similarly, SSC increased in 'Julie' and 'Graham' mango fresh-cut slices held at 10 °C or 5 °C (Allong et al., 2001), while no significant changes in SSC were

measured during the storage of several other cultivars of fresh-cut mangoes held at 4 °C or 5 °C for periods of 8 to 14 d (Rattanapanone et al., 2001; Gil et al., 2006; González-Aguilar et al., 2007a).

For both harvests, whole fruit had significantly higher SSC than the fresh-cut slices with no regard to whether the fruit were HW-treated or not, which was similar to the results of Tovar et al (2000), who reported that partially ripe ‘Kent’ mango slices continued to ripen after cutting, but did not reach the same level of ripeness as whole mangoes did after 5 to 7 d at 13 °C or 23 °C.

For H1, the -HW treated fresh-cut slices and whole fruit had higher SSC than the +HW treatments, but significant differences were evident past the marketable period (Figure 4-6). For H2, -HW-treated fruit had significantly higher SSC only on day 0 and day 7. Rattanapanone et al. (2001) reported that SSC did not change significantly as a function of temperature, atmosphere or storage time in fresh-cuts prepared from ripe, heat-treated mangoes (‘Kent’ and ‘Tommy Atkins’) held at 5 or 10 °C. Moreover, Paull and Chen (2000) reported no significant effects of heat treatment on SSC for mango, grapefruit, orange, and tomato.

Total ascorbic acid

The initial amounts of total ascorbic acid (AA) expressed on a fresh weight basis were different in the two harvests (Figure 4-6); the AA levels for H1 were much higher than for H2, which could be explained by different climatic conditions and/or the location where the fruit were harvested (Lee and Kader, 2000). For both harvests, the concentration of AA changed during storage (Table 4-3). Actually, for H1, AA was significantly lower past the marketable period. While for H2, AA was initially lower on day 0.

It has been reported that AA degrades very little during short-term refrigerated storage (about 1 wk) in some fresh-cut fruits (Beaulieu and Gorny, 2004). Tovar et al. (2001) reported

that the AA concentration in mango decreased as ripening progressed while the opposite occurred in fresh-cut slices. In fact, the AA content of the slices kept at 5 or 13 °C increased during storage but never reached the level of the whole fruit. Other authors (Thomas, 1975, Thomas and Joshi, 1988) have reported increases in AA during refrigerated storage (5, 7, 10 or 15 °C) of 'Alphonso' mangoes and suggested ascorbate synthesis under such conditions. Ôba et al. (1994) demonstrated that activity of L-galacto- γ -lactone dehydrogenase was induced and was responsible for ascorbate synthesis in injured tissue of potato tubers; which suggests that the same may occur in injured mango tissue. The hypothesis that the increase of AA concentration on a fresh weight basis during storage may be due to water loss during storage rather than an actual increase in AA (Nunes et al., 1998) is not supported in this case since the percentage of weight loss (data not shown) was less than 0.5% of the initial weight and no exudates was noticed in the containers of fresh-cut fruit.

No difference between AA content of whole and fresh-cut slices was observed for H1, while for H2, AA content of fresh-cut slices was lower than in the whole fruit. It is known that levels of AA can decrease after processing or during ripening. Since oxidative processes occur more rapidly in fresh-cut products, they are expected to have more AA losses compared with the whole fruit (Allong et al., 2000) mostly due to the loss of compartmentalization of the cells, allowing degradative enzymes and substrates to come into contact. Moreover, no difference in AA content between HW treatments was found in this study.

Volatiles

For ease of comparison, the 16 volatiles measured were grouped and compared. Therefore, all of the aldehydes (acetaldehyde, hexanal), one ketone (acetone), the terpenes (α -pinene, β -pinene, limonene, *p*-cymene, α -copaene, 3-carene, myrcene, α -terpinolene, caryophyllene) and

the esters (ethyl acetate, ethyl butyrate) were summed and presented as total volatiles; ethanol and methanol were summed separately and presented as total alcohols (Figure 4-7).

No significant differences were observed among all sources of variation for total volatiles content in samples from H1. In fact, when analyzing each individual volatile compound separately, only β -pinene, limonene, and ethyl butyrate presented significantly higher concentrations on day 7 (and day 2 for limonene). No differences were found between whole fruit and fresh-cut slices during storage. Total alcohol content also varied during storage (Table 4-3), with the least alcohol content present on day 10 (Figure 4-7).

For H2, however, there was much higher content of alcohols (mainly ethanol) on day 10 of storage and the levels were significantly higher for the fresh-cut slices than for the whole fruit. Moreover, fresh-cut slices had higher total volatile content than whole fruit in H2. This effect was marked on the last day of storage. Acetaldehyde, acetone, α -pinene, limonene, p -cymene, α -copaene, and α -terpinolene were the only volatiles to present a significant difference in H2 during storage (data not shown). In fact, higher concentrations were present in the whole fruit compared with the fresh-cut slices, except for acetaldehyde, which was present in higher concentrations in fresh-cut slices compared with whole fruit.

Beaulieu and Lea (2003) suggested that volatile production by fresh-cut mangoes could undergo a transient upsurge because skin removal creates secondary compound formation (i.e. terpenes and aldehydes), allows rapid off-gassing, and increases available O_2 for enzymatic action. Through storage, as starch declines and less sugar is catabolized, less acetyl-CoA would be available as substrate for continued volatile production. In this experiment, a slight decline in total volatiles was observed during storage at 5 °C. During storage of fresh-cut chunks processed from commercially mature melons, the total volatile concentration generally increased during the

first 2 d of storage and then remained relatively stable or decreased gradually during the remainder of storage (Saftner et al., 2006). No significant difference between fresh-cut slices and whole fruit were noticed in H1, but for H2, fresh-cut slices had significantly higher total volatiles, mainly due high acetaldehyde concentration, compared to whole fruit at the end of the storage at 5 °C.

The high content of acetaldehyde and ethanol present in the slices may be attributable to fermentative processes that occurred during storage. It is known that anaerobic respiration in fruit tissue is characterized by increases in ethanol, ethyl acetate, ethyl butanoate, and acetaldehyde during storage (Beaulieu and Lea, 2003). The major plant fermentative metabolism products in fruits are ethanol and acetaldehyde and their accumulation is well-correlated with off flavor development (Agar et al, 1999). For example, Sothornvit and Rodsamran (2008) reported that both storage time and temperature significantly affected ‘Nam Dokmai’ mango flavor, and panelists indicated that off flavors caused by the release of alcohol and acetaldehyde were the main attributes negatively affecting mango flavor. However, acetaldehyde and ethanol appear to be normal components of ripe mango since both are present in mango fruit at the beginning of ripening and before storage, and their levels normally increase during ripening, even in air (Bender et al., 2000b).

Objectionable concentrations of ethanol and acetaldehyde due to fermentative metabolism may appear before the visual quality declines and limits the shelf life of fresh-cut fruits. For example, fresh-cut orange segments that had acceptable appearance after 14 d 4 °C were found to have unacceptable flavor quality after only 5 d (Beaulieu and Gorny, 2004). Likewise, undesirable flavor was the limiting factor in sliced and wrapped watermelon stored for 7 d at 5

°C, even though the aroma was still acceptable and microbial populations were not problematic after 8 d (Saftner et al., 2006).

In this study, the HW treatment did not affect the levels of total volatiles and alcohols in mango tissue for either of the harvests. Similar results were found by Plotto et al (2006), where the levels of acetaldehyde, ethanol, and β -pinene did not differ between +HW and –HW-treated ‘Kent’ mango pieces stored for 2 wk at 7 °C in clamshells. Moreover, it has been reported by several authors (Paull and Chen, 2000; Jacobi et al., 2001a, c; Dang et al., 2008) that whole mangoes that are undamaged by heat treatment (either hot water or hot air) have organoleptic qualities (i.e., flavor, aroma, pH, TSS, and TA) that are comparable to those of untreated fruit.

Conclusion

Edge tissue damage and desiccation of the slices were the most obvious visual quality changes observed in ripe, fresh-cut ‘Kent’ mango slices, limiting the shelf life to 5 d at 5 °C. No HW treatment effect was found in this experiment for the visual quality, RR, firmness, pH, TA, AA, total volatiles, or alcohols, but fresh-cut slices from non-HW-treated fruit had higher SSC than the HW-treated samples. Overall, the results suggest that the HW quarantine treatment used in this study and required by the USDA to be applied to mangoes entering the USA does not have a significant effect on the quality of fresh-cut ‘Kent’ mango slices prepared from those fruit and stored at 5 °C.

In this study, HW treatment was performed under optimal conditions, using fruit that were at a more advanced ripeness stage than typical commercially harvested mangoes, and the HW treatment was followed by appropriate cooling, which is not always done commercially and may have improved the recovery rate of treated fruit. Thus, the fact that the HW treatment in this study did not cause injury to the mangoes and did not affect the quality of the fresh-cut fruit during subsequent storage at 5 °C may not be representative of the commercial situation. In fact,

it is common to observe symptoms of heat injury on mangoes available on the market, due to improper quarantine heat treatment; therefore, it would be interesting to repeat this study under non-optimal conditions in order to observe the effect of treating unripe mangoes with HW on fresh-cut quality following storage.

Table 4-1. ANOVA table - Visual quality and aroma of fresh-cut 'Kent' mango slices.

Source of variation	d.f.	<i>F</i> -value				
		Overall color	Edge tissue damage	Aroma	Spoilage	Desiccation
<i>Harvest 1</i>						
Storage period	4	776.51***	85.89***	1164.11***	809.46***	556.94***
Hot water	1	< 0.01 ns	2.97 ns	2.15 ns	3.92 ns	1.18 ns
<i>Harvest 2</i>						
Storage period	4	1059.67***	<0.0001***	1693.76***	1874.54***	<0.0001***
Hot water	1	0.48 ns	< 0.01 ns	2.64 ns	1.10 ns	< 0.01 ns

ns, *, **, *** = Non-significant or significant at $P < 0.05$, 0.01 , or 0.001 , respectively

Table 4-2. AVOVA table - Respiration rates, electrolyte leakage, firmness, hue angle, lightness, of fresh-cut 'Kent' mango slices and whole mangoes.

Source of variation	d.f.	F-values				
		Respiration rate (mg/kg·h)	Electrolyte leakage (% of total)	Firmness (N)	Hue angle (H°)	Lightness (L*)
Harvest 1						
Storage period	4	13.07***	3.39 *	-	-	-
Hot water (H)	1	0.31 ns	0.01 ns	-	-	-
Fresh-cut/whole fruit (F)	1	6.91*	79.66***	-	-	-
H × F	1	1.67 ns	0.86 ns	-	-	-
Harvest 2						
Storage period	4	5.53**	8.96***	72.02***	6.53***	5.48**
Hot water (H)	1	13.62**	0.04 ns	0.27 ns	4.72*	1.21 ns
Fresh-cut/whole fruit (F)	1	146.52***	27.75***	64.42***	0.33 ns	106.17***
H × F	1	1.69 ns	0.16 ns	1.67 ns	0.15 ns	0.12 ns

ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively

Table 4-3. AVOVA table - Composition of fresh-cut 'Kent' mango slices and whole mangoes.

Source of variation	d.f.	<i>F</i> -values					
		pH	TA (% citric acid)	SSC (%)	AA (mg/100g fruit tissue)	Total alcohols (μ L/L)	Total non- alcohol volatiles (μ L/L)
<i>Harvest 1</i>							
Storage period	4	7.11 ^{***}	3.86 ^{**}	3.03 [*]	5.58 ^{***}	3.08 [*]	1.90 ns
Hot water (H)	1	5.50 [*]	9.06 ^{**}	13.24 ^{**}	1.40 ns	0.68 ns	0.35 ns
Fresh-cut/whole fruit (F)	1	0.00 ns	3.20 ns	11.01 ^{**}	2.09 ns	0.44 ns	0.12 ns
H \times F	1	0.22 ns	6.31 [*]	0.40 ns	3.86 ns	0.54 ns	0.59 ns
<i>Harvest 2</i>							
Storage period	4	20.98 ^{***}	16.06 ^{***}	1.18 ns	8.32 ^{***}	13.32 ^{***}	2.11 ns
Hot water (H)	1	0.04 ns	0.58 ns	9.96 ^{**}	0.05 ns	0.00 ns	0.98 ns
Fresh-cut/whole fruit (F)	1	5.80 [*]	0.75 ns	102.62 ^{***}	27.25 ^{***}	20.79 ^{***}	5.94 [*]
H \times F	1	8.13 ^{**}	0.07 ns	0.16 ns	3.65 ns	4.54 ^{**}	1.78 ns

ns, *, **, or *** = non-significant or significant at $P < 0.05, 0.01, \text{ or } 0.001$, respectively

Storage duration

Day 0

Day 2

Day 5

Day 7

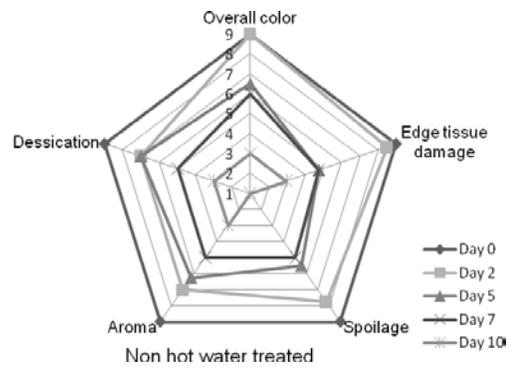
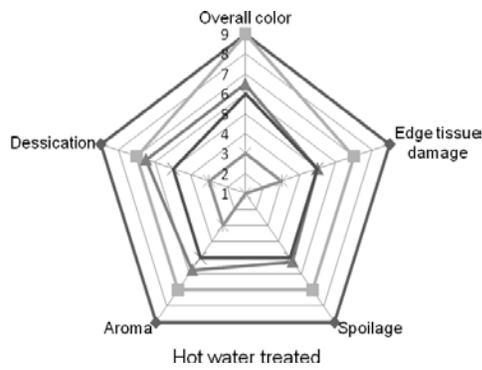
Hot water treatment

+HW

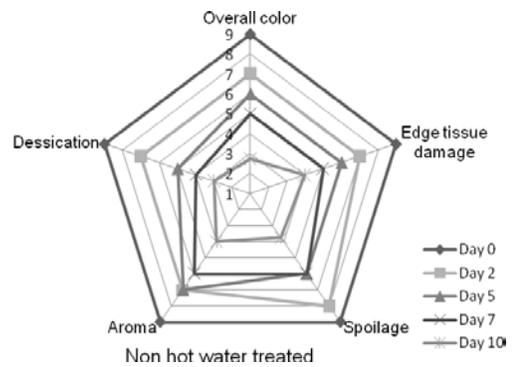
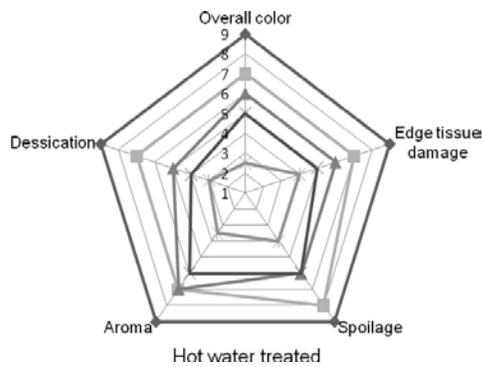
-HW



Figure 4-1. Fresh-cut slices from hot water (+HW) or non hot water (-HW) treated 'Kent' mangoes from harvest 1 during storage at 5°C.



A



B

Figure 4-2. Subjective visual evaluation of hot water-treated and non hot water-treated fresh-cut 'Kent' mango slices during storage from A) Harvest 1 or B) Harvest 2. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1, poor, inedible. Five is the minimum subjective score (limit) for marketing any product.

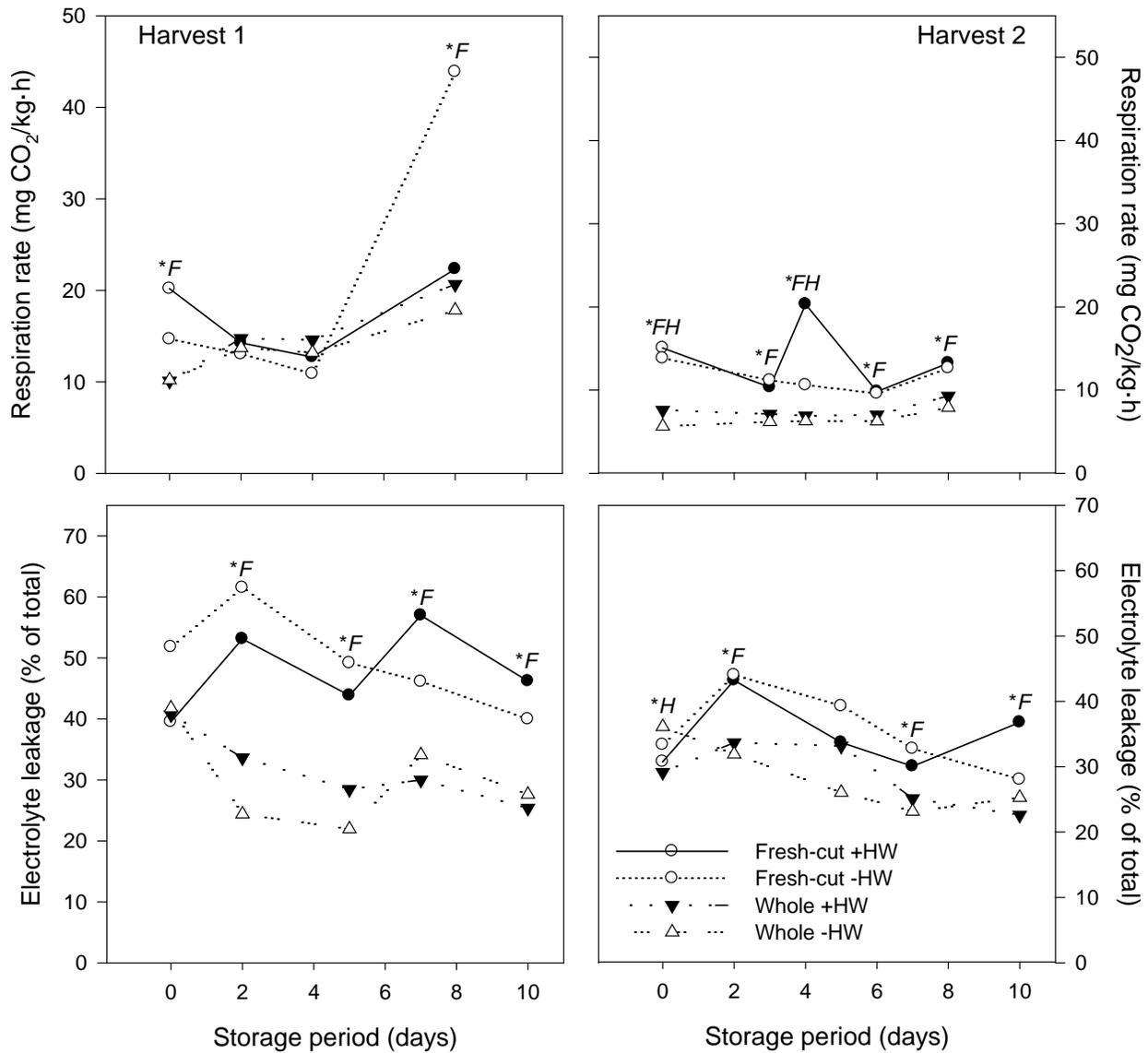


Figure 4-3. Respiration rate and electrolyte leakage during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non hot water (-HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and W (*H), or both (*FH), respectively, using LSD test.

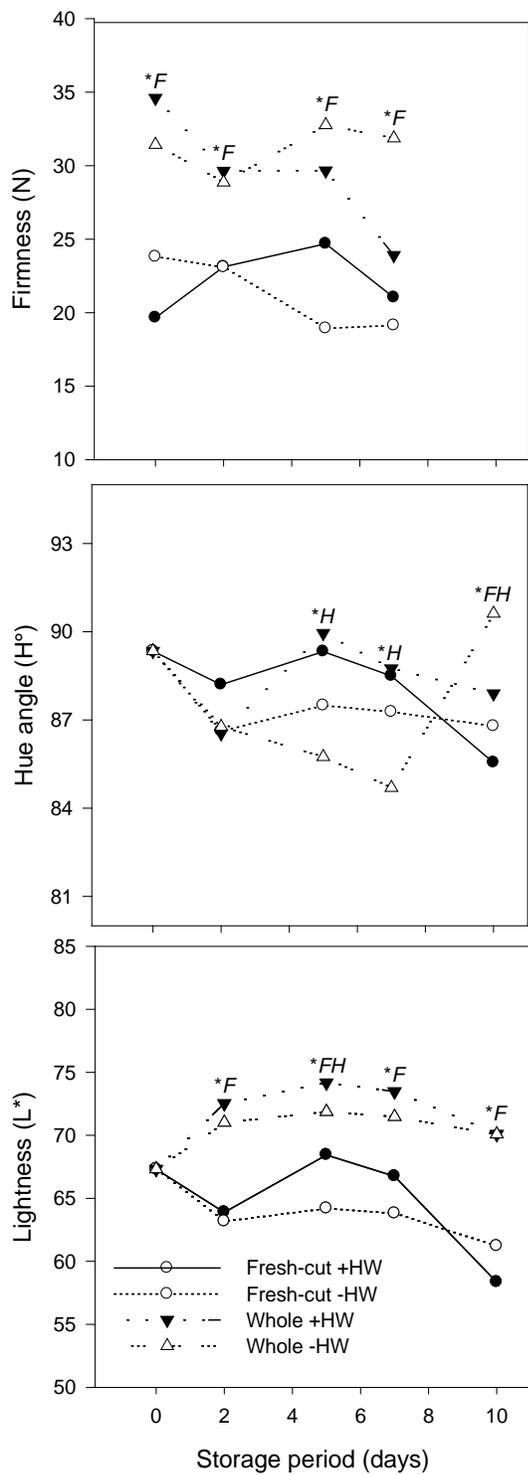


Figure 4-4. Changes in firmness, hue angle, and lightness during storage of fresh-cut ‘Kent’ mango slices and whole mangoes from hot water (+HW) or non hot water (-HW) treatments for Harvest 2. The symbols **F*, **H* or **FH* for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (**F*), +HW and -HW (**H*), or both (**FH*), respectively, using LSD test

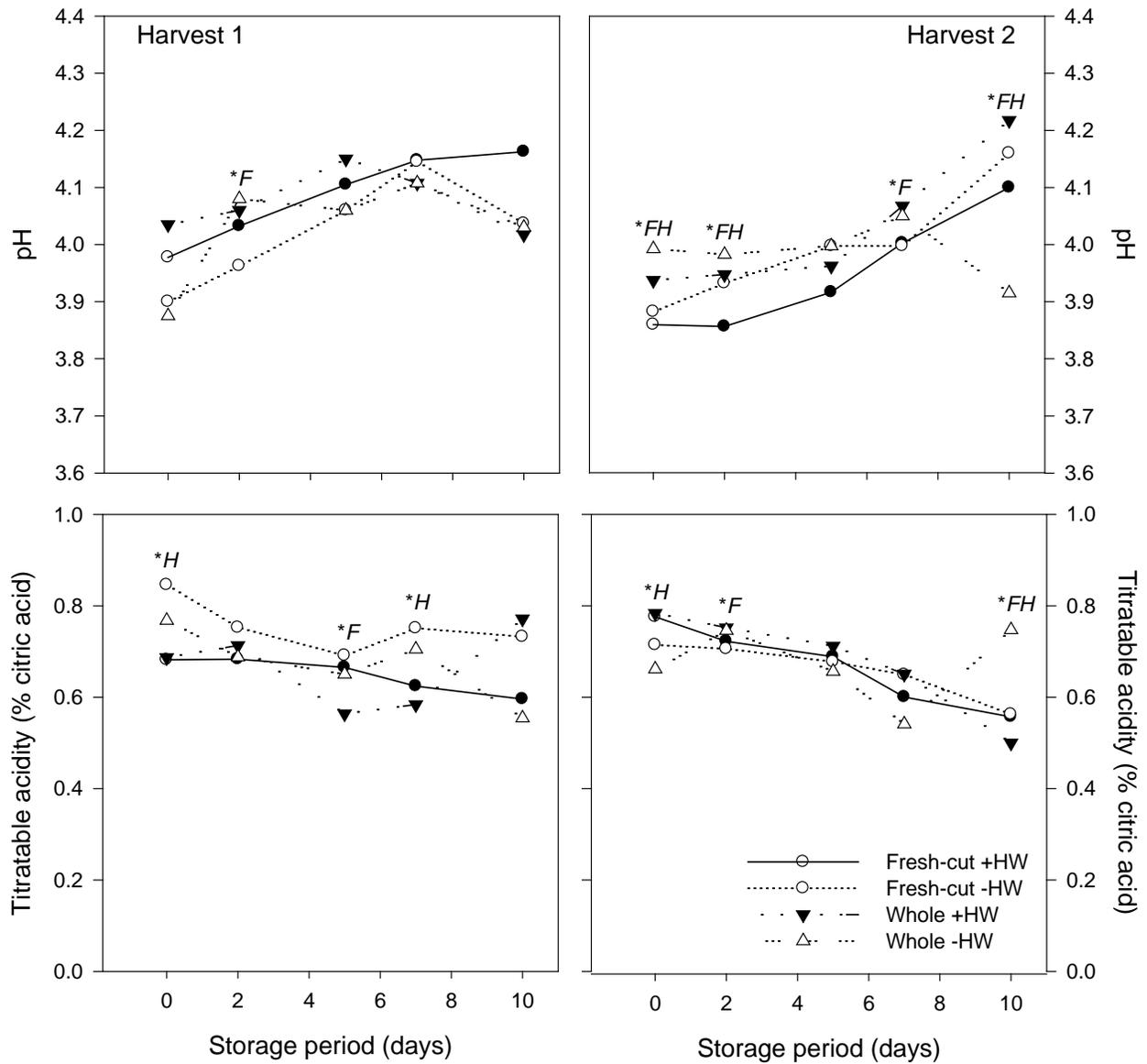


Figure 4-5. Changes in pH and titratable acidity during storage of fresh-cut ‘Kent’ mango slices and whole mangoes from hot water (+HW) or non hot water (-HW) treatments for Harvests 1 and 2. The symbols **F*, **H* or **FH* for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (**F*), +HW and -HW (**H*), or both (**FH*), respectively, using LSD test

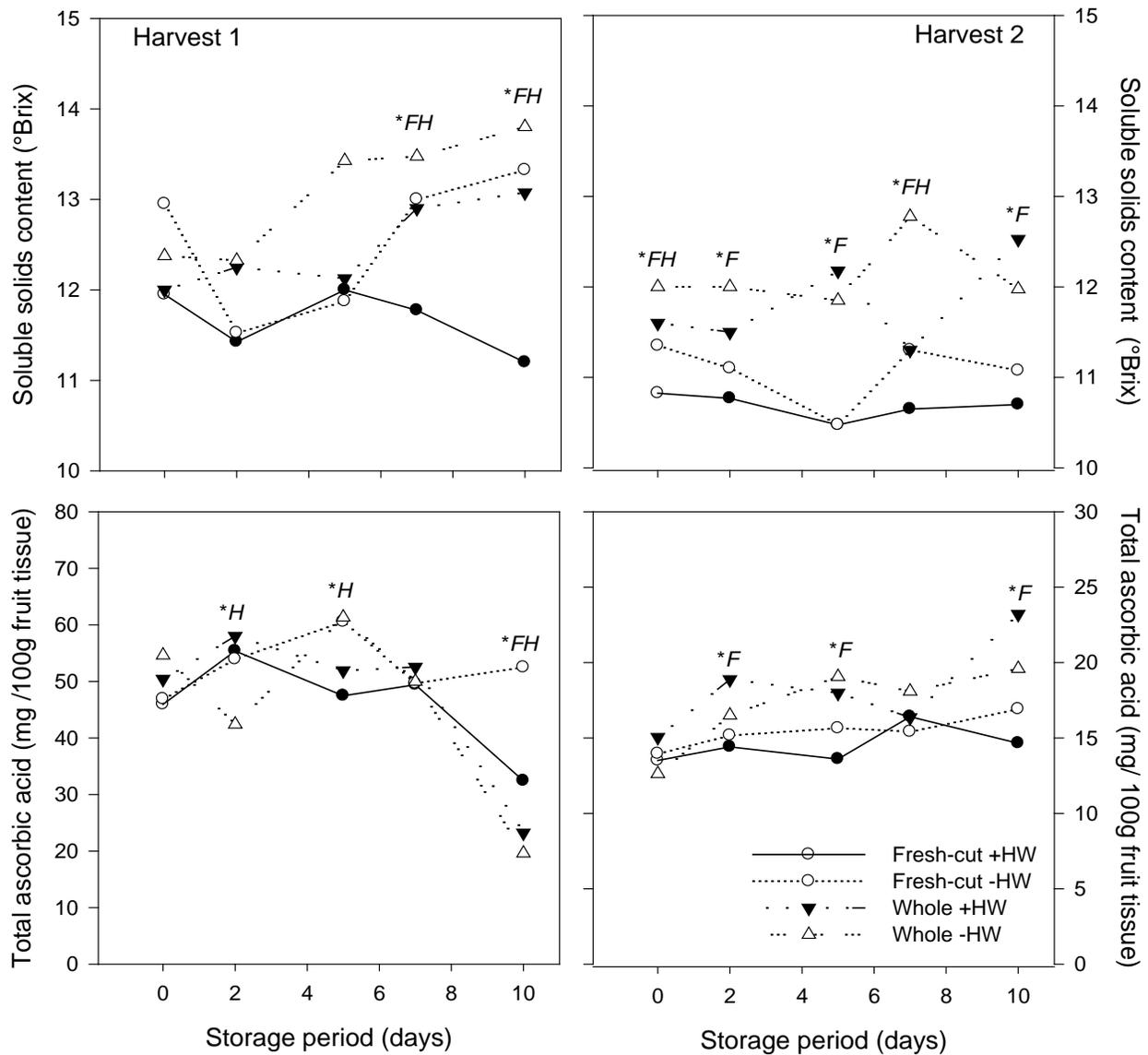


Figure 4-6. Changes in soluble solids content and total ascorbic acid during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non hot water (-HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and -HW (*H), or both (*FH), respectively, using LSD test.

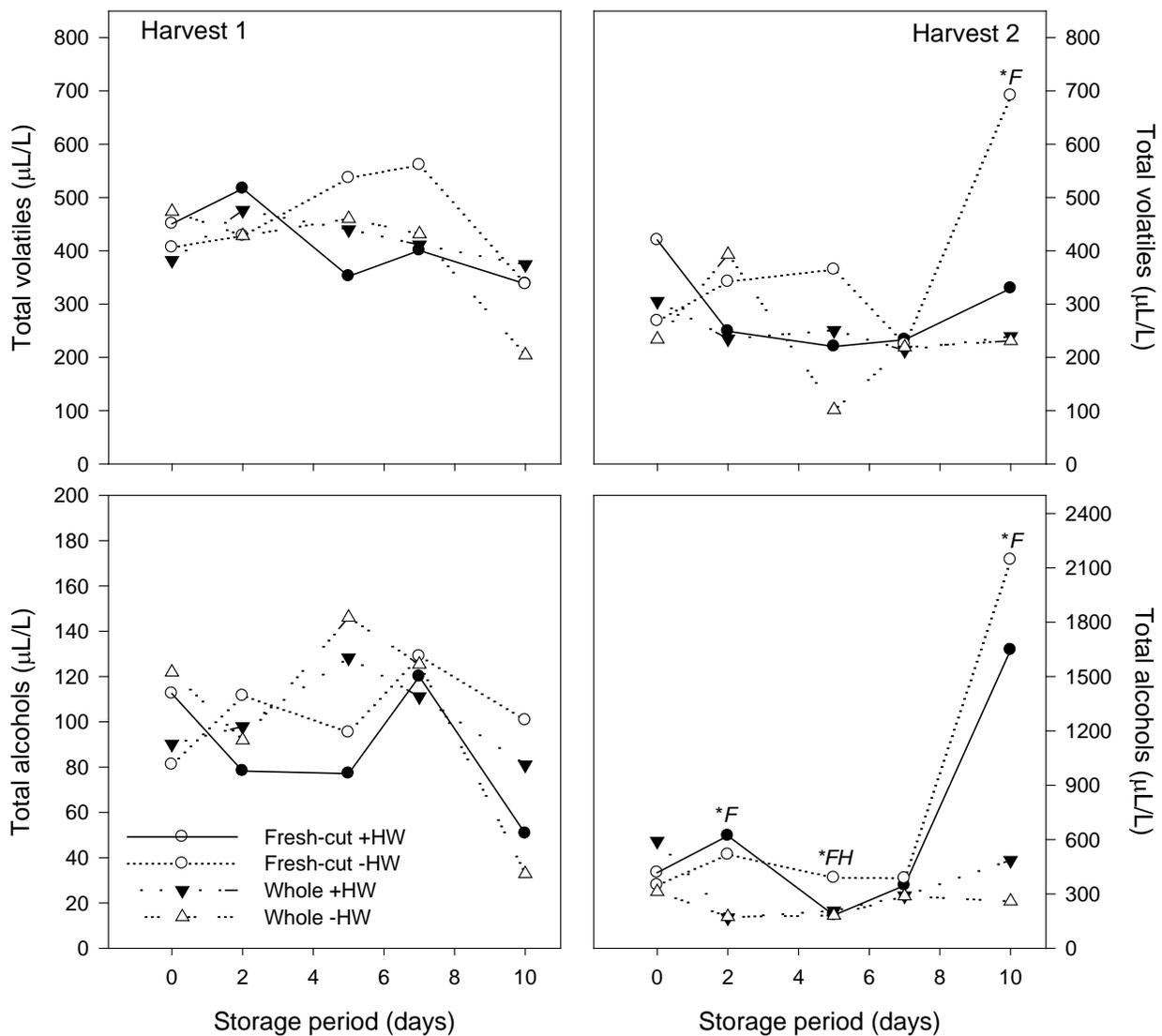


Figure 4-7. Changes in total volatiles (aldehydes, ketones, terpenes and esters) and total alcohols (methanol and ethanol) during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non hot water (-HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and -HW (*H), or both (*FH), respectively, using LSD test.

CHAPTER 5 OCCURRENCE OF CHILLING INJURY IN FRESH-CUT 'KENT' MANGOES

Introduction

To preserve the quality and safety of fresh-cut fruits and vegetables and to extend the shelf life, good temperature management is of prime importance. Due to their highly perishable nature, fresh-cut fruits are preferably stored at a temperature that may cause a slight amount of chilling injury (CI) over a temperature that is conducive to rapid natural deterioration (Watada and Qi, 1999). However, it is possible that low temperature storage of fresh-cut tropical fruit, like mangoes (*Mangifera indica* L.), may jeopardize their overall sensory quality by induction of CI.

It is known that poor flavor retention in fresh-cut products, especially fruit, is a widely recognized problem (Beaulieu and Gorny, 2004) and may be a symptom of CI related to inhibition of aroma volatile production. Moreover, some indications that fresh-cut products are subjected to CI have been noted despite little visual manifestations. For example, elevated respiration rates (RR) in fresh-cuts compared to the corresponding whole fruit may in some cases and to some extent, be an indicator of CI (Brecht et al., 2004). Juice leakage or tissue translucency due to membrane damage and solute leakage that occurs in fresh-cut tomatoes and melons is a critical problem in commercial fresh-cut products. It has been suggested that these symptoms may be manifestations of CI in fresh-cut tropical and subtropical fruit (Hong and Gross, 2001, Hodges and Toivonen, 2008). Besides, it may be possible to extrapolate the symptoms of CI occurring in whole fruit to their fresh-cut products, such as softening or other textural changes, increased rates of electrolyte leakage (EL), skin/peel darkening, loss of pigments, and increase in CO₂ production (Hodges and Toivonen, 2008).

Although CI of whole mango is well documented (Abou-Aziz et al. 1976a, b; Thomas and Oke, 1983; Chaplin et al., 1991; Lizada, 1991; Nair et al., 2004), very few studies have addressed

the effect of temperature on the incidence and symptoms of CI on fresh-cut mango (Beaulieu and Lea, 2003; Allong et al., 2000; Sothornvit and Rodsamran, 2008). In fact, most studies have indirectly reported the effect of temperature and focused on only a few quality attributes, often combined with different treatments that are known to alleviate CI, at least in whole fruit, such as coatings or modified atmosphere packaging (González-Aguilar et al., 2001; Tasneem et al., 2004; Pesis et al., 1997; Tefera et al., 2007). Therefore, a general conclusion regarding the incidence and symptoms of CI in fresh-cut mango remain unsettled. There may be sufficient expectation that the flavor of fresh-cut mango could be improved by avoiding chilling temperatures to justify efforts to develop supplementary treatments and procedures that allow this product to be handled at higher temperatures than those currently being used.

This study was conducted to evaluate the occurrence of CI in fresh-cut ‘Kent’ mango, using fresh-cut mango slices and whole mango fruit controls stored at chilling versus non-chilling storage temperatures.

Materials and Methods

Plant Material

This study was conducted twice during two Florida harvest seasons. Mangoes (cv. Kent) were obtained from a commercial growing operation in Homestead, Florida [first harvest (H1), July 2006] and from trees at the University of Florida Tropical Research and Education Center in Homestead, Florida [second harvest (H2), July 2007]. Fruit were removed from the field with minimal delay after harvest and transported to the postharvest laboratory in Gainesville, Florida, within approximately 6 h. Mangoes were selected based on uniformity of size, color, and freedom from defects.

Following HW and ethylene treatment, the mangoes were held overnight in refrigerated and sanitized rooms at either 5 ° or 12 °C before being processed into fresh-cut slices. Half of the fruit at each temperature were processed into fresh-cut slices while the other half were left whole (control) as described in Chapter 3. Whole fruit controls and a total of eight mixed slices per container were stored at 5 or 12 °C for 10 d. Four whole fruit and four containers of fresh-cut slices per treatment were used for analysis at each sampling time. Prior to analysis, the whole fruit were also processed into fresh-cut slices as described in Chapter 3.

Visual Quality Evaluation and Measurement of Flesh Color, Respiration Rate, Electrolyte Leakage, and Composition, Including Volatiles

‘Kent’ mangoes were evaluated for visual quality, and the flesh color, respiration rate (RR), electrolyte leakage (EL) and composition of the tissue, including volatiles, were measured as described in Chapter 3.

Firmness Evaluation

Slice firmness of fruit from H2 was measured following the method described in Chapter 4.

Statistical Analysis

A completely randomized design was used for this study with evaluation or analysis of composite samples of eight slices from four replicate containers per treatment and sampling time, except that 10 color measurements were made on 10 slices taken from 4 containers per treatment and sampling time. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. Statistical analysis was performed using the PC-SAS software package (SAS-Institute, 1985). Analysis of variance (ANOVA), using the General Linear Model, was conducted to identify significant main effects due to storage duration, fresh-cut versus whole, and storage temperature. Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. The harvest seasons,

H1 and H2, showed significantly different effects for all treatments evaluated, and were therefore analyzed separately. This difference could be explained by different climatic conditions and/or the location where the mangoes were grown.

Results and Discussion

Subjective Quality

Storage duration and temperature had significant effects on the visual quality of fresh-cut 'Kent' mango slices (Table 5-1) in that the visual quality and aroma of slices from both harvests and storage temperatures decreased consistently during storage, but the changes were significantly faster at 12 °C than at 5 °C (Figures 5-1 and 5-2).

For H1, the fresh-cut slices stored at 12°C reached the marketability limit (rating of 5) after 3 d of storage, compared to 5 d at 5 °C. The shelf life of fresh-cut mango slices stored at 5 °C was limited by edge tissue damage, characterized by edges that were slightly soggy or water-soaked with darker color, veins markedly brown, and a gooey appearance from tissue breakdown, while the slices stored at 12 °C rapidly became water-soaked, with obvious edge damage, like compression bruising, with a gooey appearance and a strong fermented off odor.

For H2, the shelf life of fresh-cut slices stored at 5 °C was limited to 5 d due to desiccation, characterized by a progressive drying of the slice edges with little to no surface gleam, and slightly dehydrated surfaces (Figure 5-2). At 12 °C, the slices became unmarketable after about 4 d due to progressive drying, followed by off odor, edges slightly soggy or water-soaked with darker color, and slight softening of the tissues.

Even though the variability in the shelf life of fresh-cut mango is mostly cultivar and ripeness stage dependent (Allong et al., 2001), in this study slices stored at 5 or 12 °C had similar shelf life compared with values previously reported in the literature. For example, Rattanapanone et al. (2001) reported that the marketable period of fresh-cut 'Tommy Atkins' and 'Kent' mango

cubes was 3 to 5 d at 10 °C and 5 to 8 d at 5 °C, and shelf life was limited by watery condition, discoloration, and loss of fresh appearance of the mango cubes. The shelf life of ‘Nam Dokmai’ mango cubes was only 2 d at 5 °C and 1 d at 13 °C, and was limited by browning and water soaked appearance on the cut surfaces (Poubol and Izumi, 2005a, b). Beaulieu and Lea (2003) reported that shelf life of fresh-cut mango cubes from “soft-ripe” mangoes was limited to 7 d when stored at 4 °C with the most critical factor being edge or tissue damage, resulting in mushy tissue and poor texture, followed by aroma loss and general discoloration.

Compared with fresh-cut slices stored at 12 °C, slices stored at 5 °C did not show any visible signs of CI. However, the natural visual quality loss of the fresh-cut slices was faster at the higher temperature. Moreover, even though the grading system that we used for evaluating fresh-cut mango aroma was designed to detect off odors in the samples, little aroma was perceived in the slices stored at 5 °C compared with freshly prepared slices from stored whole fruit (data not shown). Loss in aroma was previously reported in fresh-cut fruits (Beaulieu and Gorny, 2004, Forney, 2007) and has been identified as a symptom of CI in whole mango fruit (Nair et al., 2003; 2004). On the other hand, no external CI symptoms developed on the whole mangoes stored at 5 °C during the same storage period as fresh-cut mango slices (data not shown). Even though the whole fruit were not transferred to room temperature to allow the CI symptoms to develop, it is plausible that the fruit may not have suffered from CI since they were partially ripe when exposed for a short period to 5 °C. Mango susceptibility to CI declines as the fruit mature and ripen as reported by Mohammed and Brecht (2002) who found that immature-harvested ‘Tommy Atkins’ mangoes stored at 5 °C for 18 d exhibited higher incidence of visible CI symptoms upon warming to 20 °C than half-mature fruit, which showed a trace of CI, and mature fruit (ripening not initiated at harvest), which showed no trace of CI. Furthermore, Mohammed and Brecht (2000) showed that exposure of half-mature ‘Palmer’ mangoes to 100

$\mu\text{L/L}$ ethylene for 1 d at 20 °C prevented visible CI symptom development during 15 d storage at 5 °C plus 1 or 3 d at 20 °C compared with non-ethylene-treated fruit, which developed moderate symptoms of CI.

Respiration Rate Measurements

The overall RR of fresh-cut slices was significantly higher than that of whole fruit for both harvests (Table 5-2, Figure 5-3). Storage duration and temperature did not significantly affect the RR of whole or fresh-cut mango in H1 (Table 5-1), but had significant effects on the RR of fruit from H2 (Table 5-2) with those fruit stored at 12 °C exhibiting higher RR than the fruit stored at 5 °C (Figure 5-3).

For H1, from day 0 to day 2, the RR of the fresh-cut slices stored at 5 °C decreased to rates that were similar to those of whole fruit and remained comparable for the rest of the marketable period. At 12 °C, however, the RR of the slices decreased during storage to reach rates similar to whole fruit only at day 8, which was past the marketability limit.

For H2, fresh-cut slices had higher RR compared with whole fruit; except on days 3 and 8 when the RR of fresh-cut slices and whole fruit reached comparable levels (Figure 5-3). A burst on RR was observed on day 4 in the fresh-cut slices stored at 5 °C, which returned on day 6 to rates similar to those observed on day 3. This sudden increase in respiration could have been a response to chilling stress, although the same was not observed in H1, but was rather observed as an increase in RR at the end of the storage period, past the marketable period.

The RR of fresh-cut mango slices measured in this study was in accordance with data previously reported. For example, Allong et al. (2001) showed high RR for 'Julie' and 'Graham' mangoes measured immediately after slicing, with RR decreasing significantly within the first 12 h of storage at 5 or 10 °C. Slices held at 10 °C produced substantial amounts of CO₂ but storage at 5 °C greatly reduced CO₂ production rates at all stages of ripeness (Allong et al., 2001).

Electrolyte Leakage

For both harvests, higher electrolyte leakage (EL) was measured from fresh-cut slices that were stored for a few days before analysis compared to the whole fruit controls that were cut on the day of analysis (Table 5-2). This is to be expected since EL is an indicator of loss of cell membrane integrity attributable to ripening, or any damage that can arise from stress or mechanical injury (Nyanjage et al., 1999).

For H1, storage at 5 °C induced higher EL from fresh-cut slices than storage at 12 °C, while the levels of EL for whole fruit stored at 5 °C or 12 °C were similar, and tended to decrease during storage (Figure 5-3). The high EL of fresh-cut tissue at 5 °C compared with slices stored at 12 °C may be a sign of CI related to loss of integrity of the fruit tissue (Vicente et al., 2006), while the decrease of EL in whole fruit could be attributable-to further ripening that may have led to higher osmotic potential and thereby reduced electrolyte leakage (Nyanjage et al., 1999).

For H2, storage temperature did not have a significant effect on the EL level during storage, while storage duration and the type of sample significantly affected the EL measured (Table 5-2). However, the EL of fresh-cut slices was significantly higher than that of whole fruit after the marketable period had passed (Figure 5-3). The EL of whole fruit tended to decrease slightly during storage, as observed in H1, while the EL measured in fresh-cut slices from both storage temperatures showed a similar increase from day 0 to 2, and a decrease during the rest of the storage period.

Firmness

Storage duration and fresh-cut processing had significant effect on the firmness of the fruit whereas storage temperature had no significant effect on fruit firmness (Table 5-2). For both harvests, slice firmness decreased during storage regardless of the temperature. However, greater softening occurred in the fresh-cut slices than in the whole fruit (Figure 5-4). In this study, the

fresh-cut slices were prepared a few hours earlier than the initial whole fruit samples were cut, and the firmness of all of the sample replicates was measured at the same time, which may have contributed to the initial lower firmness (day 0) of fresh-cut slices compared to whole fruit.

Fresh-cut slices stored at 5 °C showed a slight increase in firmness during storage, while a significant loss of firmness was measured for the slices stored at 12 °C. More interestingly, firmness of whole fruit stored at 5 °C decreased by approximately 31.0% during storage while no change in firmness occurred in the whole fruit stored at 12 °C. This difference may be attributable to CI caused by exposure of the fruit to low temperature. It is recognized that the primary response to chilling temperatures involves a decrease in fluidity of the micro-domains of cell membranes, and damage to critical membrane proteins leading to increased membrane rigidity, resulting in softening of the tissue (Wang, 1982; Kays, 1991). The decrease in firmness in whole mango fruit stored at 5 °C suggests that CI may have occurred during storage in both whole fruit and fresh-cut slices.

Flesh Color

Storage duration, storage temperature, and fruit type (whole or fresh-cut) had significant effects on the lightness (L^* value) of the slices (Table 5-2) in that the whole fruit flesh lightness tended to increase during storage, while the flesh lightness of the fresh-cut slices decreased during storage, indicating darkening of the surface color (Figure 5-4). The increase in lightness of the whole fruit may be attributable to a loss of green color that occurred prior to a rise in yellow-orange color as indicated by an increase in a^* value, which followed a similar pattern to the L^* value during storage (data not shown). Moreover, darkening was more pronounced in the fresh-cut slices stored at 12 °C than in those stored at 5 °C.

Hue angle decreased during storage, but no differences between fresh-cut slices and whole fruit were observed (Table 5-2). The slices and whole fruit stored at 12 °C had lower hue angle

(more orange) than the slices and whole fruit stored at 5 °C (more yellow), probably due to the continuation of ripening during storage at the higher storage temperature.

Fruit Composition

pH, titratable acidity, soluble solids content

Storage duration and temperature had significant effects on the pH of whole and fresh-cut fruit (Table 5-3) as the fruit pH increased significantly throughout storage for all treatments and in both harvests (Figure 5-5). Greater increases were observed for the fruit stored at 12 °C than those stored at 5 °C, but the pH levels were similar for fresh-cut slices and whole fruit. Although there was a statistically significant effect of storage duration on pH, the pH changes were so small (≤ 0.2 pH units) that it would have been practically impossible to detect such differences between fruit by taste evaluations. Several previous studies reported that there were no significant changes in pH during the storage of fresh-cut mangoes (Paull and Chen, 2000; Gil et al., 2006; González-Aguilar et al., 2007a).

No significant differences in fruit TA were observed, for both harvests, or between fresh-cut slices and whole fruit, whereas storage duration and temperature both significantly affected fruit acidity (Table 5-2). The acidity of fresh-cut and whole mango decreased slightly during storage for both harvests (Figure 5-5). Lower TA was measured in slices and whole fruit stored at 12 °C than in those stored at 5 °C, most likely due to the faster continuation of ripening and higher RR of the fruit stored at 12 °C. Results from this study agree with others that reported declining TA as mangoes ripen (Tharanathan et al., 2006; Karla and Tandon, 1983; Medlicott and Thompson, 1985; Selvaraj et al., 1989).

Storage duration did not have a significant effect on the SSC of the fruit from both harvests (Table 5-2). The whole fruit retained significantly higher SSC during storage than the fresh-cut slices, regardless of the storage temperature (Figure 5-6). These results are in accordance with

some previous reports in which no significant changes were noticed in SSC during the storage of fresh-cut mangoes held at 4 or 5 °C for periods of 8 to 14 d (Rattanapanone et al., 2001; Gil et al., 2006; González-Aguilar et al., 2007a). Lower acidity, higher pH, and higher SSC in whole fruit and fresh-cut slices stored at 12 °C compared to the fruit and slices stored at 5 °C indicates that ripening continued at a faster rate in fruit stored at the higher temperature.

Total ascorbic acid

The initial amounts of total ascorbic acid (AA) expressed on a fresh weight basis were much higher in fruit from H1 than in fruit from H2 (Figure 5-6). This could be explained by the different growing locations, seasons and climatic conditions under which the mangoes were grown (Lee and Kader, 2000).

For H1, there were no significant effects of storage duration and type of fruit (whole or processed) on the AA content (Table 5-2). However, the AA concentration did vary between storage temperatures. On day 2, the whole fruit and slices stored at 5 °C had higher AA than those stored at 12 °C, but for the rest of the storage period, the whole fruit and slices stored at 12 °C had higher AA than those stored at 5 °C (Figure 5-6).

For H2, significant effects of storage duration and fresh-cut versus whole fruit on the AA content were observed (Table 5-2). The concentration of AA increased during storage and whole fruit showed significantly higher AA than the fresh-cut slices (Figure 5-6). There was also a significant effect of temperature on the AA content, with the fruit stored at 12 °C having higher AA than those stored a 5 °C.

It has been reported that AA degrades very little during short-term refrigerated storage (about 1 wk at 5 °C) in some fresh-cut fruits (Beaulieu and Gorny, 2004). Tovar et al. (2001) reported that the AA concentration in mango decreased as ripening progressed while the opposite occurred in fresh-cut slices. In fact, they found that the AA content of the slices stored at 5 or 13

°C increased, but never reached the levels measured in whole fruit. Others have reported increases in AA during refrigerated storage (5, 7, 10 or 15 °C) of ‘Alphonso’ mangoes and suggested that ascorbate synthesis occurred under such conditions (Thomas, 1975; Thomas and Joshi, 1988). The hypothesis that the increase of AA concentration on a fresh weight basis during storage may be due to water loss during storage rather than to actual increase in AA (Nunes et al., 1998) is not supported in this case since the percentage of weight loss (data not shown) was less than 0.5% of the initial weight and no exudates was noticed in the containers of fresh-cut fruit.

No difference between AA content of whole fruit and fresh-cut slices was observed for H1, while for H2, AA content of fresh-cut slices was lower than in the whole fruit. It is known that levels of AA can decrease after processing or during ripening. Since oxidative processes occur more rapidly in fresh-cut products, these are expected to have more AA losses compared with whole fruit (Allong et al., 2000). Moreover, the reduced AA content of fresh-cut fruit at 5 °C compared with those stored at 12 °C, probably due to reactions with reactive oxygen species induced by chilling stress (Tatsumi et al., 2006), suggests that the fresh-cut slices did suffer from CI.

Volatiles

For ease of comparison, and due to the lack of significant differences between the treatments for the majority of the 16 volatiles measured, the aldehydes (acetaldehyde, hexanal), ketone (acetone), terpenes (α -pinene, β -pinene, limonene, ρ -cymene, α -copaene, 3-carene, myrcene, α -terpinolene, caryophyllene), and esters (ethyl acetate, ethyl butyrate) were summed and presented as total (non-alcohol) volatiles; ethanol and methanol were summed separately and presented as total alcohols (Figure 5-7).

Total non-alcohol volatiles decreased during storage for H1 (Figure 5-7) but no significant differences were found between whole fruit and fresh-cut slices or between storage temperatures

(Table 5-2). Changes in total alcohol content were also observed during storage (Table 5-2), with the least alcohol content measured on day 10 (Figure 5-7). No difference between fresh-cut slices and whole fruit or between storage temperatures was observed (Table 5-2). In fact, acetaldehyde, methanol, myrcene, and ethylacetate were the only volatiles to show significant changes during storage (data not shown). In general, acetaldehyde concentration decreased by day 5 and remained constant for the rest of the storage, while methanol was significantly higher on day 2 and higher concentrations of myrcene and ethyl acetate were present on day 10.

For H2, however, there was significantly higher content of alcohols (mainly ethanol) throughout the storage period in the fresh-cut slices stored at 12 °C, and on day 10 for the fresh-cut slices stored at 5 °C, compared with the whole fruit. No significant differences were found for the total non-alcohol volatiles present in the fruit from H2. But, when the volatiles were analyzed individually, acetaldehyde, ethyl acetate, and ethyl butyrate were significantly reduced in the fruit stored at 5 °C compared with 12 °C (data not shown). However, acetaldehyde content was higher in stored fresh-cut slices compared to whole fruit at 5 °C, while whole fruit had higher α -pinene, limonene, and *p*-cymene contents. At 12°C, fresh-cut slices had higher contents of acetaldehyde, acetone, ethyl acetate, and ethyl butyrate compared with whole fruit (data not shown).

It is known that anaerobic respiration in fruit tissues is characterized by increases in ethanol, ethyl acetate, ethyl butanoate, and acetaldehyde (Beaulieu and Lea, 2003). The major plant fermentative metabolic products in fruit are ethanol and acetaldehyde, and their accumulation is well-correlated with off flavor development (Ke et al., 1991; Ke and Kader, 1992; Agar et al, 1999). Normally these volatiles accumulate at low levels during mango fruit ripening and thereby play an important role in the development of mango aroma volatiles. But, following exposure to anoxic conditions, acetaldehyde and ethanol may be markedly enhanced, leading to the perception of off flavor (Shi et al., 2007). For example, Sothornvit and Rodsamran

(2008) reported that both storage duration and temperature significantly affected 'Nam Dokmai' mango flavor, and panelists indicated that off flavors caused by the release of alcohol and acetaldehyde were the main attributes negatively affecting mango flavor. In this study, development of such off flavor was observed only in the fresh-cut slices stored at 12 °C.

It is also known that chilling temperatures adversely affect volatile production. Nair and Singh (2004) reported that the mean total monoterpenes, sesquiterpenes, hydrocarbons, esters, aldehydes, norisoprenoids, and total aroma volatiles were significantly reduced in whole 'Kensington Pride' mangoes stored at chilling temperature (5 °C) compared with the fruit stored at non-chilling temperature (15 °C). Overall, in this study, volatile profiles did not appear to be greatly compromised by exposure to chilling temperature, although subjective evaluation indicated that aroma intensity tended to decline more during storage of fresh-cut slices at 5 °C than at 12 °C. This difference in aroma perception could be explained by a modest decrease in one or more odor active volatiles due to low storage temperature that was not apparent from statistical analysis. Also, volatiles not measured during this study, such as lactones, which are believed to be important flavor notes in some Indian and Florida varieties (Wilson et al., 1990), or others such as sesquiterpenes or ketones (Pandit et al., 2009), could have been affected by low storage temperature (Nair and al., 2004) and modified the aroma of fresh-cut slices.

Moreover, it is possible that the samples were not all at the same temperature when evaluated. All samples from 5°C were exposed to room temperature (22 °C) for less than 1 h before being evaluated, while those from 12 °C were evaluated upon removal from the storage room. Thus, there may have been less aroma volatilization and lesser aroma perceived in the colder samples. Or, it is also probable that, compared with the slices stored at 12 °C, which rapidly developed a strong off flavor during storage, the 5 °C samples would be perceived to have less strong aroma in comparison.

Conclusion

This study compared the effect of putative chilling (5 °C) and non-chilling (12 °C) storage temperatures on the quality and physiology of fresh-cut 'Kent' mango slices compared with whole mango fruit controls. The shelf life of fresh-cut mango slices was about 5 to 6 d at 5 °C versus 3 to 4 d at 12 °C. The shelf life of the slices was limited by slight sogginess of the slice edges or water-soaking with darker color, or darkening of veins, slight softening, and desiccation; aroma intensity declined in slices stored at 5 °C while off odors related to fermentative metabolism developed in slices stored at 12 °C. The overall difference in the quality of whole fruit versus fresh-cut slices was more important than the effect of storage temperature for EL, RR, firmness, and SSC. However, the effect of temperature on the overall quality was more important than the effect of whole fruit versus fresh-cut for pH, TA, color (hue angle), and total AA.

The most striking difference between the two storage temperatures was the appearance and aroma of the slices and to a lesser extent their compositional changes. It is unclear whether the storage duration at 5 °C was sufficiently long enough to cause CI in the fresh-cut mango slices since no visual CI symptoms developed in the whole fruit. However, reduced AA content, limited reductions of volatiles, and increased softening of whole fruit stored at 5 °C, which are all indicative of CI, suggest that the fresh-cut slices probably experienced chilling stress. Nevertheless, injury of fresh-cut 'Kent' mango slices resulting from exposure to 5 °C, if at all, was apparently less significant than the natural deterioration and off odor development of the fresh-cut slices stored at 12 °C. Thus, fresh-cut mango slices had a longer shelf life when stored at 5 °C than at 12 °C.

Table 5-1. ANOVA table - Visual quality and aroma of fresh-cut 'Kent' mango slices.

Source of variations	d.f.	F-value				
		Overall color	Edge or tissue damage	Aroma	Spoilage	Desiccation
<i>Harvest 1</i>						
Storage duration	4	150.63***	67.34***	88.94***	33.29***	175.05***
Storage temperature	1	13.98**	14.12**	12.93**	3.48**	18.57**
<i>Harvest 2</i>						
Storage duration	4	379.95***	1104.80***	313.05***	18.08***	292.50***
Storage temperature	1	0.09 ns	92.00***	21.84***	0.01 ns	21.82***

ns, *, **, *** = Non-significant or significant at P< 0.05, 0.01, or 0.001

Table 5-2. AVOVA table - Respiration rates, electrolyte leakage, firmness, hue angle, lightness, and composition of fresh-cut 'Kent' mango slices and whole mangoes.

Source of Variation	d.f.	F-value				
		Respiration rate (mg/kg·h)	Electrolyte leakage (% of total)	Firmness (N)	Hue angle (H°)	Lightness (L*)
<i>Harvest 1</i>						
Storage duration	4	1.26 ns	2.39ns	-	-	-
Fresh-cut/Whole fruit (F-W)	1	15.62**	30.02***	-	-	-
Storage temperature (T)	1	0.01 ns	7.12**	-	-	-
(T)× (F-W)	1	1.10 ns	6.97*	-	-	-
<i>Harvest 2</i>						
Storage duration	4	3.22*	5.51**	33.01***	4.79**	3.87**
Fresh-cut/Whole fruit (F-W)	1	138.69***	20.01***	78.17***	1.46 ns	118.77***
Storage temperature (T)	1	51.65***	3.55 ns	1.95 ns	21.14***	18.70***
(T)× (F-W)	1	0.02 ns	0.01 ns	8.26**	0.07 ns	3.06*

^aRespiration rate

^bElectrolyte leakage

ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively

Table 5-3. AVOVA table - Respiration rates, electrolyte leakage, firmness, hue angle, lightness, and composition of fresh-cut 'Kent' mango slices and whole mangoes.

Source of Variation	d.f.	F-value					
		pH	TA (% citric acid)	SSC (%)	AA (mg/100g)	Total alcohol volatiles (μ L/L)	Total non- alcohol volatiles (μ L/L)
<i>Harvest 1</i>							
Storage duration	4	14.66***	7.11***	0.95 ns	1.16 ns	4.23**	2.21**
Fresh-cut/Whole fruit (F-W)	1	0.28 ns	0.52 ns	9.46**	2.91 ns	2.96 ns	0.77 ns
Storage temperature (T)	1	62.97***	20.58***	4.82*	10.88**	0.02 ns	2.69 ns
(T) \times (F-W)	1	0.92 ns	2.01 ns	0.60 ns	1.76 ns	2.61 ns	0.008 ns
<i>Harvest 2</i>							
Storage duration	4	57.80***	66.22***	0.45 ns	13.76***	2.81 ns	1.62 ns
Fresh-cut/Whole fruit (F-W)	1	7.69**	0.24 ns	26.92***	36.13***	2.77 ns	17.31***
Storage temperature (T)	1	124.02***	85.96***	0.13 ns	18.88***	1.30 ns	12.95**
(T) \times (F-W)	1	4.71*	0.24 ns	21.48***	0.03 ns	0.35 ns	8.98*

^aRespiration rate

^bElectrolyte leakage

ns, *, **, or *** = non-significant or significant at $P < 0.05$, 0.01 , or 0.001 , respectively

Storage duration

Day 0

Day 2

Day 5

Day 7

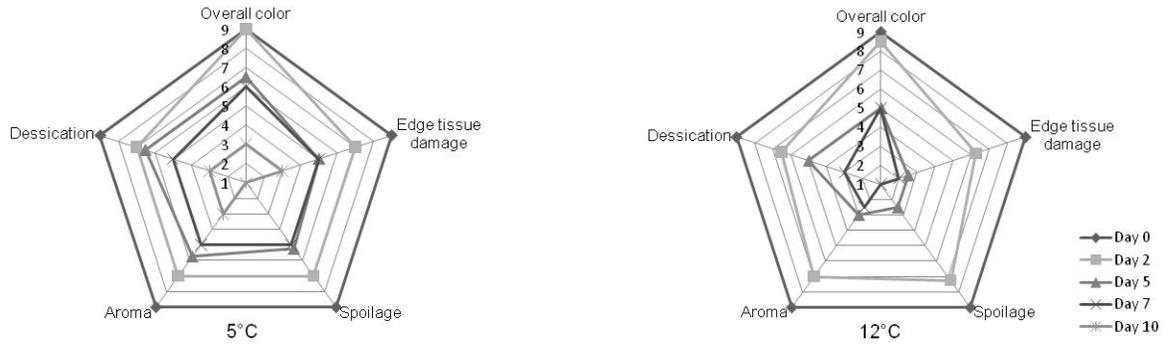
Storage temperature

5 °C

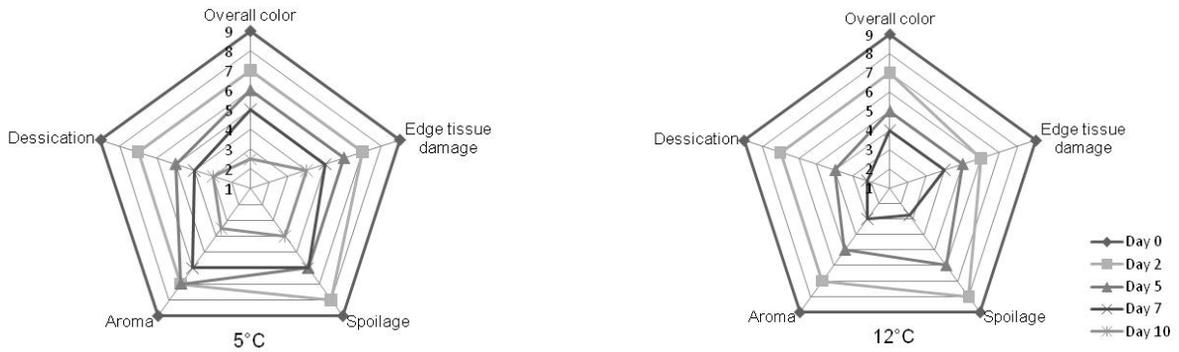
12 °C



Figure 5-1. Fresh-cut 'Kent' mango slices from Harvest 1 during storage at 5 °C or 12 °C.



A



B

Figure 5-2. Subjective visual evaluation of fresh-cut 'Kent' mango slices during storage at 5°C or 12°C. A) Harvest 1. B) Harvest 2. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1, poor, inedible. Five is the minimum subjective score (limit) for marketing any product.

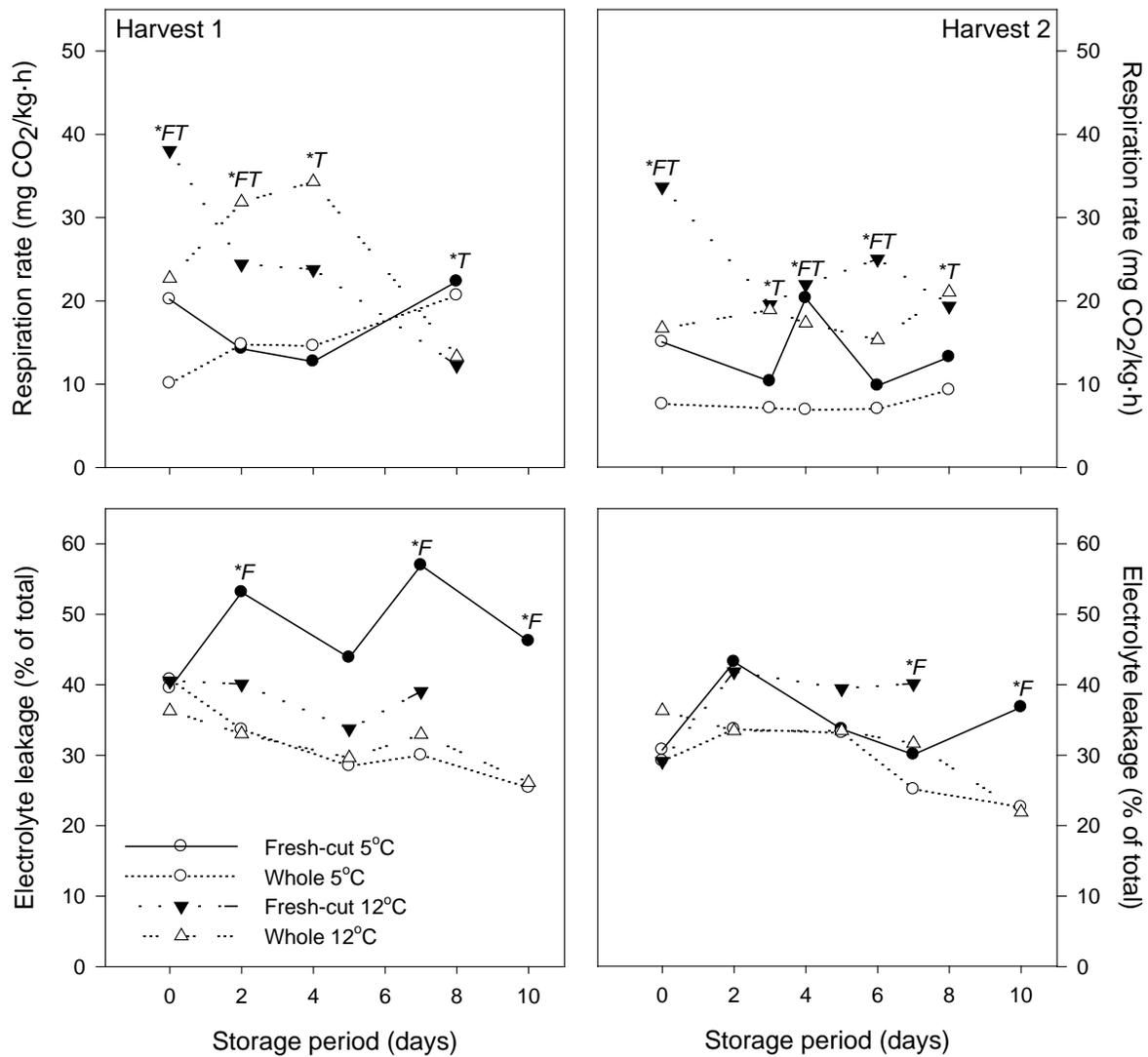


Figure 5-3. Changes in respiration rate and electrolyte leakage during storage of fresh-cut 'Kent' mango slices and whole mangoes at 5 °C or 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 °C and 12 °C), or both, respectively, using the LSD test.

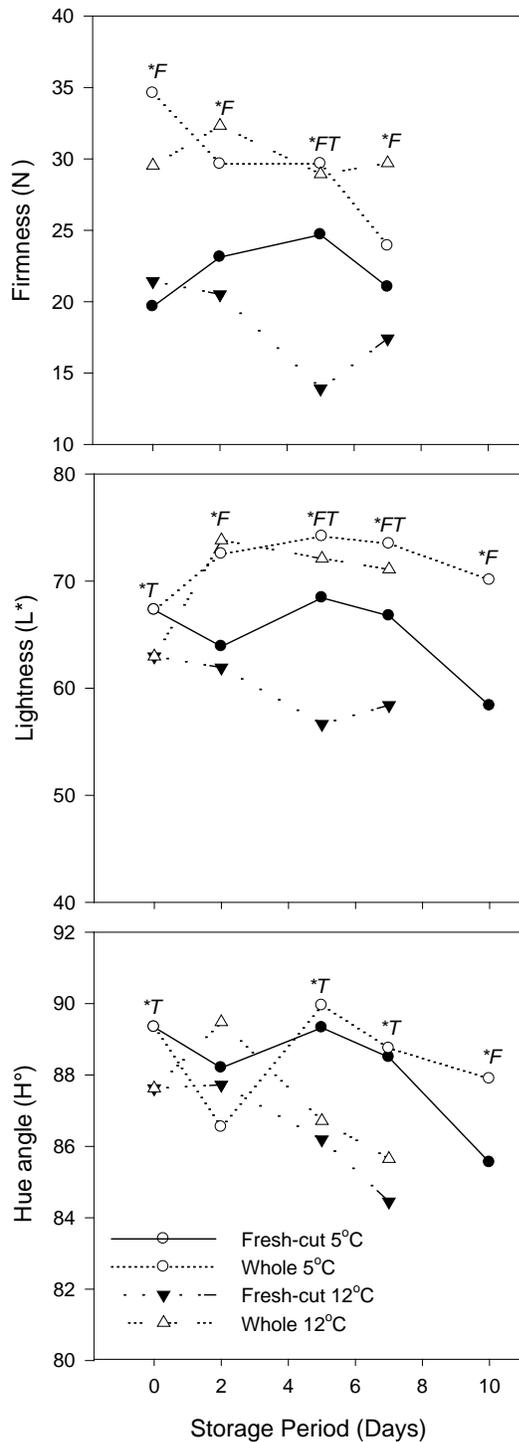


Figure 5-4. Changes in firmness, hue angle and lightness during storage of fresh-cut 'Kent' mango slices and whole mangoes at 5 °C or 12 °C for Harvest 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 °C and 12 °C), or both, respectively, using the LSD test.

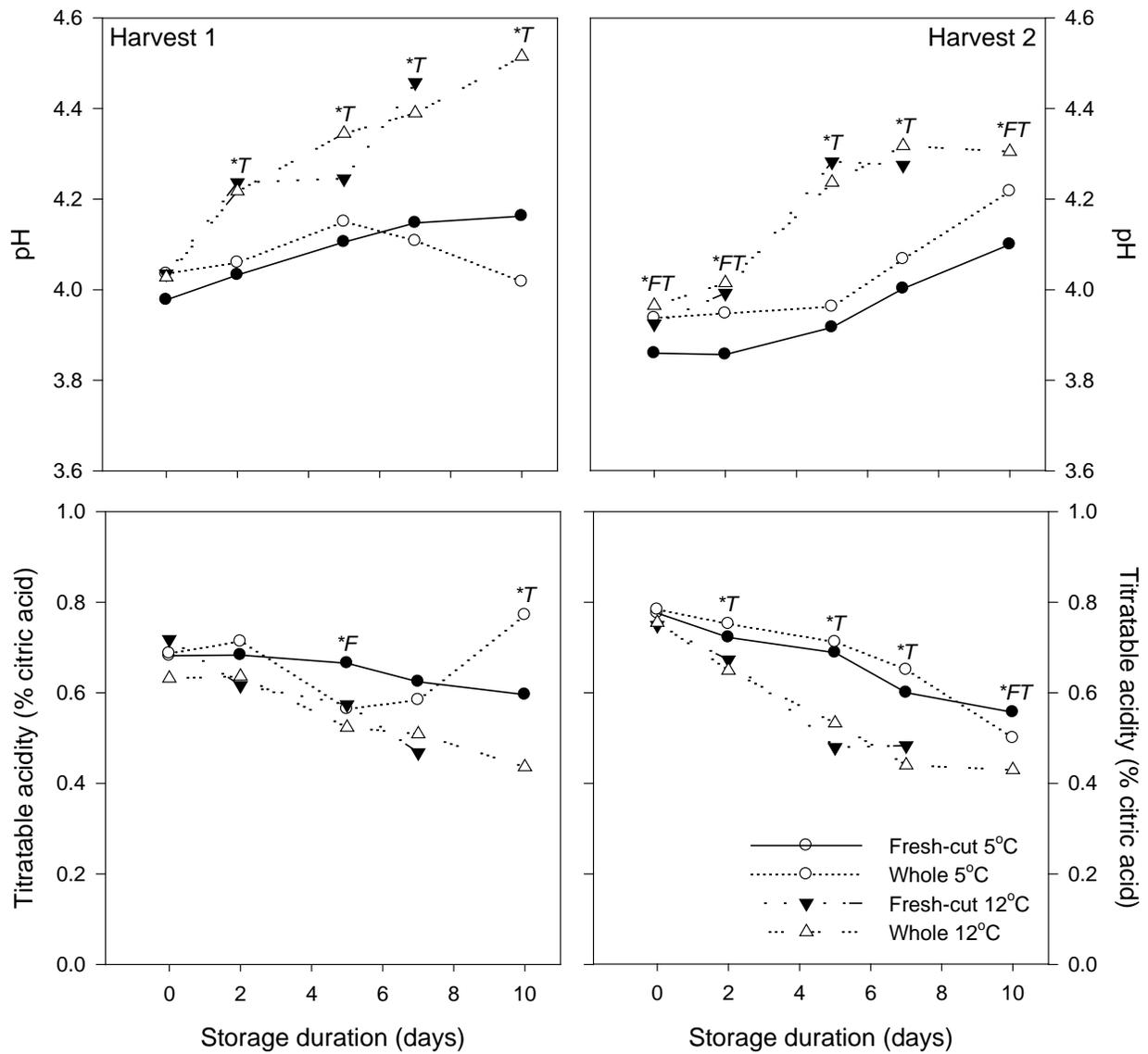


Figure 5-5. Changes in pH and titratable acidity during storage of fresh-cut ‘Kent’ mango slices and whole mangoes at 5 °C or 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time, between fresh-cut and whole fruit, storage temperature (5 °C and 12 °C), or both, respectively, using the LSD test.

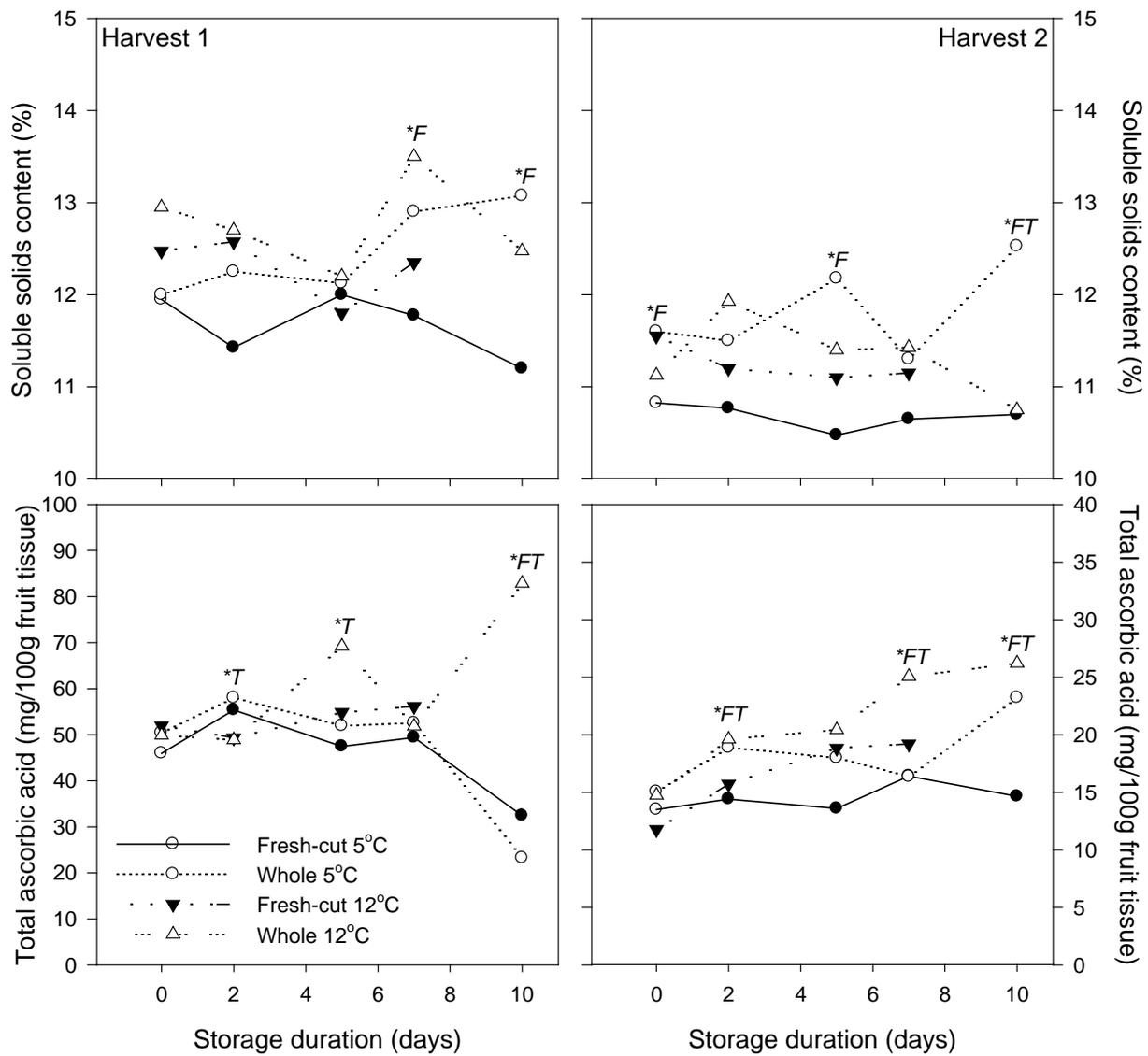


Figure 5-6. Changes in soluble solids content and total ascorbic acid during storage of fresh-cut 'Kent' mango slices and whole mangoes at 5 °C or 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 °C and 12 °C), or both, respectively, using the LSD test.

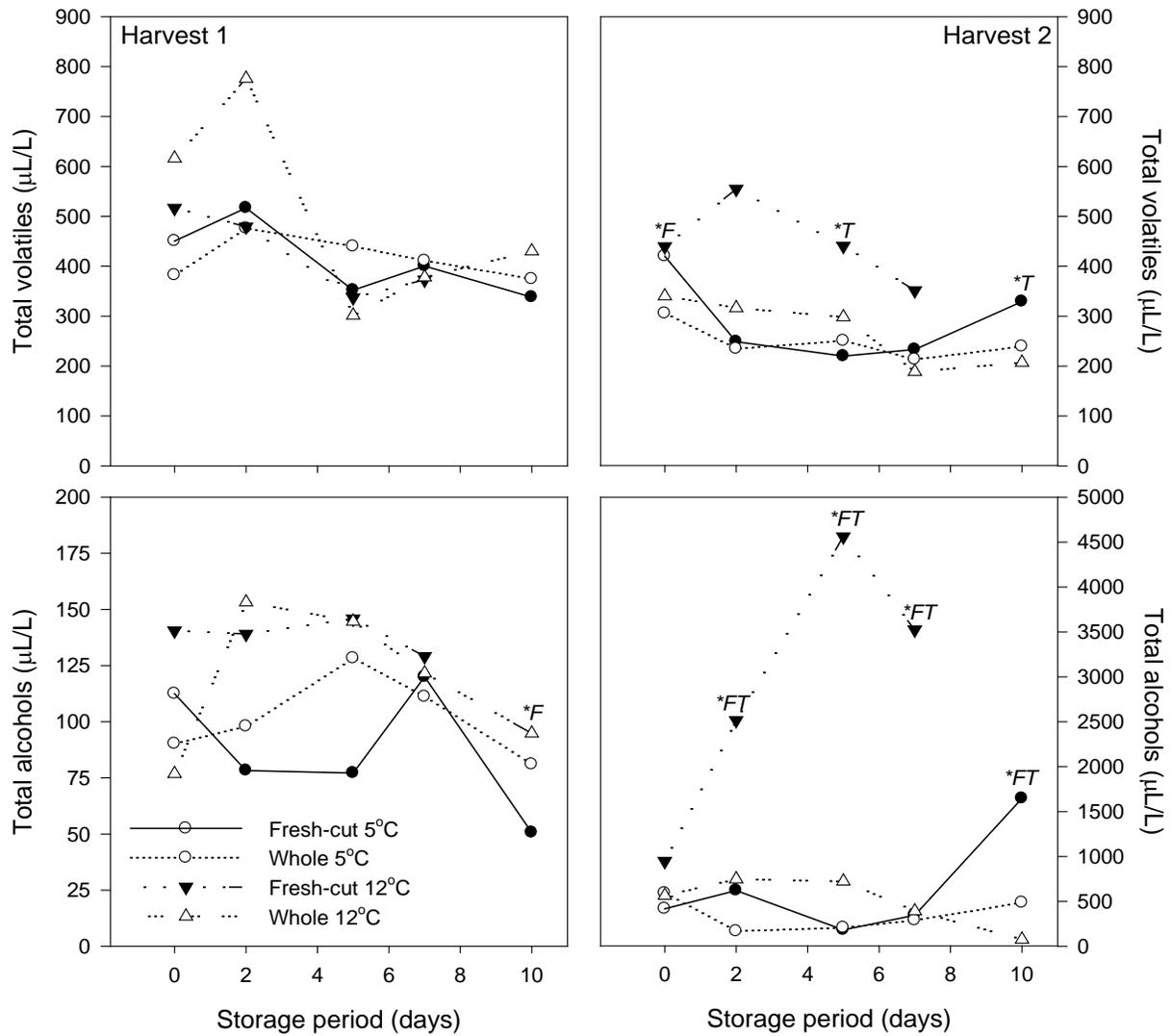


Figure 5-7. Changes in total non-alcohol volatiles (aldehydes, ketones, terpenes and esters) and total alcohol volatiles (methanol and ethanol) during storage of fresh-cut 'Kent' mango slices and whole mangoes at 5 °C or 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 °C and 12 °C), or both, respectively, using the LSD test.

CHAPTER 6
REDUCED OXYGEN AND ELEVATED CARBON DIOXIDE TOLERANCE LIMITS OF
FRESH-CUT 'KENT' MANGO DURING STORAGE

Introduction

Modified atmosphere packaging (MAP) systems are commonly used to extend the shelf life of fresh-cut fruits and vegetables. For fresh-cut fruits, the main benefits of MAP are reduction of water loss, inhibition of respiration, and inhibition of the growth of spoilage microorganisms (Gorny, 2003; Forney, 2007). In an effort to design an efficient MAP system suitable for the commercialization of fresh-cut 'Kent' mango, it was necessary to collect preliminary information regarding the product respiration rates at various temperatures and atmosphere combinations, and consequently determine what atmospheres will provide benefit and what atmospheres may induce accelerated physiological deterioration or microbial decay.

Reduced oxygen (O₂) and elevated carbon dioxide (CO₂) treatment has been successfully used to maintain the quality of fresh-cut mango cubes (Izumi et al., 2003; Rattanapanone et al., 2001). However, in those studies it was found that, if kept under steady refrigeration, the effect of low temperature on the quality of fresh-cut mango was more significant than the effect of the altered gas concentrations. Nevertheless, a recent study conducted by Nunes et al. (2009) showed that poor temperature management regularly occurs in commercial handling of fresh-cut products, reducing their quality and maximum potential shelf life. Moreover, the permeability of films used in MAP systems for fresh-cut products is known to change with temperature at a slower rate than the changes in product respiration rates (Forney, 2007). Therefore, exposure to unfavorable temperatures may induce the development of injurious atmospheres inside the package, compromising the quality and safety of the product. Often, to mitigate the limitations imposed by the film permeability, MAP systems are designed to function at the highest temperature that is expected to be encountered during distribution and retail display (Silva et al.,

1999; Beaudry, 2000). Therefore, if at some point in the handling system, proper temperature management fails, the MAP system may help to reduce the negative effects of high temperature exposure without inducing injury, and help to reduce the rates of quality deterioration of the fresh-cut fruit.

There is a lack of information in the scientific literature regarding the effects of reduced O₂ and elevated CO₂ levels on fresh-cut mango held at different temperatures. Additionally, it may be possible that handling fresh-cut mango at a higher temperature than is typically considered to be the optimum would better maintain maximum product quality by avoiding some effects of chilling injury. Therefore, the aim of this study was to determine the optimal reduced O₂ and/or elevated CO₂ concentrations suitable for fresh-cut ‘Kent’ mango handling at a non-chilling temperature. A temperature of 15 °C was chosen for the MAP design because it is known to be a non-chilling temperature for mango fruit (Chaplin et al., 1991) and it has been reported to be a typical temperature encountered during retail display of fresh-cut fruits (Nunes et al., 2009).

This study is comprised of two parts: 1) determine the reduced O₂ levels tolerated by fresh-cut ‘Kent’ mango slices; and 2) determine the elevated CO₂ levels tolerated by fresh-cut ‘Kent’ mango slices while also investigating the synergy of reduced O₂ and elevated CO₂ on fresh-cut mango quality.

Materials and Methods

Plant Material

Effects of reduced oxygen concentration on fresh-cut mango quality

The first part of this study was conducted twice during the Mexican mango season (June and July 2008). For each experiment (E1 and E2), a total of 145 hot-water-treated (USDA-APHIS, 2005) size 8 ‘Kent’ mangoes (eight fruit per 4.5-kg carton) were obtained from a

wholesaler in Texas and shipped to Florida by refrigerated truck. Upon arrival at the laboratory, the mangoes were ripened at 20 °C until they have reached a firmness of approximately 30N. The fruit were selected for processing following the same procedure described in Chapter 5. Two lots of 90 mangoes with firmness equal to $29.2 \pm 4.3\text{N}$ for E1 and $27.0 \pm 6.2\text{N}$ for E2 were selected for fresh-cut processing.

Effects of reduced oxygen plus elevated carbon dioxide on fresh-cut mango quality

The second part of the study was conducted twice during the Florida mango season (August 2008). Large ‘Kent’ mangos (500 –1000g) were obtained from the University of Florida Tropical Research and Education Center in Homestead, Florida. Fruit were removed from the field with minimal delay after harvest and transported by air-conditioned vehicle to the postharvest laboratory in Gainesville, Florida, within approximately 6 h. All fruit received a quarantine hot water (HW) treatment following the USDA treatment schedule T102-a (USDA-APHIS, 2002). The mangoes were immersed in water at 46 °C for 90 min, which is the requirement for fruit with weights greater than 500 g. Following the HW treatment, the fruit were left at room temperature (24 °C) for about 90 min to cool down and dry. Half of the fruit were placed at 20 °C for immediate ripening, while the other half was stored at 15 °C to delay ripening in order to be used in a second, replicate experiment 1 wk later.

The fruit were selected following the same procedure described in Chapter 5. Two lots of 70 mangoes (with firmness of $33.0 \pm 5.2\text{N}$ and $33.2 \pm 7.8\text{N}$) for the two replicate experiments were selected for fresh-cut processing. The latter set of fruit was not transferred to 20 °C for ripening since after 1 wk at 15 °C the fruit had already reached the desired firmness.

Fresh-cut Processing

For both experiments, those involving reduced O₂ concentrations and those involving combination atmospheres of reduced O₂ plus elevated CO₂, the fruit were prepared into fresh-cut

slices in a sanitized environment at 5 °C following the procedure described in Chapter 3. About 250 g of mango slices per treatment replicate were packed in polyethylene terephthalate (PETE) containers with leak-free snap-on covers that had a 1.5-cm diameter hole.

Exposure of Fresh-cut Mango to Reduced Oxygen and Elevated Carbon Dioxide at 15 °C

The fresh-cut mango samples were transferred to a 15 °C room where they were randomly distributed into 18.9-L (5-gal) buckets, with four PETE containers per bucket. Each bucket was connected to a manifold, with four buckets per manifold. Each manifold received a flow of humidified O₂, nitrogen (N₂), and/or CO₂ mixed in calculated amounts to create different atmospheres. The flow rates were adjusted so that the CO₂ concentration due to sample respiration did not exceed 0.2 kPa in the humidified air controls. In the first experiment, the slices were exposed to 0, 2.5, 5, 7.5 or 21 kPa O₂ at a flow rate of 210 mL/min per manifold. In the second experiment, the slices were exposed to 21 kPa O₂ or to 2.5 kPa O₂ plus 0, 10 or 20 kPa CO₂, also at a flow rate of 210 mL/min per manifold.

When necessary, each bucket was sealed and initially flushed with N₂ or with an appropriate mixture of N₂ plus CO₂ to rapidly reach the desired atmosphere before being connected to the appropriate manifold. The gas concentrations were measured with a gas analyzer (Checkmate 9900, PBI Dansensor, Denmark).

Respiration Rate Measurements

The respiration rate (RR) of four replicate samples per treatment was determined by measuring the differences in the concentrations of the inflow and outflow gases of the 18.9-L buckets (flowing system) (Eq. 6-1).

$$R_{CO_2} = (y_{CO_2\ out} - y_{CO_2\ in}) \times F / (100 \times M) \quad (6.1)$$

Where R_{CO_2} is the respiration rate as a function of the CO₂ evolution; y , the volumetric concentration; F , the flow rate; and M , the mass.

A 0.5-mL headspace sample was withdrawn by syringe through a rubber septum at the outflow of each bucket. The RR was measured after 1, 2, 3, and 4 d. CO₂ was measured by gas chromatography as previously describe in Chapter 3.

Quality Evaluation

After 1, 2, 3, and 4 d, following the RR measurements, one bucket was disconnected from each gas treatment and four replicate samples were used for visual quality evaluation as described in Chapter 3. The firmness, flesh color, and composition of the tissue, including volatiles, were measured as described in Chapter 3, after 1, 2, and 3 d at 15 °C, except for the aroma volatiles, which were analyzed on days 1 and 3 only.

Statistical analysis

Analysis of variance (ANOVA), using the General Linear Model, was conducted to identify significant main effects due to the experiments replicates, gas composition, and treatment duration, using the PC-SAS software package (SAS-Institute, 1985). Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. Composite samples of 8 slices from four replicate PETE containers per treatment and sampling time were used. For color and firmness, 16 measurements were made on 16 slices taken from four PETE containers per treatment and sampling time. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. For the RR measurements, means \pm S.E. (standard error) were used.

Results

Effect of Reduced Oxygen Concentration on Fresh-cut Mango Quality

Visual evaluation

Significantly lower overall color, microbial spoilage, and aroma scores were recorded in the first reduced O₂ experiment than in the second reduced O₂ experiment, while for edge tissue

damage and desiccation, the scores were significantly higher in the first experiment than in the second (Figure 6-1). This difference was attributed to differences in the initial fruit quality, and to their different origins.

For the air control and for all reduced O₂ treatments, the visual quality significantly decreased during storage (Figures 6-1, 6-2, and 6-3). For most of the reduced O₂ treatments, the quality attributes evaluated reached the marketability limit (score of 5) early (2 d) during storage), but that same score was maintained over 1 or 2 d. This was attributed to the variation among fruit samples, since visual evaluations were performed on a different set of samples on each evaluation day. Thus, to discriminate from the effect of reduced O₂ on fresh-cut fruit visual quality, the attribute(s) that reached a score less than 5 were identified as the limiting quality factor(s) for the fresh-cut mango slices from a particular treatment.

On day 4 of the first reduced O₂ experiment, the slices from the 0 kPa O₂ treatment attained a visual quality score below 5 (data not shown), and on day 3 for the other treatments. The specific visual quality attributes that reached a score below that of the marketability limit on those days varied significantly among the treatments. For the slices from 0 kPa O₂, overall color and desiccation were the main visual quality limiting factors. For 2.5 kPa O₂, visual quality was limited by edge damage and some development of slimy surface (signs of spoilage). For the slices from 5 kPa O₂, the development of off odor, signs of spoilage, and desiccation were the limiting visual quality factors, while for the slices from 7.5 and 21 kPa O₂, development of off odor, edge tissue damage, and spoilage; in addition, objectionable desiccation occurred in the slices from 21 kPa O₂ only limited the visual quality. On the other hand, in the second reduced O₂ experiment, the visual quality of the slices from all reduced O₂ treatments passed the marketability limit on day 3 due to edge tissue damage. Moreover, the development of off odor

was also a limiting factor for slices from 5 and 7.5 kPa O₂, and whitish discoloration limited the marketability of the slices from the air control.

Overall, slices exposed to 7.5 or 21 kPa O₂ showed more apparent loss of yellow color during storage compared with those slices exposed to 2 or 5 kPa O₂. Exposure to 0 kPa O₂ resulted in significantly less color change and less edge tissue damage during storage, than that observed in slices from 2.5, 5 or 7.5 kPa O₂. Storage in 21 kPa O₂ caused rapid and more pronounced edge tissue damage, leading to a water-soaked and soggy appearance. The slices exposed to 0 or 7.5 kPa O₂ showed the least trace of spoilage during storage compared with 2.5 and 5 kPa O₂, while slices stored in air had developed visible microbial colonies by the end of the storage period. Off odor developed more rapidly in 7.5 kPa O₂ compared with 5 kPa O₂. Slices from the 0, 2.5 and 21 kPa O₂ treatments had similar aroma scores, which declined with treatment duration, leading to detectable off odor. However, after removal from reduced O₂ treatments, and exposure to air for several minutes, the off odor dissipated.

Respiration rate

In general, significantly lower RR was measured in the first reduced O₂ experiment compared with the second experiment (Figure 6-4). In the first reduced O₂ experiment, the RR showed a significant increase from 12 h to 1 day following exposure to reduced O₂. Slices exposed to 0 kPa O₂ had the lowest RR at the end of the storage duration. In the second reduced O₂ experiment, slices exposed to 0 or 5 kPa O₂ had the lowest RR, while no significant differences were observed between samples exposed to the other reduced O₂ treatments.

The effects of the different reduced O₂ treatments on the RR of the mango slices was difficult to differentiate due to large standard errors obtained for each of the RR measurements. Therefore, the method used in this study to measure RR of fresh-cut mango slices was of questionable value. The variability associated with the RR measurements may have been due to

variations in the flow rates within each bucket. It was not possible to accurately measure the flow rate delivered into each buckets without disrupting the gas flow. All potential affective factors (tubing length, connectors, and sample configuration in the buckets) were carefully monitored for uniformity. Therefore, it was assumed that the flow rate of the humidified gas coming from the manifold was evenly distributed among the buckets. A closed system, that is, when the buckets are sealed for a specified period of time (e.g., 1 to 2 h), would probably have produced more accurate results.

Firmness

Mango slices from the first reduced O₂ experiment were significantly less firm than those from the second experiment (Table 6-1). Neither the storage duration nor the reduced O₂ treatments significantly affected the firmness of the fresh-cut mango slices (Table 6-1; Figure 6-5).

Flesh Color

Overall, the slices from the first reduced O₂ experiment were significantly less yellow and more green than those from the second experiment (Table 6-1), which had smaller hue angle, indicating that they developed a more yellow color (Figure 6-5). The hue angle decreased from day 1 to day 2 and then remained quite constant past day 3. Overall, slices exposed to 0 kPa O₂ maintained a larger hue angle (were more yellow and less orange) than those exposed to 2.5 kPa O₂, followed by progressively smaller hue angles for the 5 and 7.5 kPa O₂ treatments, and finally slices exposed to air, which had the smallest hue angle and the most yellow-orange colored slices.

In general, slices from the first reduced O₂ experiment had significantly lower L* value (were darker) than the slices from the second experiment (Table 6.1) and L* value decreased significantly after day 3 (Figure 6-5). Among all reduced O₂ treatments, mango slices stored at 0

or 2.5 kPa O₂ showed the significantly least darkening (highest L*value), while mango slices stored in air were the significantly darkest.

Compositional analysis

pH, TA and SSC. The pH of the slices was significantly higher in the first reduced O₂ experiment than in the second experiment, and slices stored at 7.5 kPa O₂ had the lowest pH compared with the other treatments (Figure 6-5). In fact, only the pH of samples from the second experiment were significantly affected by the reduced O₂ treatments, in which slices stored at 7.5 and 21 kPa O₂ had the lowest pH compared with slices stored in the other treatments. Despite the significant difference observed, the variations in pH between treatments were less than 0.2 units, therefore, maybe not significant in terms of changes in taste.

Mango slices from the first reduced O₂ experiment had higher concentrations of TA and SSC compared with slices from the second experiment. Overall, the SSC/TA ratio did not differ significantly between the two experiments; nor were the TA, SSC or SSC/TA ratio significantly affected by the reduced O₂ treatments (data not shown).

Aroma volatiles. For ease of comparison, the volatiles were grouped into their respective categories: aldehydes (acetaldehyde and hexanal), ketones (acetone), terpenes (α -pinene, β -pinene, limonene, *p*-cymene, α -copaene, 3-carene, myrcene, α -terpinolene, and caryophyllene), esters (ethyl acetate and ethyl butyrate), and alcohols (ethanol and methanol) (Figure 6 -6). Acetaldehyde, 3-carene, ethyl acetate and ethanol were the predominant volatile compounds in their respective categories.

Significantly higher volatile levels were measured in the first reduced O₂ experiment compared with the second experiment (Table 6.2). The slices exposed to 0, 2.5 or 5 kPa O₂ had similar, but higher volatile contents than slices stored at 7.5 or 21 kPa O₂. However, when both experiments were analyzed separately, significant differences were found. In the first

experiment, higher total aldehyde content was measured in slices from 0 kPa O₂ followed by similar lower levels in slices exposed to 2.5, 5, or 7.5 kPa O₂, and the lowest amount was measured in slices held in air. Conversely, in the second experiment, slices exposed to 5 kPa O₂ had higher total aldehyde content than those exposed to 2.5 kPa O₂, followed by 0 and 7.5 kPa O₂ and then by 21 kPa O₂.

Ketones were significantly higher in the first reduced O₂ experiment compared with the second experiment (Table 6.2). No significant differences were observed between reduced O₂ treatments or during storage for that category. A significant effect of O₂ concentration was found for the terpenes, for which slices exposed to 5 kPa O₂ had the lowest terpenes concentration, although this was only true for the second experiment. The esters were detected in higher concentration in the second experiment compared with the first experiment. No esters were detected on day 3 of the first experiment, and in the second experiment, higher esters were measured on day 1 compared to day 3. Significant higher alcohol content was measured in the first reduced O₂ experiment compared with the second experiment. Slices exposed to 2 or 5 kPa O₂ had the highest alcohol content compared with the 21 kPa O₂ control, which had the least alcohol content. Unexpectedly, slices stored at 0 kPa O₂ had lower content of alcohols than those exposed to 2 or 5 kPa O₂.

More specifically, the contents of hexanal, α -copaene, α -terpinolene, and ethyl butyrate in the fresh-cut mango slices did not differ significantly between the two experiments or in response to O₂ concentration or exposure time (Table 6-2). The contents of acetaldehyde, acetone, and ethanol were higher in the first reduced O₂ experiment compared to the second experiment (Table 6.3), while for methanol, caryophyllene and ethyl acetate lower concentrations were found in the first reduced O₂ experiment compared to the second

experiment. Significantly higher amounts of α -pinene, myrcene, limonene, ρ -cymene, and ethyl acetate were measured on day 1 compared with day 3 in both experiments, while the ethanol content increased from day 1 to day 3. The content of acetaldehyde and ethanol was lower in slices exposed to air compared to the reduced O₂ treatments. Higher ethyl acetate and α -pinene content was found in slices exposed to air. 3-carene was found higher in slices stored at 7 kPa O₂ and lower at 5 kPa O₂ and similar content were measured in 0 and 2 kPa O₂ and in air. Finally, limonene content was found in slices stored at 0 kPa O₂ and similar levels in the other treatments.

Effect of Reduced Oxygen Plus Elevated Carbon Dioxide on Fresh-cut Mango Quality

Visual evaluation

The overall color, spoilage and desiccation scores of fresh-cut mango slices were significantly higher in the first reduced O₂ plus elevated CO₂ experiment than in the second experiment. Thus, the slices from the first experiment had a better overall color, less spoilage, and less desiccation. On the other hand, the scores for edge tissue damage were similar in both experiments. The aroma scores were significantly lower in the first experiment, indicating that the slices developed more off odor in the first reduced O₂ plus elevated CO₂ experiment compared to the second experiment.

The visual quality of the mango slices deteriorated over time (Figures 6-7, and 6-8), and the slices were considered unsuitable for marketing (scores below 5) on days 3 or 4, depending on the atmosphere treatment. In the first reduced O₂ plus elevated CO₂ experiment, slices held in air or in 2.5 kPa O₂ plus 0 or 20 kPa CO₂ attained scores below the marketability limit on day 3. The development of off odor and increased edge tissue damage (development of water-soaking) were simultaneously the visual quality attributes that limited the quality of mango slices exposed to 2.5 kPa O₂ plus 0 or 20 kPa O₂, while increased spoilage was observed only in slices held in

air or 2.5 kPa O₂ with no CO₂. Moreover, in the first reduced O₂ plus elevated CO₂ experiment, slices exposed to 2.5 kPa O₂ plus 10 kPa CO₂ were considered below the marketability limit on day 4, and the development of off odor, signs of spoilage, and increased desiccation were the main visual quality limiting factors. In the second reduced O₂ plus elevated CO₂ experiment, mango slices exposed to 2.5 kPa O₂ plus 10 kPa CO₂ remained marketable for the entire duration of the experiment in terms of their visual quality attributes. Slices exposed to 2.5 kPa with no CO₂ crossed the limit of marketability on day 4, and this was due to clear edge tissue damage, spoilage, and poor aroma scores.

Overall, slices exposed to reduced O₂ plus elevated CO₂ had better overall color scores than slices held in low O₂ alone or in air. Exposure to 2.5 kPa O₂ plus 10 kPa CO₂ resulted in less apparent edge damage than exposure to 2.5 kPa plus 0 or 20 kPa CO₂. Slices held in air developed the most tissue edge damage. In general, the spoilage was greater for the slices held in air, and lowest for slices held in reduced O₂ plus elevated CO₂. Slices exposed to reduced O₂ plus 10 kPa CO₂ had the best aroma scores, followed by slices held in reduced O₂ with no CO₂, reduced O₂ plus 20 kPa CO₂, and finally, slices held in air.

Respiration rate measurements

As for the first part of this study, large variations in the RR were measured during the experiments. Moreover, it was not possible with the equipment that was available to accurately measure the differences in CO₂ due to product respiration in treatments that included exposure to elevated CO₂ concentrations.

Firmness

Slices from the first reduced O₂ plus elevated CO₂ experiment were significantly less firm than the slices from the second experiment (Table 6.3). Overall, firmness decreased significantly from day 1 to day 2 and then remained constant for the duration of the experiments (Figure 6-9)

Slices stored in air or in reduced O₂ plus 10 kPa CO₂ in the first experiment were firmer compared with slices stored in reduced O₂ plus 0 or 20 kPa CO₂. However, in the second experiment, there were no significant differences in the firmness of the mango slices in the different atmosphere treatments.

Flesh color

Overall, the hue angle values of the slices exposed to 2.5 kPa O₂ plus 0, 10 or 20 kPa CO₂ were significantly larger than that of the slices stored in air (Table 6.3; Figure 6-9), indicating that the reduced O₂ treatment and the reduced O₂ plus elevated CO₂ treatments better retained the original yellow color of the slices. The L* values were lower in the first reduced O₂ plus elevated CO₂ experiment than in the second experiment, indicating that the slices from the second experiment were lighter than those from the first experiment. Overall, L* value was highest for the mango slices exposed to 2.5 O₂ plus 10 kPa CO₂, follow by slices held in low O₂ plus 0 or 20 kPa CO₂ and then by slices held in air.

Compositional quality

pH, TA, SSC. Higher pH values developed in slices in the first reduced O₂ plus elevated CO₂ experiment compared with the second experiment (Figure 6-9). In general, the slices exposed to 2.5 kPa O₂ plus 10 kPa CO₂ maintained lower pH compared to the mango slices from other atmosphere treatments (Figure 6-9). Nevertheless, the pH changes measured in all treatments were less than 0.2 units.

Slices exposed to 2.5 kPa O₂ plus 10 kPa CO₂ maintained higher TA slices from the other atmosphere treatments. No significant changes in SSC of the mango slices were noted in either reduced O₂ plus elevated CO₂ experiment (data not shown).

Aroma volatiles. For ease of comparison and due to lack of significant effect of experiments, CA treatments or storage duration on most of the aroma volatiles compounds measured, the individual volatiles were grouped into their respective categories (Figure 6-10).

The ester and alcohol contents of the mango slices were significantly higher in the first reduced O₂ plus elevated CO₂ experiment than in the second experiment (Table 6-4). Only ethanol and ethyl butyrate concentrations differed significantly between the experiments.

Fresh-cut mango slices held in air had the lowest aldehydes (mainly acetaldehyde) concentrations, followed by higher levels in slices held in 2.5 kPa O₂ without added CO₂, and similar, higher levels of aldehydes in slices exposed to reduced O₂ plus 10 or 20 kPa CO₂. Slices held in air also had the lowest content on alcohols (ethanol) and esters (ethyl butyrate), while similar, higher levels were found in slices stored in the other treatments.

Discussion

Effect of Reduced Oxygen Concentration on Fresh-cut Mango Quality

Storage at 15 °C significantly accelerated the deterioration in overall quality of fresh-cut mango slices compared with the behavior that was previously observed in experiments in which the fresh-cut mango slices were held at 5 °C. Even though the visual quality deteriorated rapidly for all atmosphere treatments, reaching unacceptable marketability scores within 3 d, the intensity and the severity of color and aroma deterioration, spoilage and edge tissue damage varied between treatments. Slices exposed to 0 kPa O₂ maintained overall better visual quality, followed by slices exposed to 2.5, 5, or 7.5 kPa O₂ and finally by slices held in air. Off odor was perceived more rapidly when slices were held in 7.5 kPa or 5 kPa O₂, while slices stored at 0, 2.5 or 21 kPa O₂ had similar aroma during storage. Moreover, hue angle and L* value were highest in the slices held in 0 or 2.5 kPa, while storage in air led to a lower Hue angle and L* values,

indicating that the original color of the slices was better maintained in the most reduced O₂ atmospheres.

Results from this study are in accordance with previous studies in which exposure to reduced O₂ concentrations (<5 kPa) has been reported to minimize fresh-cut mango surface darkening, which is associated with translucency and browning. Rattanapanone et al. (2001) reported that for 'Kent' mango cubes exposed to 2 kPa O₂ plus 10 kPa CO₂ at 5 or 10°C, the visual quality deterioration was related to water-soaked tissue, discoloration, and loss of fresh appearance. Low O₂ (0.5, 1 or 2 kPa O₂) in combination with low temperature storage (5 °C) was reported to be the best conditions for maintaining quality of cubes from partially ripe 'Carabao' mango (Izumi et al., 2003). Moreover, exposure of fresh-cut 'Kensington' mangos slices to 2.5 kPa O₂ at 3°C significantly inhibited darkening of the tissues, and had a significant positive impact on visual appearance, but had no significant effects on firmness, TA or SSC (de Souza et al., 2006). Similarly, in this study exposure to reduced O₂ versus air had no significant effects on the firmness, TA or SSC of the fresh-cut 'Kent' mango slices.

Rattanapanone et al. (2001) reported that 2 kPa O₂ was slightly above the breakpoint of the respiratory quotient for fresh-cut 'Kent' mango cubes. In this study, even though the RR measurements were not satisfactory, in the second reduced O₂ experiment RR was lowered by storage in 0 or 5 kPa O₂. Watada et al. (1996) reported for some fresh-cut products that CO₂ production is lower in reduced O₂ than in air, but for fresh-cuts, such as strawberry, kiwifruit, peach and Crenshaw melon, CO₂ production in reduced O₂ was similar to or higher than that in air.

It was previously reported that when a modified atmosphere becomes anaerobic, the primary response from fresh-cut fruits and vegetables is increased production of ethanol and, to a

lesser extent, acetaldehyde (Yahia and Vazquez-Moreno, 1993; Agar et al., 1999). In this study, the acetaldehyde content increased when the level of O₂ in the atmosphere were reduced and, was significantly lower in slices held in air. No significant differences among the reduced O₂ treatments was observed for ketones and esters, but in the second reduced O₂ experiment, the terpene content of the tissue was lower in the 5 kPa O₂ treatment. The ethanol content (alcohols) was greater in slices that were exposed to 2.5 or 5 kPa O₂. Unexpectedly, in a completely anaerobic atmosphere (0 kPa O₂), lower ethanol levels were measured compared to storage in 2.5 kPa O₂.

Even though very high concentrations of acetaldehyde and ethanol were present in slices stored in reduced O₂ compared to air, it seems that did not compromise the overall aroma as confirmed by the subjective quality evaluation. In fact, even though development of off odor during storage was noticed in all treatments, it did not become the limiting quality factor for the slices exposed 0 or 2.5 kPa O₂. Moreover, the aroma scores for those slices were similar to those of the slices held in air. So far, no data indicating the threshold (perception) level for the identification of ethanol or acetaldehyde volatiles in fresh-cut mangos by panelists (consumers) have been published (González-Aguilar et al., 2007a). Beaulieu and Lea (2003) reported that the aroma of fresh-cut ‘Palmer’ and ‘Keitt’ mangoes held in MAP was not affected by anaerobic atmospheres that increased production of ethanol, ethyl acetate, and ethyl butyrate, and that the overall sensory ratings of those mango cubes were similar to those of cubes held in an aerobic packaging. For fresh-cut ‘Carabao’ mango, ethanol was not detected when the fresh-cut cubes were held in air, but ethanol content significantly increased, reaching levels of 54.7 mg/100 g, when the cubes were exposed to 0.5 kPa O₂ at 5 °C or 13 °C (Izumi et al., 2003). Nevertheless,

the 'Carabao' mango cubes produced no detectable off odors whether in air or reduced O₂ atmospheres at both temperatures.

Effect of Reduced Oxygen Plus Elevated Carbon Dioxide on Fresh-cut Mango Quality

In this section, the effects of a reduced O₂ atmosphere (2.5 kPa) combined with different levels of CO₂ (0, 10, and 20 kPa) on fresh-cut mango slices quality stored at 15 °C were investigated. The visual quality of the slices declined during storage regardless the atmosphere treatment, while the marketability period of the fresh-cut mango slices varied with the different treatments. The shelf life was extended by 1 day when slices were held in 2.5 kPa O₂ plus 10 kPa CO₂ compared with the other reduced O₂ or reduced O₂ plus elevated CO₂ treatments or air storage. All samples developed off odors, the odors which were most severe in slices from the air control and the reduced O₂ plus 20 kPa CO₂ treatments. Spoilage first became apparent on slices held in air or in reduced O₂ with no CO₂. Overall, exposure to 2.5 kPa O₂ plus 10 kPa CO₂ decreased the rate of edge damage development, maintained better aroma, and reduced spoilage. Rattanapanone et al. (2001) also showed that the marketable period of 'Tommy Atkins' and 'Kent' mango cubes was extended by 1 to 2 d when they were held at 5 or 10°C in 4 kPa O₂ plus 10 kPa CO₂ or 2 kPa O₂ plus 10 kPa CO₂ (balance nitrogen). Furthermore, Chantanawarangoon (2000) reported that combinations of low temperature (5 °C), reduced O₂, elevated CO₂, and application of calcium chloride increased the shelf life of 'Haden', 'Keitt' or 'Kent' mangos cubes to 12 d, compared to a shelf life of 9 d when the same mango cubes were stored in air.

Firmness of mango slices was better maintained by storage in air or in 2.5 kPa O₂ plus 10 kPa CO₂ than in the other treatments. While the reduced O₂ plus elevated CO₂ treatments had no effect on the hue angle, the L* value was higher in samples exposed to reduced O₂ plus elevated CO₂ than those held in air. The L* value was best maintained by the 2.5 kPa O₂ plus 10 kPa CO₂ treatment, corresponding to less browning on the fresh-cut slices. Similarly for fresh-cut

pineapple, increasing the CO₂ concentration to 10% helped retain the luminosity (L*) of the tissue pieces, which was suggested to be due to lower activity of browning enzymes such as polyphenol oxidase (Marrero and Kader, 2006).

It has been postulated that exposure of fruit tissues to elevated CO₂ levels can result in elevated levels of dissolved CO₂ in the tissue, increasing the acidity of the cell contents (Varoquaux, 1991). In this study, the pH was lowest and the TA highest in the slices exposed to reduced O₂ plus 10 kPa CO₂. That result may be due to that atmosphere combination best maintaining the tissue acid content nearest to the initial condition at the time of processing since TA tends to decrease during ripening and storage, as the organic acids are consumed as respiratory substrate. Nevertheless, the differences were less than 0.2 units, which could be considered negligible. Thus, it may be assumed that high CO₂ did not affect the pH or TA of the fresh-cut slices during storage at 15 °C.

For fresh-cut peach slices stored at 10°C, reduced O₂ plus elevated CO₂ levels acted synergistically to increase production of fermentative metabolites (ethanol and acetaldehyde) (Gorny et al., 1999). In this study, there were higher aldehydes (mainly acetaldehyde) in samples exposed to reduced O₂ plus elevated CO₂ versus reduced O₂ with no CO₂, while similar levels of alcohols and esters were present in the reduced O₂ plus elevated CO₂ treatments and the air control. Only concentrations differed significantly between the experiments. The difference between the experiments for the ethanol and ethyl butyrate could be explained by the fact that the fruit used in the second experiment were stored longer (1 wk at 15°C) before being processed into fresh-cut slices than the fruit used in the first experiment. It is known that the ethanol content increases during storage and ripening of mango fruit (Bender et al., 2000a, b) and in turn ethanol is known to be associated with the synthesis of esters.

Nevertheless, as also found in the previous part of this study, elevated levels of aldehydes, ethanol, and esters do not necessarily render the fresh-cut mango product unmarketable. In fact, the least off odor was noted for slices stored in reduced O₂ plus 10 kPa CO₂, followed by reduced O₂ with not CO₂, while slices held in air or reduced O₂ plus 20 kPa CO₂ developed comparably strong off odors during storage.

Conclusion

This study represents the preliminary step for the design of a MAP system for fresh-cut 'Kent' mangoes. The aim was to determine the optimal reduced O₂ and/or elevated CO₂ concentrations suitable for use during handling of fresh-cut 'Kent' mango slices when exposed to a temperature of 15 °C as is typically encountered during retail display. When considering an atmosphere with only reduced O₂ and no modification of CO₂, an atmosphere of 0 or 2.5 kPa O₂ was found to be the most suitable for storage of fresh-cut 'Kent' mango at 15 °C. However, a complete anaerobic atmosphere is not recommended since it may result in tissue damage during long periods at lower temperature. Besides, anaerobic atmospheres impose limitations on the MAP design, since films with very low O₂ permeability usually also have low CO₂ permeability, which would contribute to an increase in CO₂ to injurious levels.

When reduced O₂ atmosphere (2.5 kPa) was compared with reduced O₂ plus elevated CO₂ levels of 10 or 20 kPa CO₂ and an air control at 15 °C, the 2.5 kPa O₂ plus 10 kPa CO₂ atmosphere was found to best maintain fresh-cut 'Kent' mango quality. In contrast, an atmosphere of 2.5 kPa O₂ plus 20 kPa CO₂ did not show any beneficial effect on the quality of fresh-cut 'Kent' mango. In fact, the quality of the slices exposed to 2.5 kPa O₂ plus 20 kPa CO₂ was comparable to slices stored in air.

Due to the large variations in RR measurements in these experiments, it was not possible to define the film requirements for MAP design with the precision that was desired. However,

previous experience has shown that fresh-cut product respiration is quite variable from lot to lot, even within the same cultivar, apparently due to differences in preharvest cultural and environmental conditions. Therefore, average RR values from these experiments were considered to be acceptable to use for the first iteration of the design of a prototype MAP system for fresh-cut 'Kent' mango.

Table 6-1. ANOVA table- Quality parameters for fresh-cut 'Kent' mango held at 15 °C (Experiment 1)

Source of variations	d.f.	F-value			
		Firmness (N)	Hue angle (H°)	Lightness (L*)	pH
E	1	92.44***	98.32***	4.64*	104.81***
CA	4	1.20 ns	22.59***	88.35***	3.55**
S	2	0.02 ns	211.09***	8.67**	0.93 ns
E×CA	4	1.14 ns	2.16 ns	3.56**	2.88*
E×S	2	0.21 ns	1.25 ns	2.34 ns	10.12***
R×S	8	0.24 ns	0.77 ns	1.39 ns	0.99 ns
E×CA×S	8	2.04*	0.90 ns	1.53 ns	1.06 ns

Fresh-cut mango slices from both experiments (E) were exposed to different gas composition (0, 2.5, 5, 7.5 and 21 kPa O₂) (CA) and analyzed on days 1, 2, and 3 during holding at 15 °C (S);

ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 6-2. ANOVA table - Volatile compounds and volatiles categories for fresh-cut 'Kent' mango held at 15 °C (Experiment 1)

Source of variations	d.f.	<i>F</i> -value							
		Aldehydes (µL/L)	Ketone (µL/L)	Terpenes (µL/L)	Esters (µL/L)	Alcohols (µL/L)	Acetaldehyde (µL/L)	Acetone (µL/L)	Ethanol (µL/L)
E	1	108.31***	4.78*	2.80 ns	105.84***	121.74***	110.14***	4.78*	121.82***
CA	4	22.79***	0.76 ns	2.74*	1.74 ns	45.97***	22.79***	0.76 ns	45.97***
S	1	1.92 ns	2.06 ns	2.54 ns	18.46***	226.27***	1.94 ns	2.06 ns	226.23***
E×CA	4	7.90***	1.32 ns	2.88*	0.96 ns	4.86**	7.47***	1.32 ns	4.86**
E×S	1	2.17 ns	0.13 ns	2.73 ns	14.26**	0.42 ns	2.41 ns	0.13 ns	0.42 ns
R×S	4	2.32 ns	0.56 ns	2.89*	1.59 ns	8.96***	2.40 ns	0.56 ns	8.96***
E×CA×S	4	5.51**	0.51 ns	2.88*	1.99 ns	2.74*	5.44**	0.51 ns	2.74*

Source of variations	d.f.	<i>F</i> -value							
		α-pinene (µL/L)	β-pinene (µL/L)	3-Carene (µL/L)	Myrcene (µL/L)	Limonene (µL/L)	Cymene (µL/L)	Caryophyllene (µL/L)	Ethyl acetate (µL/L)
E	1	0.12 ns	1.71 ns	0.46 ns	1.46 ns	0.20 ns	0.00 ns	4.37*	107.64***
CA	4	0.90 ns	2.61*	1.6 ns	0.77 ns	1.14 ns	0.64 ns	2.45 ns	1.72 ns
S	1	6.43*	1.44 ns	3.42 ns	8.95**	19.92***	14.25**	0.37 ns	18.01***
E×CA	4	1.49 ns	2.34 ns	2.56*	1.37 ns	1.22 ns	0.25 ns	1.19 ns	1.02 ns
E×S	1	0.01 ns	0.05 ns	0.44 ns	0.18 ns	0.28 ns	0.00 ns	0.12 ns	14.32**
R×S	4	1.14 ns	0.12 ns	1.77 ns	0.86 ns	1.26 ns	0.64 ns	0.53 ns	1.77 ns
E×CA×S	4	0.19 ns	0.32 ns	2.60*	0.47 ns	0.14 ns	0.25 ns	1.70 ns	2.12 ns

Fresh-cut mango slices from both experiments (E) were exposed to different gas composition (0, 2.5, 5, 7.5 and 21 kPa O₂) (CA) and analyzed on days 1 and 3 during holding at 15 °C (S);

ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 6-3. ANOVA table - Quality parameters of fresh-cut ‘Kent’ mango held at 15 °C (Experiment 2)

Source of variations	d.f	<i>F-value</i>				
		Firmness (N)	Hue angle (H°)	Lightness (L*)	pH	Titrateable acidity (% citric acid)
E	1	236.29***	1.66 ns	4.04 ns	4.12*	2.55 ns
CA	3	2.74*	4.54**	18.93**	3.35*	3.10*
S	3	6.08**	0.74 ns	0.54 ns	0.12 ns	2.05 ns
E×CA	3	0.14 ns	0.11 ns	1.43 ns	1.76 ns	0.72 ns
E×S	3	0.95 ns	0.68 ns	3.23*	0.52 ns	2.22 ns
R×S	3	1.30 ns	1.12 ns	0.35 ns	0.33 ns	0.50 ns
E×CA×S	9	1.63 ns	1.34 ns	0.89 ns	0.74 ns	1.12 ns

Fresh-cut mango slices from both experiments (E) were exposed to different gas compositions (2.5 kPa O₂ plus 0, 10 or 20 kPa CO₂ or 21 kPa O₂) (CA) and analyzed on days 1, 2, and 3 during holding at 15 °C (S); ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

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Table 6-4. ANOVA table - Volatile categories of fresh-cut ‘Kent’ mango measured on day 3 at 15°C (Experiment 2)

Source of variations	d.f.	<i>F-value</i>				
		Aldehydes (µL/L)	Ketone (µL/L)	Terpenes (µL/L)	Esters (µL/L)	Alcohols (µL/L)
E	1	0.27 ns	2.02 ns	0.30 ns	57.44***	107.65***
CA	3	19.40***	1.68 ns	0.79 ns	6.10**	18.95***
E×CA	3	0.61 ns	0.43 ns	0.21 ns	4.18*	0.41

Fresh-cut mango slices from both experiments (E) were exposed to different gas composition (2.5 kPa O₂ with 0, 10 or 20 kPa CO₂ and in 21 kPa O₂) (CA) and analyzed on days 1, 2, and 3 during holding at 15 °C (S); ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

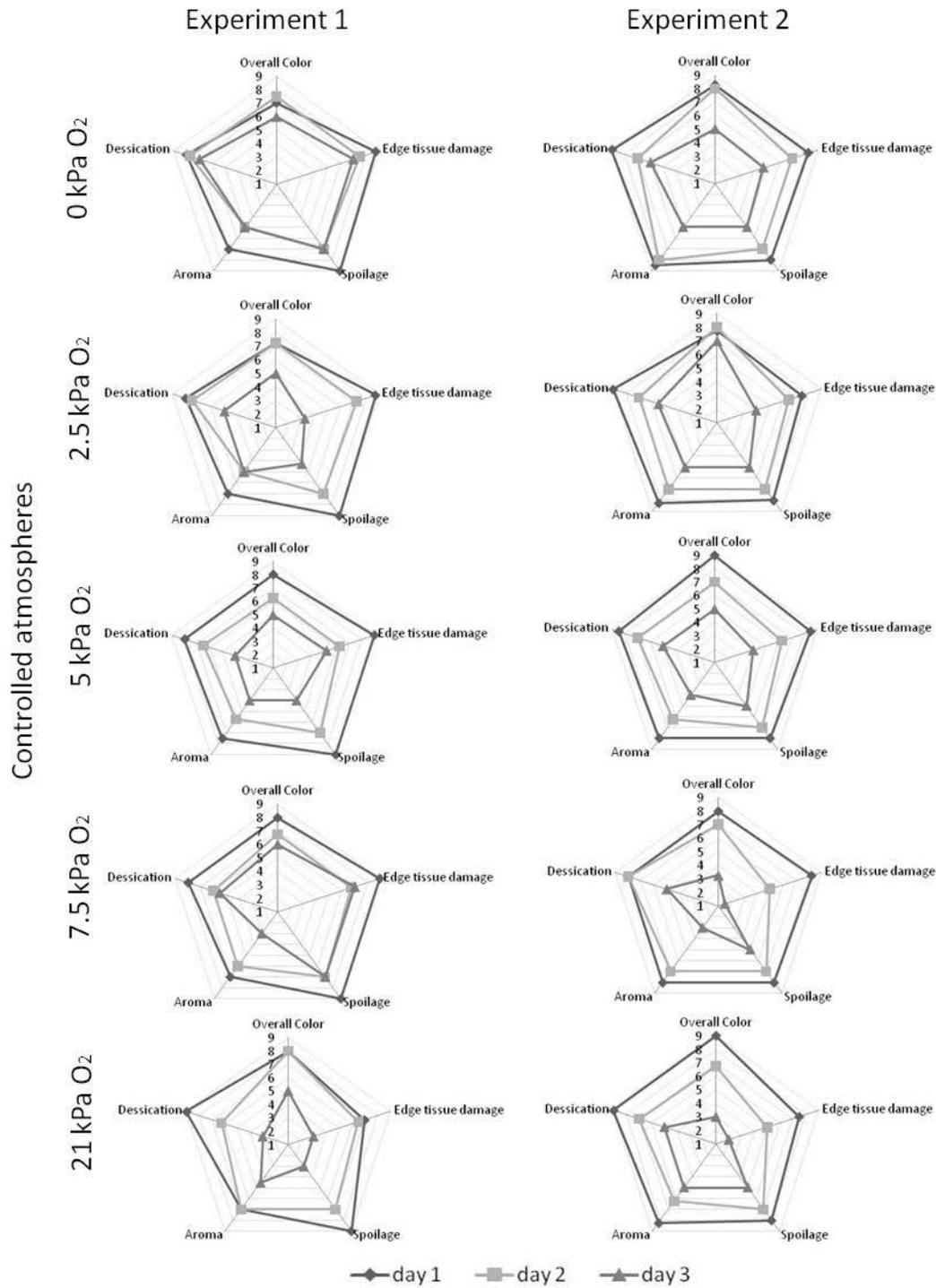


Figure 6-1. Subjective visual evaluation for fresh-cut 'Kent' mango slices held in air or reduced O₂ for 3 days at 15 °C. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1, poor, inedible. Five is the minimum subjective score (limit) for marketing any product.

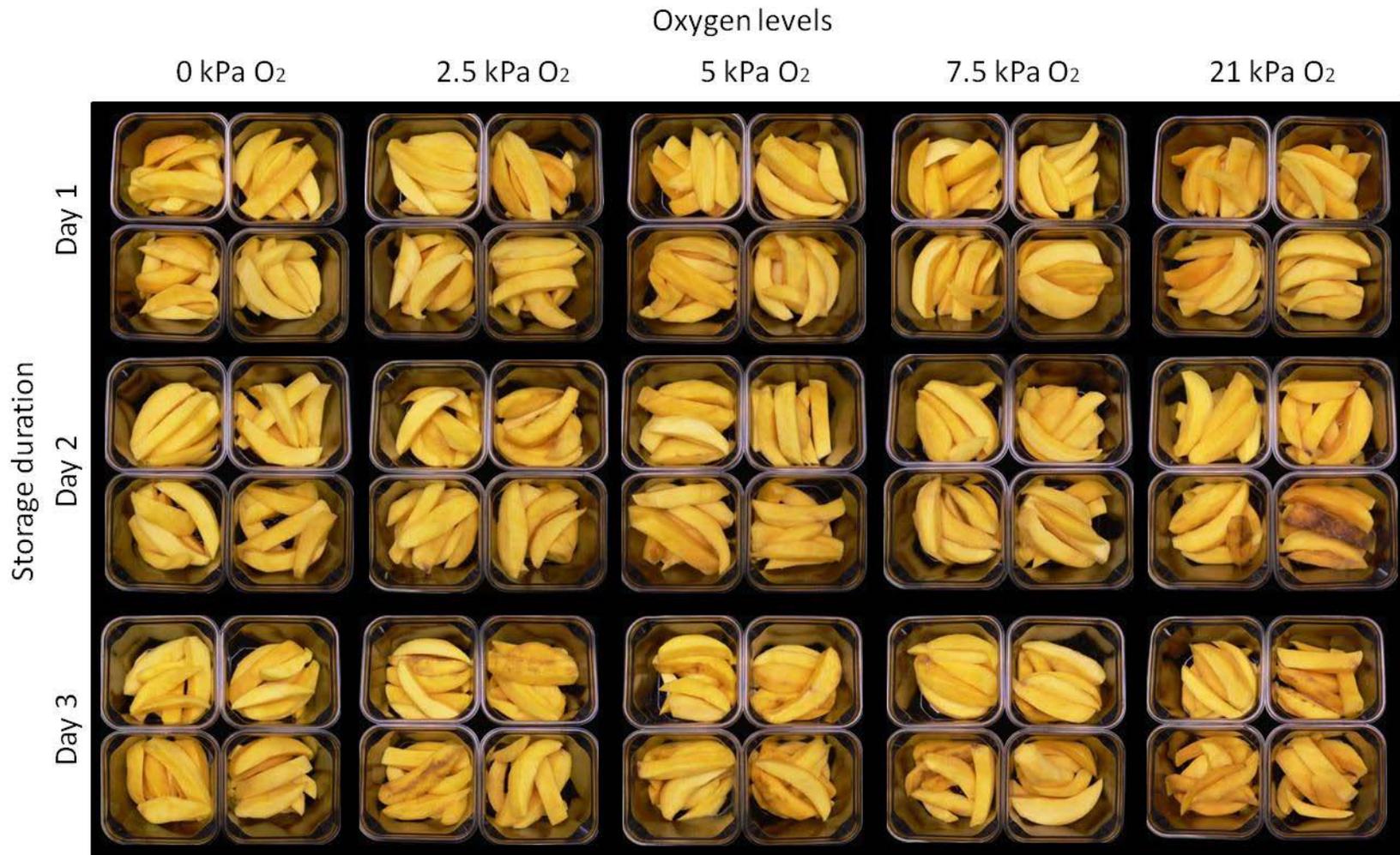


Figure 6-2. Changes in appearance of fresh-cut 'Kent' mango slices held in air or reduced O₂ for 3 days at 15 °C (Experiment 1).

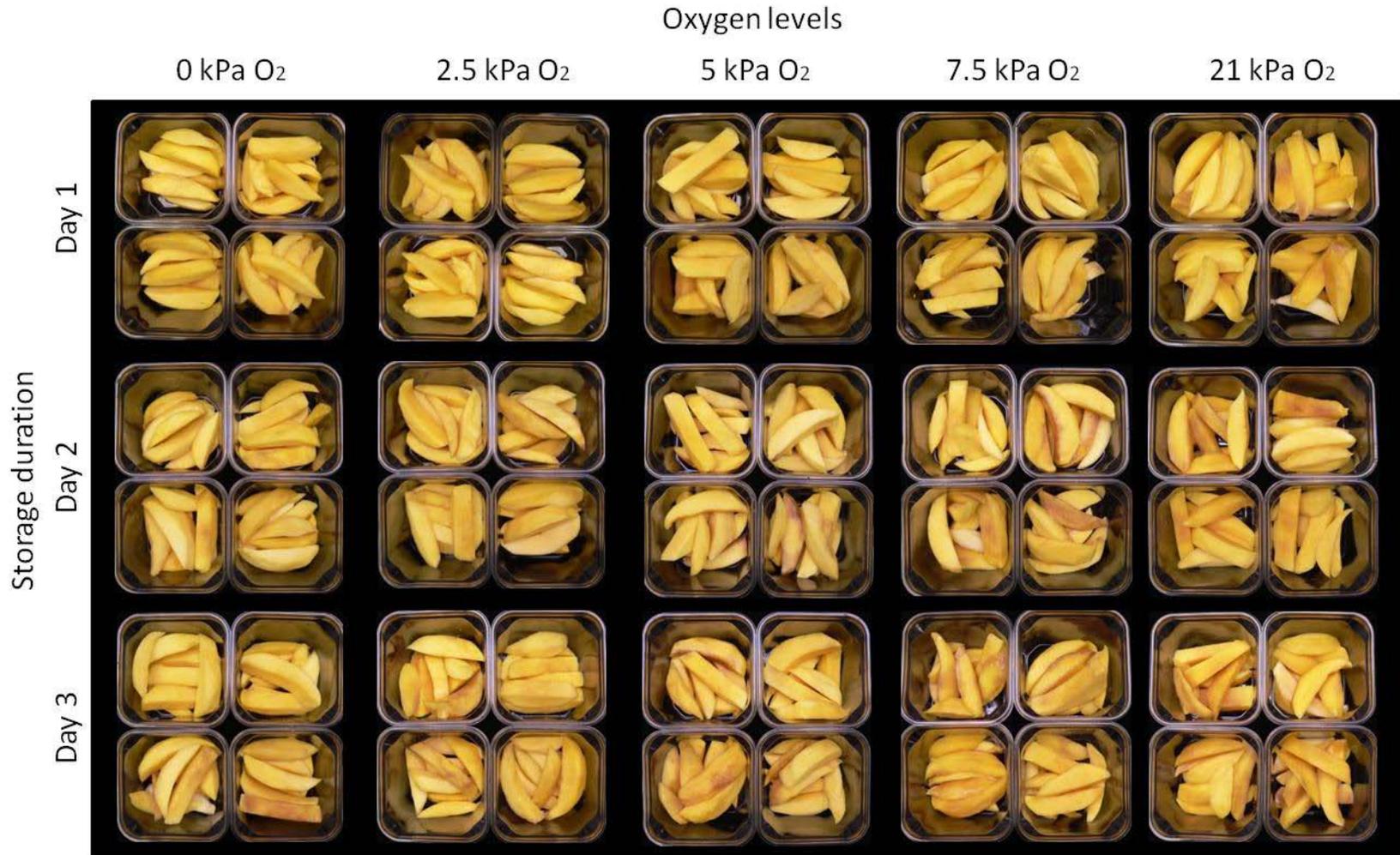


Figure 6-3. Changes in appearance of fresh-cut 'Kent' mango slices held in air or reduced O₂ for 3 days at 15 °C (Experiment 2).

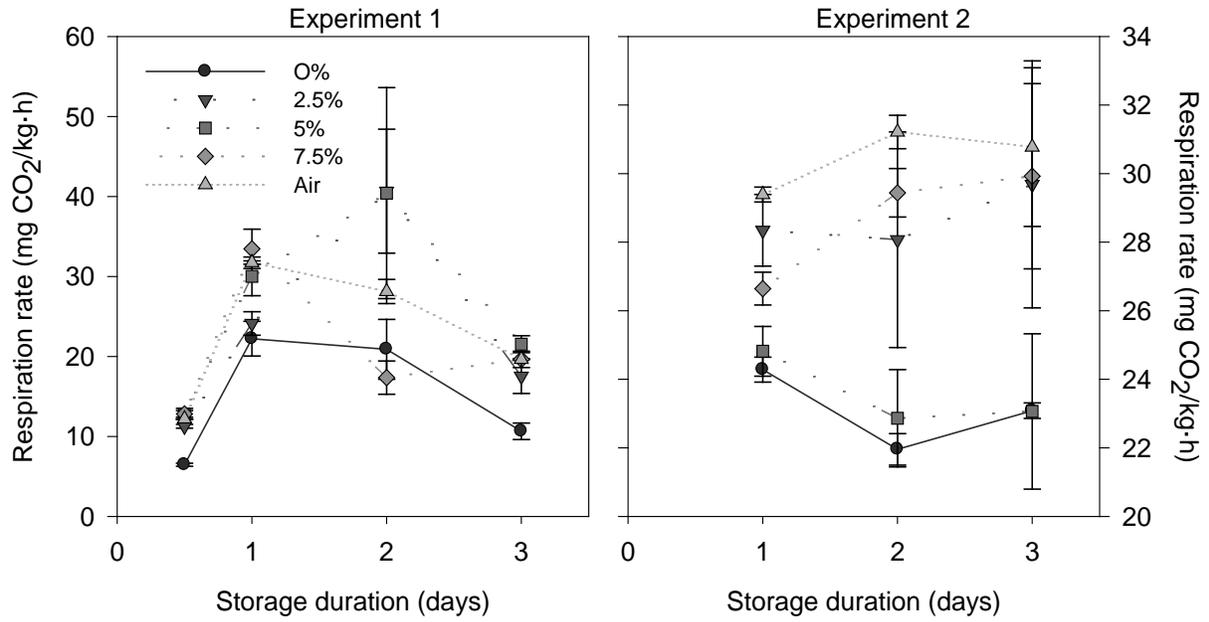


Figure 6-4. Respiration of fresh-cut 'Kent' mango slices held in air or reduced O₂ for 3 days at 15 °C.

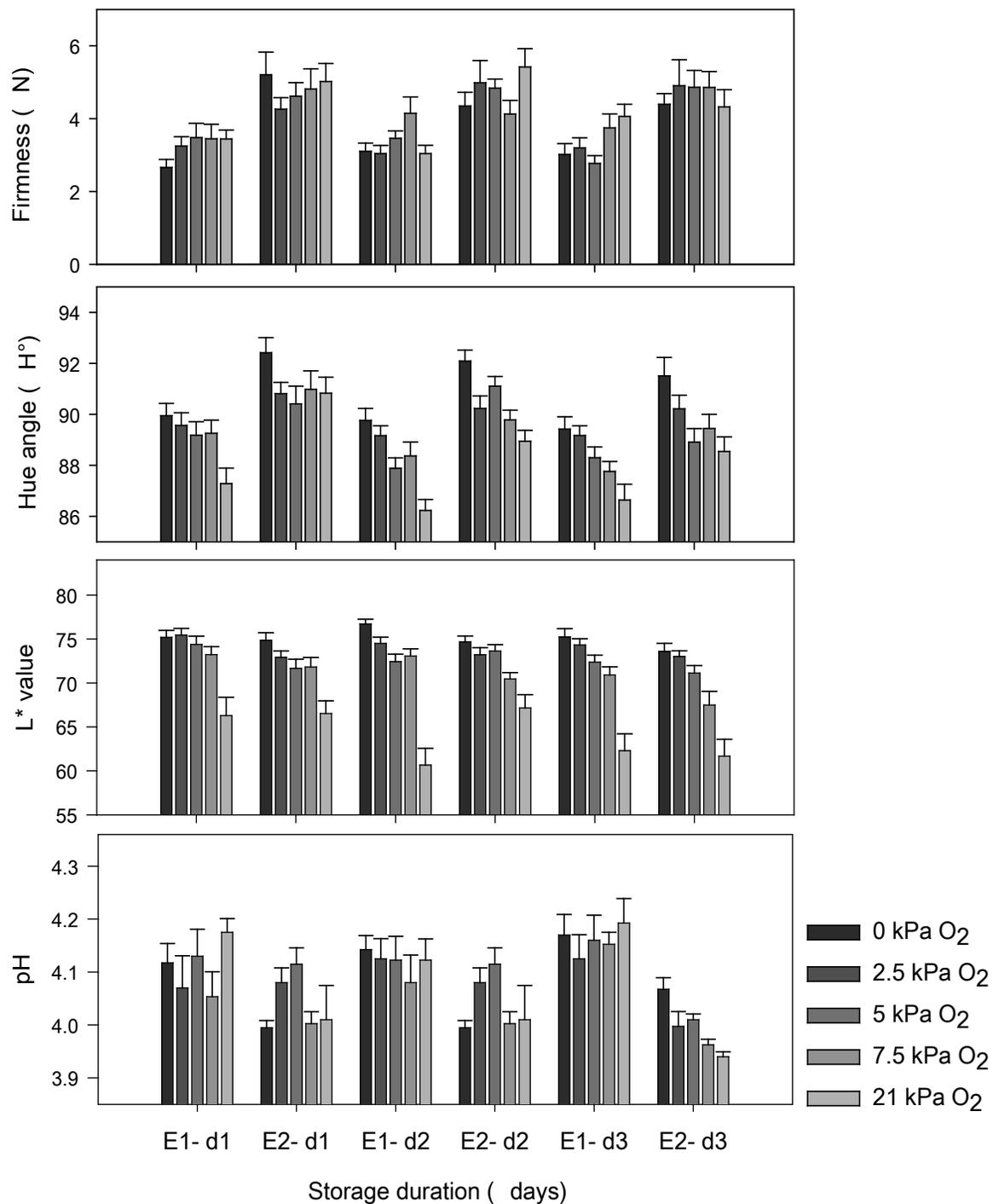


Figure 6-5. Firmness, flesh color (hue angle and L*value), and pH of fresh-cut ‘Kent’ mango slices held in air or reduced O₂ for 3 days at 15 °C(Experiment 1 and Experiment 2).

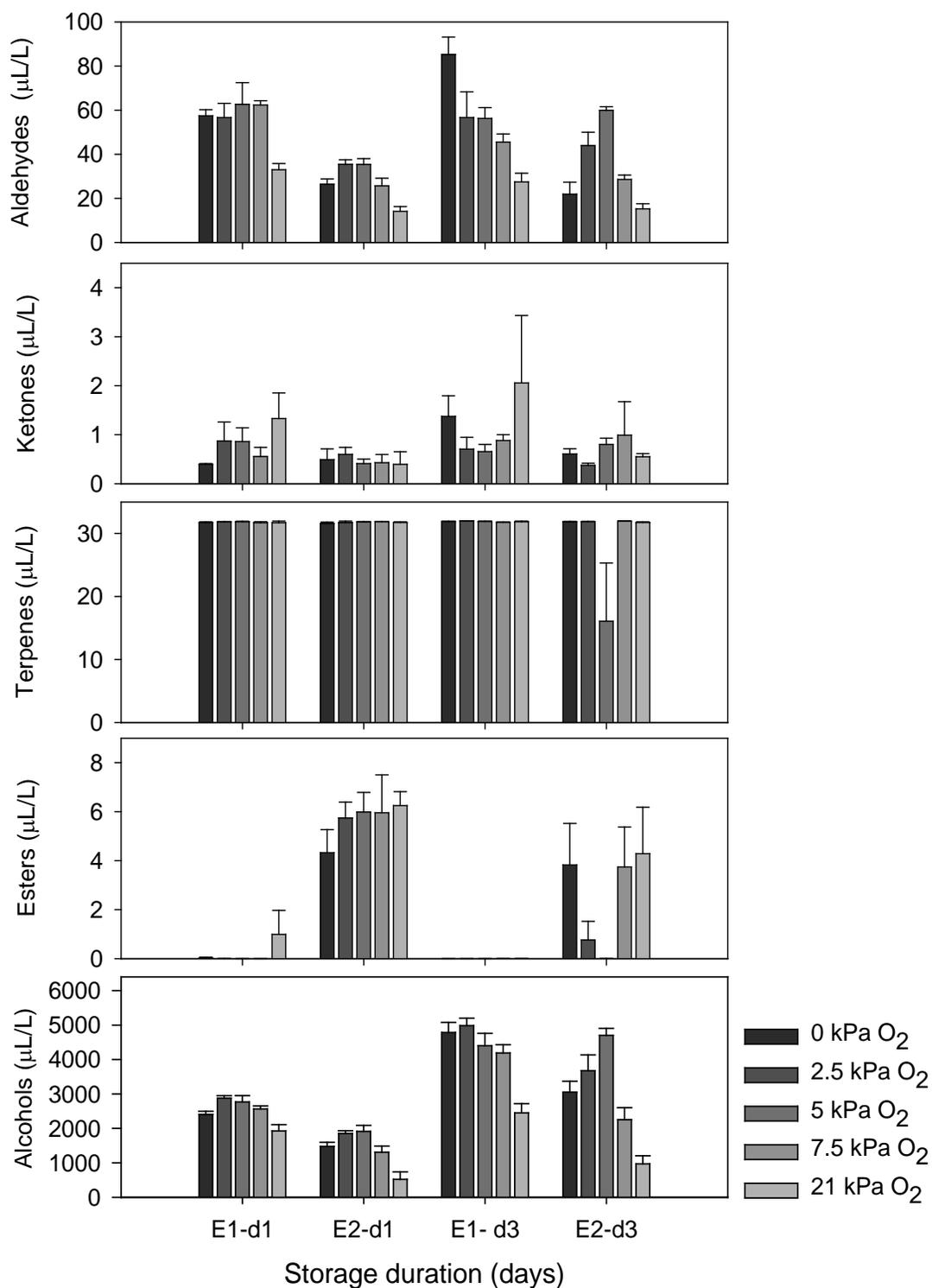


Figure 6-6. Aldehydes, ketones, terpenes, esters, and alcohols content of fresh-cut 'Kent' mango slices held in air or reduced O_2 for 1 or 3 days at 15 °C (Experiment1 and Experiment 2).

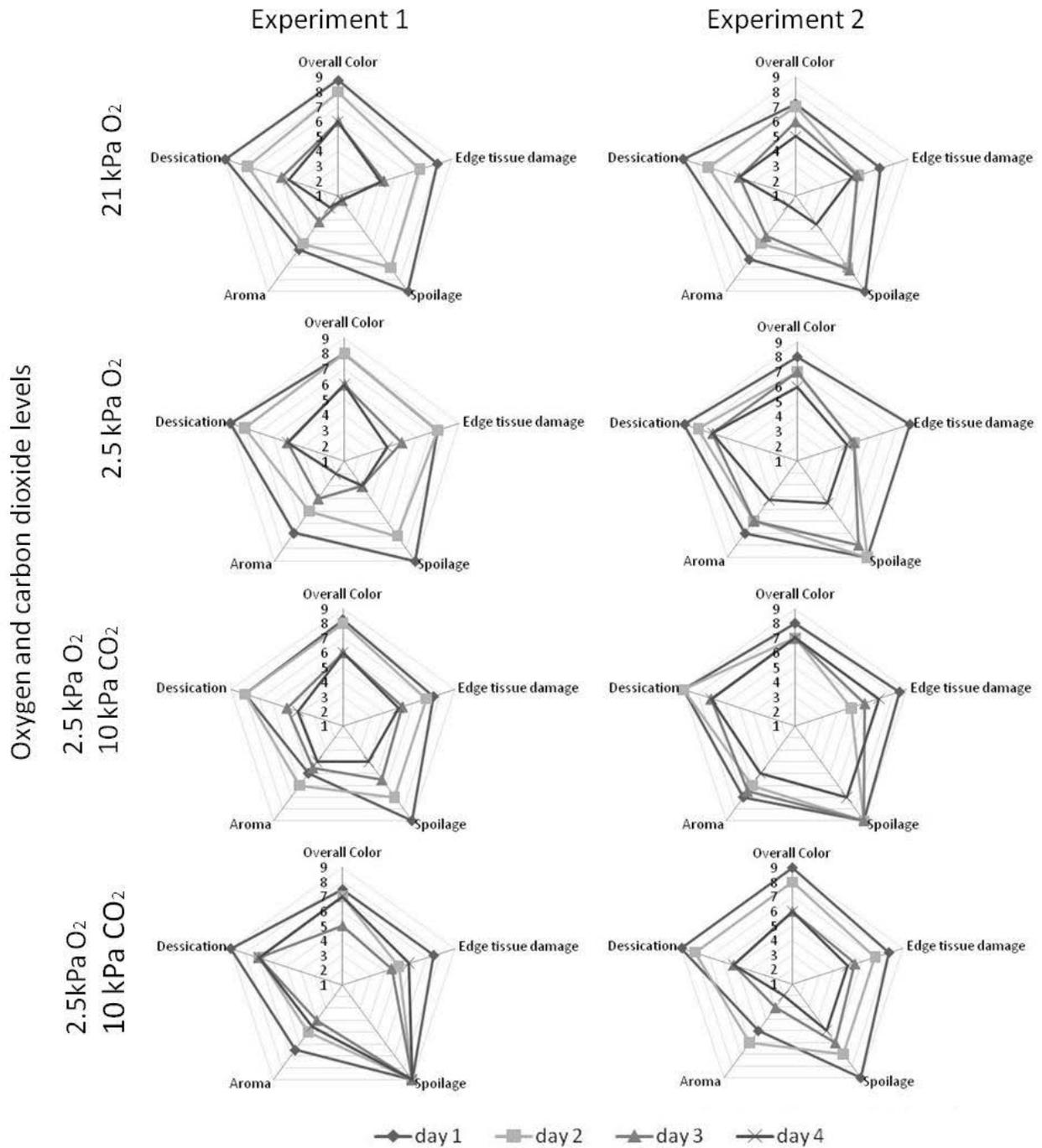


Figure 6-7. Subjective visual evaluation of fresh-cut 'Kent' mango slices held in air, reduced O₂ or reduced O₂ plus elevated CO₂ for 4 days at 15 °C. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1, poor, inedible. Five is the minimum subjective score (limit) for marketing any product.

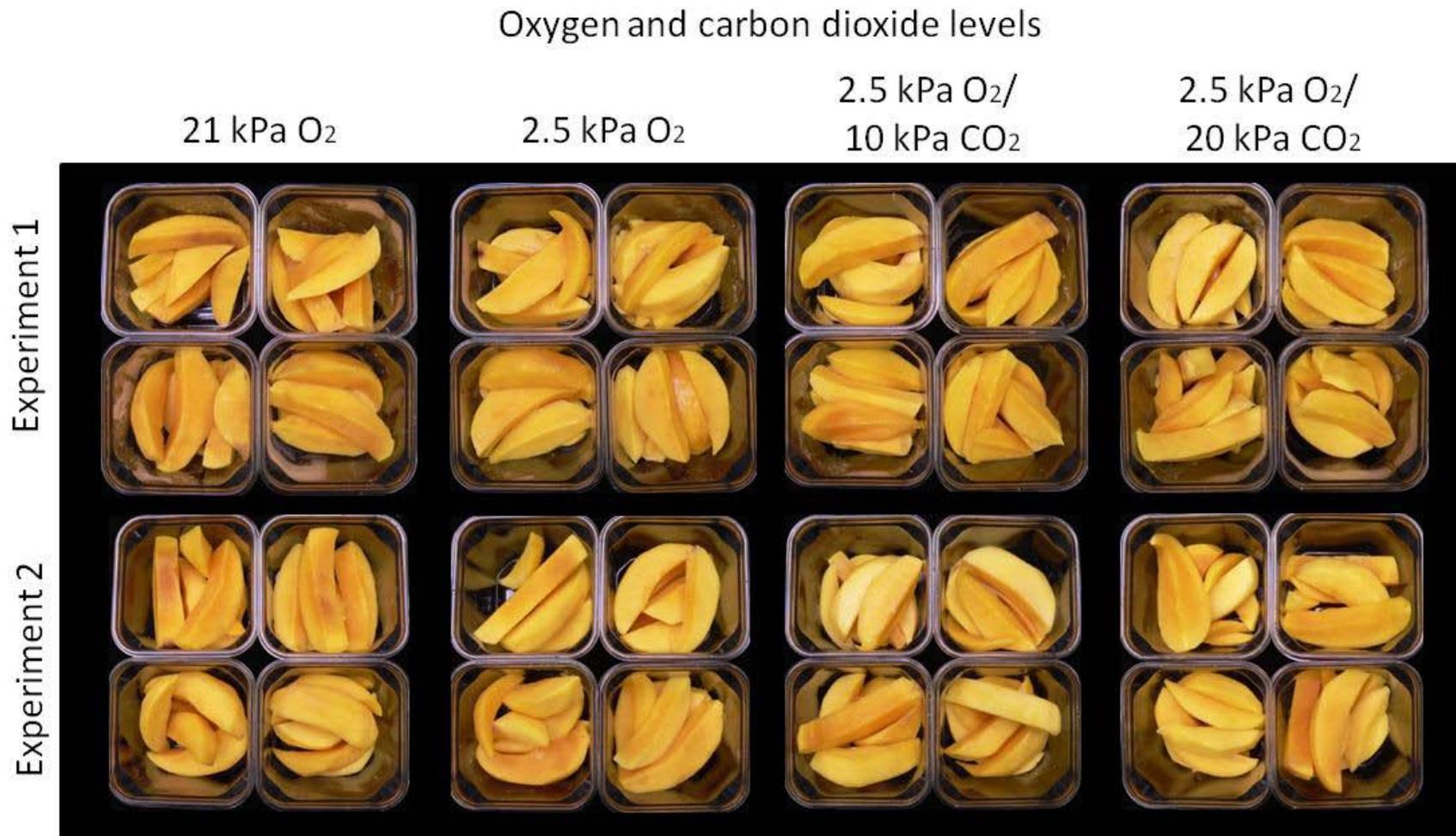


Figure 6-8. Appearance of fresh-cut 'Kent' mango slices held in air, reduced O₂, or reduced O₂ plus elevated CO₂ for 3 days at 15 °C.

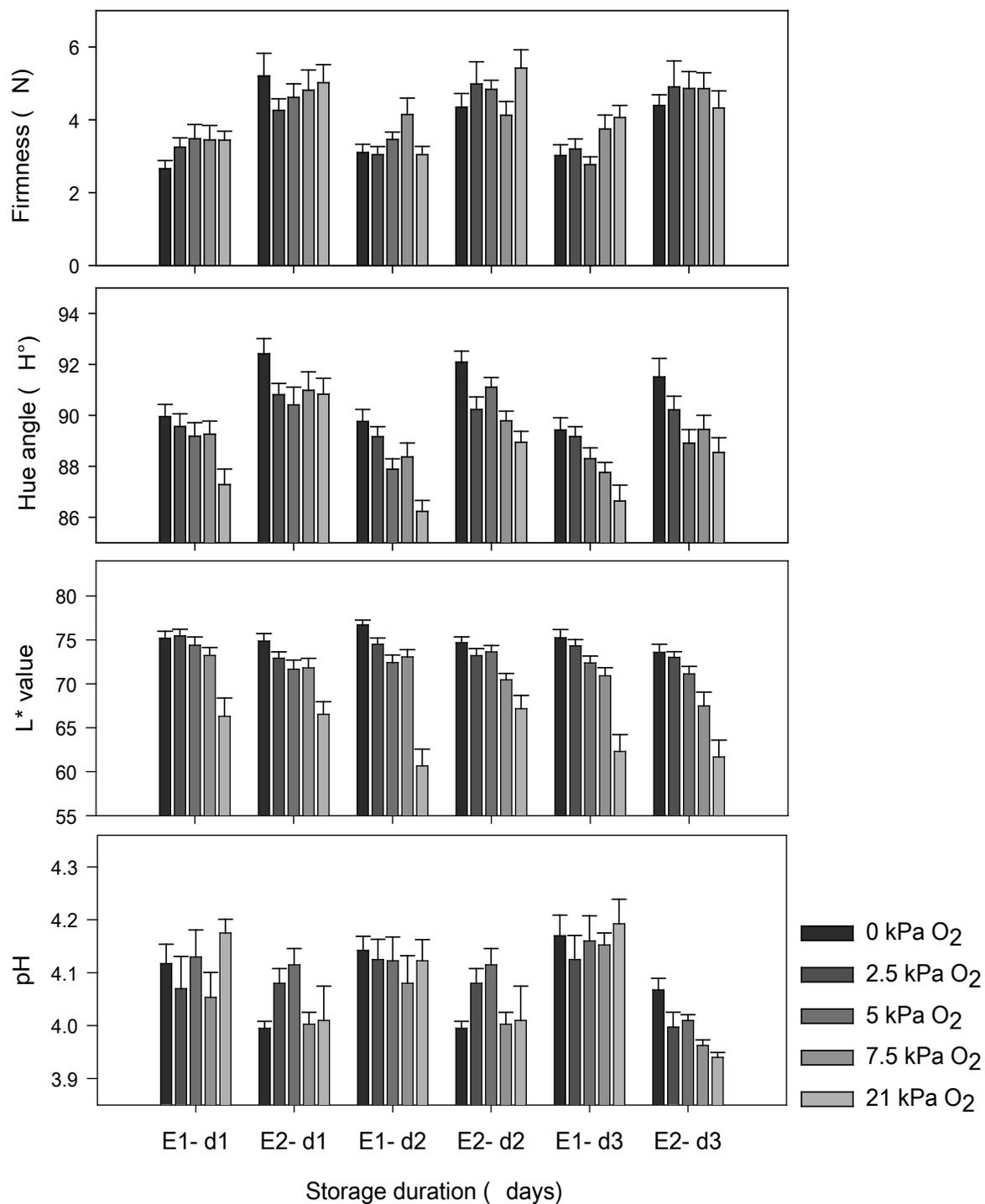


Figure 6-9. Changes in firmness, flesh color (hue angle and L*value), pH, and titratable acidity of fresh-cut 'Kent' mango slices held in air, reduced O₂, or reduced O₂ plus elevated CO₂ for 3-days at 15 °C(Experiment 1 and Experiment 2).

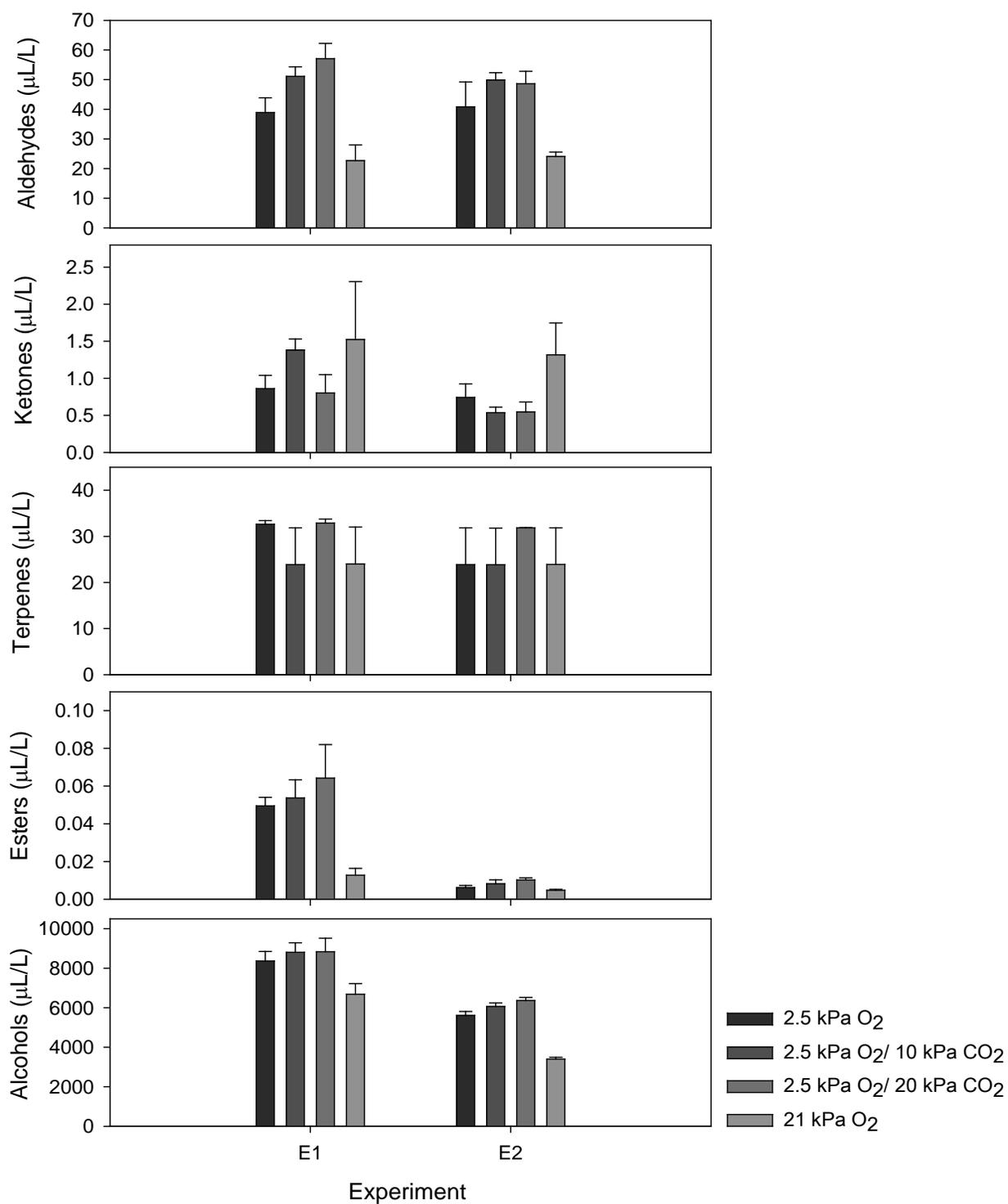


Figure 6-10. Aldehydes, ketones, terpenes, esters and alcohols content of fresh-cut 'Kent' mango slices held in air, reduced O₂ or reduced O₂ plus elevated CO₂ for 3 days at 15 °C.

CHAPTER 7
EFFECTS OF REDUCED OXYGEN AND ELEVATED CARBON DIOXIDE ON
RESPIRATION RATES AND QUALITY OF FRESH-CUT 'KENT' MANGO

Introduction

Results from the previous chapter suggested that storage of fresh-cut 'Kent' mango slices at 15°C in 2.5 kPa O₂ plus 10 kPa CO₂ could be an effective method to prolong the shelf life of mango slices handled at non-chilling temperatures or when they are inadvertently exposed to higher than desired temperatures during retail display.

In previous experiments, it was found that the quality of fresh-cut mango slices rapidly decreased at 15 °C. However, a reduced O₂ plus elevated CO₂ atmosphere regime at 15 °C, better maintained the visual quality and slice color compared with storage in air. However, firmness, pH, TA and SSC of the mango slices were not significantly affected by the atmosphere composition. Higher levels of fermentative aroma volatiles (i.e., acetaldehydes and ethanol) occurred in slices held in reduced O₂ atmospheres compared with air, but no objectionable aroma was detected subjectively. Moreover, 2.5% O₂ plus 10 kPa CO₂ was more effective in maintaining firmness, color, and visual quality of slices than 2.5% O₂ plus either 0 or 20 kPa CO₂ or air.

Nevertheless, information regarding the effects of different reduced O₂ plus elevated CO₂ on the respiration rate (RR) of fresh-cut mango slices was questionable due to the great variation of replicated sample measurements. Thus, results from the previous chapter regarding RR of fresh-cut mango slices were inconclusive with regard to the best atmosphere combination for fresh-cut 'Kent' mango held at the non-chilling temperature of 15 °C. The RR plays an important role in the shelf life of fresh-cut products, as it is closely linked with the metabolic activity of the tissues. Atmospheres with reduced O₂ plus elevated CO₂ levels may extend the product shelf life by decreasing the RR and retarding the use of the finite energy supply that is available (Gorny,

1997). But, if the product is exposed to unfavorable atmospheres, the respiration can rapidly increase as the tissue shifts to fermentative metabolism, leading to the production of ethanol, acetaldehyde, and other fermentative compounds that reduce product quality and shelf life. Moreover, information about the RR of a particular product is fundamental when designing a modified atmosphere packaging (MAP) system. In fact, the product RR provides the driving force for gas movement in and out of the MAP (Mir and Beaudry, 2004) and, thus influences the choice of the appropriate film or type of packaging. So, knowledge about the RR of a specific product when it is exposed to an optimal atmosphere at a targeted temperature for a given duration is essential when designing a MAP system.

The main objective of this study was to collect data on the RR and assess the visual and compositional quality of fresh-cut mango slices held in reduced O₂ and/ or elevated CO₂ atmospheres at 15°C.

Materials and Methods

Plant Material

This study was conducted twice during the Peruvian mango season in February 2009. A total of 200 size 8 mature green ‘Kent’ mangoes (eight fruit per 4.5-kg carton) were received from an importer/distributor in Miami, FL and transported to Gainesville in an air-conditioned vehicle. Upon arrival at the laboratory, half of the fruit were stored at 20 °C for immediate ripening (E1), while the other half were stored at 10 °C to delay ripening. The latter lot of fruit was then transferred to 20°C after 4 d to be ripened and used for the second experiment (E2).

Mangoes were ripened at 20 °C until they reach a firmness of about 30N. The fruit for processing were selected following the procedure described in Chapter 3. A total of 70 mangoes were selected to be processed into fresh-cut slices for each experiment.

Fresh-cut Processing

For both studies, fruit were processed into fresh-cut slices in a sanitized environment at 5 °C following the procedure described in Chapter 3. About 250g of mango slices were packed in replicate terephthalate (PETE) containers with leak-free snap-on covers that had a 1.5-cm diameter hole.

Storage in Reduced O₂ and Reduced O₂ Plus Elevated CO₂ Atmospheres

The fresh-cut samples were transferred to 15 °C and were randomly distributed into 18.9-L (5-gal) buckets, with four containers per bucket. Each bucket was connected to a manifold, with three buckets per manifold. Each bucket received a continuous humidified flow of O₂, N₂, and/or CO₂ mixed in predetermined amounts to generate different atmospheres. The flow rates were adjusted so that the CO₂ concentration due to sample respiration did not exceed 0.2 kPa in the humidified air controls. The slices were exposed to 2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or to 21 kPa O₂ (air control) at a flow rate of 160 mL/min per manifold.

When necessary, each bucket was sealed and initially flushed with N₂ and CO₂ to rapidly reach the desired atmosphere before being connected to the appropriate manifold. The gas concentrations were measured with a gas analyzer (Checkmate 9900, PBI Dansensor, Denmark).

Quality Evaluation

Visual quality, firmness, flesh color (hue angle and L* value), pH, TA and SSC of fresh-cut mango slices were evaluated after 1, 2, and 3 d, as described in Chapter 3.

Respiration Rate Measurements

Each bucket containing four sample replicates was sealed and 0.5-mL headspace samples were withdrawn by syringe through a rubber septum 1) after sealing and 2) after 1 to 2 h. The CO₂ concentration was determined using a gas chromatograph (CG) (Gow-Mac Series 580,

Bridge Water, N.J.) as previously described in Chapter 3. Initial and final CO₂ measurements were also taken with a gas analyzer (Checkmate 9900, PBI Dansensor, Denmark).

Aroma Volatiles

Fresh-cut mango tissue samples were juiced using a Braun MP80 Juicer (Germany) and, from each juiced sample, 1 mL of juice (homogenized, without foam or air) was combined with 4 mL 62.5% saturated NaCl solution in a 10-mL vial and. One stir bar sorptive extraction (SBSE) bar (10 mm length, Gerstel, Muelheim an der Ruhr, Germany) conditioned at 300 °C for 1 h was then added to each sample. The samples were stirred for 1 h at 38.5 °C on a stir plate placed inside an incubator. After 1 h, the SBSE bars were retrieved, gently washed with deionized water, and wiped dry with a paper tissue (Kim-wipe). The SBSE bars were desorbed using a Gerstel Twister Desorption Unit (TDU) port on an Agilent 5973 MSD GC/mass spectrometer (GC-MS) with a DB5 capillary column (30 m x 0.25 mm x 0.25µm), operated in the electron ionization mode at 70 eV with a source temperature of 200 °C, and a continuous scan from m/z (mass to charge ratio) 33 to 300. The data were analyzed using MSD ChemStation Data Analysis Software (Agilent), containing a library of over 100,000 compounds of which the software can reference compounds based on their ion counts. Acetaldehyde, ethanol, ethyl acetate and ethyl butanoate compounds were identified and the ion target response for each compound was reported to compare the effects of atmosphere treatments on each volatile.

Statistical Analysis

Analysis of variance (ANOVA), using the General Linear Model, was conducted to identify significant main effects due to the experiment replicates, gas composition, and storage duration, using the PC-SAS software package (SAS-Institute, 1985). Significant differences between treatments were detected using the least significant differences (LSD) test at the 5%

level. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis.

Results

Visual Evaluation

The visual quality declined rapidly at 15 °C. After 2 d, the fresh-cut slices had already reached or passed the marketability limit (score of 5). However, extent of the quality loss varied among the atmosphere treatments (Figure 7-1).

The overall color score was higher (i.e., less discoloration) for fresh-cut mango slices exposed to 5 kPa O₂ in E1 and 21 kPa O₂ in E2 compared to the other atmosphere treatments (Figure 7-1). In both experiments, edge tissue damage was less severe in both experiments for slices exposed to 2.5 kPa O₂, followed by 5 kPa O₂. Less microbial spoilage was also observed in slices exposed to 2.5 kPa O₂. In E1, off odor was detected in all samples, but was less severe in E1 for slices exposed to 2.5 kPa O₂ than for the other atmosphere treatments. On the other hand, in E2, no significant differences were detected in the aroma of the mango slices, regardless of the atmosphere treatment. On day 3, informal subjective evaluations determined that the slices exposed to 2.5 kPa O₂ or 5 kPa O₂ had more intense ripe mango aroma than the slices held in air. Moreover, slices exposed to reduced O₂ plus elevated CO₂ were perceived as having a stronger alcoholic aroma compared with the slices from the other atmosphere treatments. Slice desiccation was more severe in the 21 kPa O₂ treatment compared with the other atmosphere treatments, and was least severe in the mango slices held in 2.5 kPa O₂ plus either 0 or 10 kPa CO₂ in E2 and E1, respectively. Differences between experiments, regarding desiccation of the slices, were probably due to the variations in the relative humidity of the gas flows.

Respiration Rate

RR was measured by GC or gas analyzer using a closed system (Table 7-2, Figure 7-2). For E1, significantly higher RR was measured using the gas analyzer than the gas chromatograph, but no difference between the two methods was observed For E2. RR could not be accurately measured for slices stored in the elevated CO₂ treatments due to negative differences between the initial and final readings for several measurements.

The RR measured in the reduced O₂ and air treatments was similar in both experiments, regardless of the sampling method (Table 7-1, 7-2). Overall, no significant changes in RR occurred during storage in any of the atmosphere treatments (Figure 7-2). No significant difference between the atmosphere treatments was measured in E1, but in E2 the RR was higher in the 2.5 kPa O₂ treatment than in the 5 kPa or 21 kPa O₂ treatments.

Overall, compared to storage in air, the reduced O₂ treatments, without elevated CO₂, did not significantly reduce the RR of the fresh-cut mango slices at 15 °C.

Firmness

The average firmness of the fruit selected for fresh-cut processing was higher than the 30N targeted ($34.7 \pm 4.38\text{N}$ for E1 and $36.2 \pm 6.2\text{N}$ for E2). This was due to the large variability in the firmness of the fruit within the lot. Besides, the relatively small amount of mangoes received did not permit a thorough selection. Accordingly, the firmness of the mango slices was lower in E1 than E2 (Table 7-1, Figure 7-3). The firmness of the slices decreased over time, but was not affected by the atmosphere treatments (Table 7-1),

Flesh Color

The reduced O₂ and elevated CO₂ treatments maintained higher lightness (L* value) in the mango slices than the air control (Table 7.1), indicating that the slices exposed to normal O₂ had more browning than those exposed to reduced O₂ and elevated CO₂.

The hue angle of the slices differed between the experiments (Table 7-1) in that slices from E1 had higher hue angle values than those from E2. Consequently, the slices from E2 were more orange than those from E1. Overall, no significant effect of atmosphere treatments on the hue angle values of the mango slices was observed (Table 7-1). However, when the experiments were analyzed separately, the hue angle values of the mango slices from E1 were significantly higher in the slices exposed to 2.5 kPa O₂ than the other treatments. Among the other treatments in E1, slices exposed to 2.5 or 5 kPa O₂ plus 10 kPa CO₂ had comparable high hue angle values, and slices exposed to 5 or 21 kPa O₂ alone had comparable lower hue angle values. In E2, the atmosphere treatments had no effect on the hue angle values of the fresh-cut mango slices.

Compositional Analysis

pH, TA and SSC.

Overall, the pH and SSC were not affected by any of the main factors of this study (Table 7-1). However, the TA of the mango slices was higher in E2 than in E1 and, in both cases, the TA decreased with storage. The TA of the slices held in air was lower than the TA of the slices exposed to reduced O₂ with or without elevated CO₂ (Figure 7-3).

Aroma volatiles

Acetaldehyde content in the fresh-cut slices was not affected by any of the main factors of this study (Table 7-3). No target response for acetaldehyde was recorded for mango samples exposed to 2.5 kPa O₂ plus 10 kPa CO₂ due to a non-identified experimental error that occurred during the procedure.

Ethanol accumulated to higher levels in the fresh-cut slices in E2 than in E1. In general, slices held in 21 kPa O₂ had lower ethanol than slices stored in reduced O₂ with or without elevated CO₂. No significant difference in ethanol content between reduced O₂ treatments with or without elevated CO₂ was observed. The significant interaction between the effects of the

replicate experiments and the atmosphere treatments that was detected by the ANOVA was caused by small differences among the ethanol levels in the different reduced O₂ plus elevated CO₂ treatments. For E1, the ethanol content of the slices was highest in the 5 kPa O₂ plus 10 kPa CO₂ treatment. While in E2, slices from the 2.5 kPa O₂ plus 10 kPa CO₂ treatment had the highest ethanol content.

The contents of ethyl acetate and ethyl butanoate in the fresh-cut mango slices were higher in E1 than in E2. Overall, lower amounts of ethyl acetate and ethyl butanoate occurred in the samples stored in air than in those from the reduced O₂ plus elevated CO₂ treatments.

Discussion

Despite the rapid loss of quality that occurred in fresh-cut mango slices at 15 °C, the visual quality of the slices was slightly improved by the reduced O₂ levels. The color of the mango slices was better preserved in the reduced O₂ treatments, and edge damage and spoilage were less severe in reduced O₂ than in air. Overall, no significant difference in aroma was noticed between samples from all treatments as they all developed off odor. Addition of elevated CO₂ did not have any supplementary effect on the visual quality of the mango slices.

Reduced O₂ concentration better maintained the color of the slices nearer to their initial color (i.e., higher hue angle values) compared with holding in air. Similarly, fresh-cut mango slices held in reduced O₂ plus elevated CO₂ maintained higher L* values than those held in air. Less browning and tissue watersoaking developed in the slices stored in reduced O₂ (with or without elevated CO₂). In fact, at the end of the experiment, the slices stored in air appeared overripe and watersoaked compared with the slices stored in reduced O₂ in which such symptoms were less severe or absent.

Firmness, pH, and SSC were not affected by the reduced O₂ plus elevated CO₂ treatments, but slices stored in reduced O₂ plus elevated CO₂ had higher TA than slices stored in air. Slices

stored in air may have continued to ripen, which may have caused a greater decrease in TA compared with the reduced O₂ plus elevated CO₂ treatments.

The relatively short-shelf life (1 to 2 d) of the fresh-cut mangoes in this study, compared to the shelf life of 3 to 4 d reported in the previous chapter, may have been due to the initial quality of the fruit, which were riper than those used in the previous study. In addition, the 2009 Peruvian mango season was relatively short due to poor climatic conditions that resulted in fewer marketable fruit of variable quality. This contributed to a difficult initial fruit selection due to a non uniform ripeness among the lots of fruit received.

In this study, the RR was not affected by reduced O₂ treatments, but a significant difference between the methods used to measure RR was observed. Higher RR was measured when using a GC (a range of 19.3 to 30.8 mg/kg·h) compared to the gas analyzer (a range of 25.0 to 33.9 mg/kg·h). This may have been due to differences in the accuracy of the sampling for the two instruments. For the gas analyzer, direct readings were taken inside the buckets by an automated sampling pump while syringes were used to manually take samples from the bucket inlets and outlets for injection into the GC. The latter procedure appeared to disrupt the atmosphere equilibrium inside the flowing gas bucket system as evidenced by several occurrences in which the CO₂ concentration measured in the incoming gas flow was higher than that of the outflow, which is physiologically impossible for a system containing respiring products.

The total RR average of fresh-cut mango slices stored at 15 °C in reduced O₂ and in air for the whole storage duration was 33.4 ± 17.8 mg/kg·h when measured by gas analyzer approximately and 27.1 ± 14.6 mg/kg·h when measured by GC.

Little information has been published regarding the RR of fresh-cut mango held in reduced O₂ plus elevated CO₂. Poubol and Izumi (2005a) reported RR ranging from 55 to 60 mg/kg·h¹ for ‘Carabao’ and ‘Nam Doc Mai’ fresh-cut mango cubes stored at 13 °C in air, while during storage in air at 5°C an RR of approximately 20 mg/kg·h was measured. In another study, Izumi et al. (2003) reported RR for mango cubes that varied from 10 to 22.5 mg/kg·h during storage in air at 5 °C; when the cubes were stored in 0.5, 1 or 2 kPa O₂, the RR decreased to about 7 mg/kg·h. In this study, 2.5 kPa and 5 kPa O₂ levels did not affect the RR of ‘Kent’ mango slices stored at 15°C.

Higher target response using the SBSE method is correlated with higher amount of volatile compounds. Thus, reduced O₂ increased the fermentative metabolites in the fresh-cut mango slices. Higher amounts of ethanol, ethyl acetate, and ethyl butanoate were produced by mango slice exposed to reduced O₂ compared with slices held in air. Nevertheless, even though the reduced O₂ levels induced greater production of fermentative volatile compounds, it did not affect the overall aroma of the fresh-cut mango slices.

Conclusion

In this study, fresh-cut ‘Kent’ mango slices were held in reduced O₂ atmospheres with or without elevated CO₂ at 15 °C and the effects on RR, visual quality, and compositional quality were evaluated.

Storage in reduced O₂ had a slight positive effect on the visual quality of the mango slices compared with storage in air. Overall, color was better maintained, and edge tissue damage and spoilage were less noticeable in slices stored in reduced O₂ plus elevated CO₂. Even though higher levels of fermentative metabolites (ethanol, ethyl acetate and ethyl butanoate) occurred in slices stored in reduced O₂ (with or without elevated CO₂), no significant difference in aroma was detected between the atmosphere treatments.

The RR of fresh-cut mango slices was measured using two different methods, GC or gas analyzer. Despite the significant differences between the RR measured by the two methods (higher RR were measured by gas analyzer), the RR were not significantly affected during by the reduced O₂ levels compared to holding in air. The RR of the slices stored in reduced O₂ and elevated CO₂ could not be accurately measured due to negative differences between the initial and final readings for several measurements.

In previous studies (Chapter 6), during storage of 3 to 4 d at 15 °C, an atmosphere of 2.5 kPa O₂ plus 10 kPa CO₂ helped to preserve the quality of fresh-cut mango and extended the shelf life by 1 d compared with holding in air. In this study, however, little beneficial effect of reduced O₂ with or without elevated CO₂ on the quality of fresh-cut mango was noticed. This may be due to the problems with the initial quality of the mangoes used in this study, especially the variability in initial ripeness stages among the fruit.

Even though the range of RR measured in this study was large, the data collected still provides valid information that can be used as starting point for the development of a MAP system that will be capable of maintaining the overall quality of fresh-cut mango slices when exposed to non-chilling temperatures.

Table 7-1. ANOVA table - Respiration rate, firmness, color, and titratable acidity of fresh-cut 'Kent' mango

Source of variations	d.f.	F-value					
		RR ^a (mg/kg·h)	RR ^b (mg/kg·h)	Firmness (N)	Hue angle (H°)	Lightness (L*)	Titratable acidity (% citric acid)
E	1	0.47 ns	3.37 ns	83.70***	0.39 ns	7.21**	65.91***
CA	4	4.80*	0.98 ns	0.52 ns	10.80***	1.22 ns	5.08**
S	2	0.18 ns	1.88 ns	16.86***	0.07 ns	3.93 ns	9.39**
E×CA	4	1.33 ns	0.74 ns	2.00 ns	0.87 ns	0.96 ns	1.01 ns
E×S	2	0.44 ns	0.80 ns	0.41 ns	5.75*	1.15 ns	1.71 ns
R×S	8	0.26 ns	3.12 ns	0.91 ns	0.65 ns	1.58 ns	1.56 ns
E×CA×S	8	0.45 ns	2.53 ns	0.81 ns	0.96 ns	1.00 ns	0.47 ns

Fresh-cut mango slices from both experiments (E1 and E2) were exposed to different gas compositions (2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or 21 kPa O₂) (CA) and analyzed on days 1, 2, and 3 at 15 °C (S);

^a Respiration rates measured by gas chromatograph;

^b Respiration rates measure by gas analyzer;

ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 7-2. Respiration rates of fresh-cut 'Kent' mango slices held in air or reduced O₂ at 15 °C as measured by gas analyzer or gas chromatograph .

Measurement method	Experiment	Oxygen levels			LSD (p<0.05)
		2.5 kPa O ₂	5 kPa O ₂	21 kPa O ₂	
Gas analyzer	E1	30.2	28.2	33.9	2.1
	E2	29.2	25.0	25.2	9.1
	LSD (p<0.05)	2.3	8.2	10.4	-
Gas chromatograph	E1	30.9	20.4	21.9	10.2
	E2	24.6	19.6	19.3	2.1
	LSD (p<0.05)	7.2	6.5	12.3	-

Table 7-3. ANOVA table - Ion target response for acetaldehyde, ethanol, ethyl acetate and ethyl butanoate retrieved by SBSE GS-MS for fresh-cut 'Kent' mango held in reduced O₂ plus elevated CO₂ at 15°C

Source of variations	d.f.	F-value			
		Acetaldehyde	Ethanol	Ethyl acetate	Ethyl butanoate
E	1	1.07 ns	9.29**	7.55**	9.61**
CA	4	2.84 ns	5.29***	4.81**	9.31***
E×CA	4	0.85 ns	2.63*	0.98 ns	0.99 ns

Fresh-cut mango slices from both experiments (E) were exposed to different O₂ levels (2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or 21 kPa O₂) (CA) and analyzed on day 2 at 15 °C.

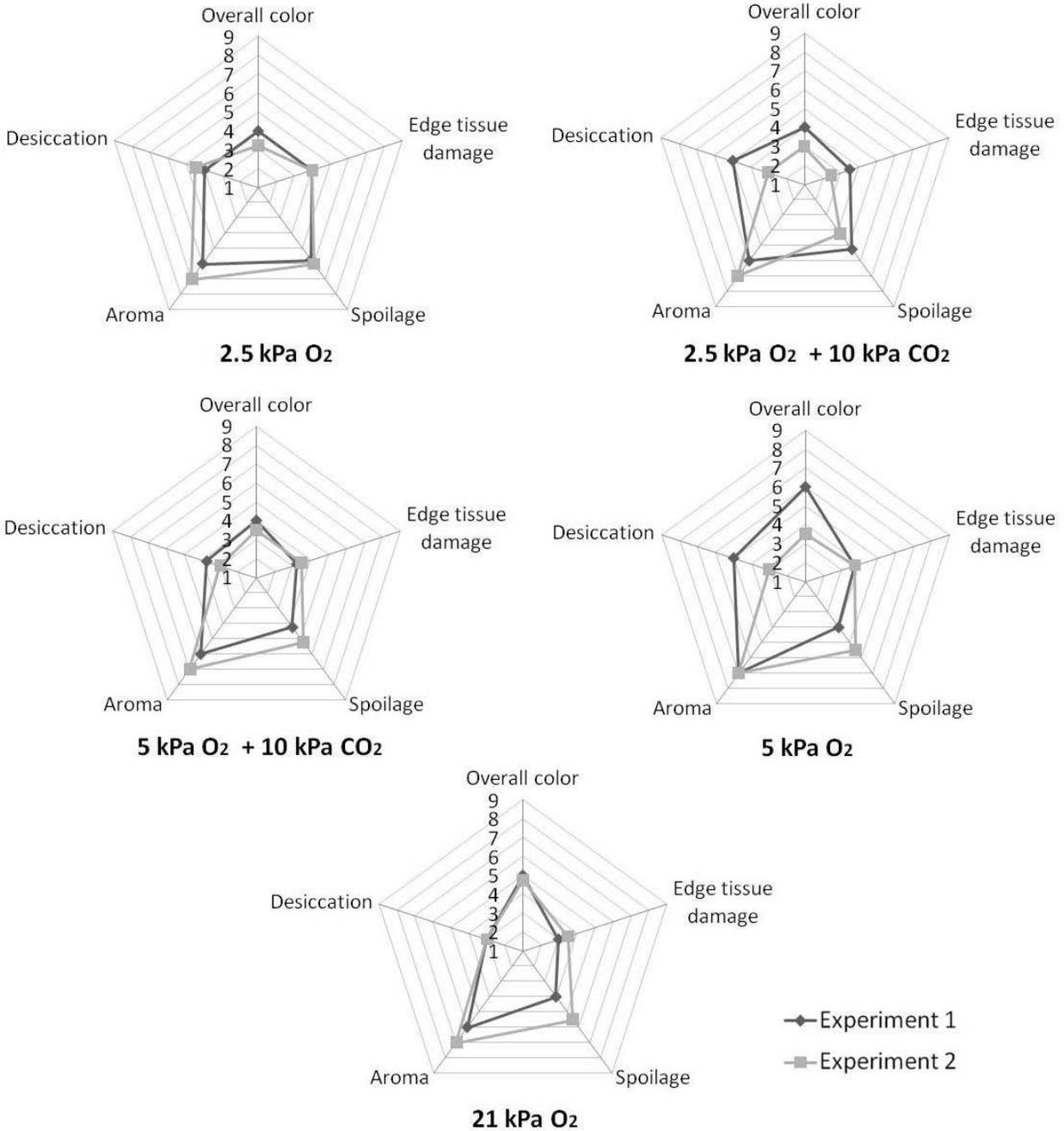


Figure 7-1. Subjective visual quality evaluation on day 2 for fresh-cut 'Kent' mango slices held in 2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or 21 kPa O₂ at 15 °C . For subjective ratings, 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1, poor, inedible. A rating of 5 was considered to be the minimum (limit) for marketing any product.

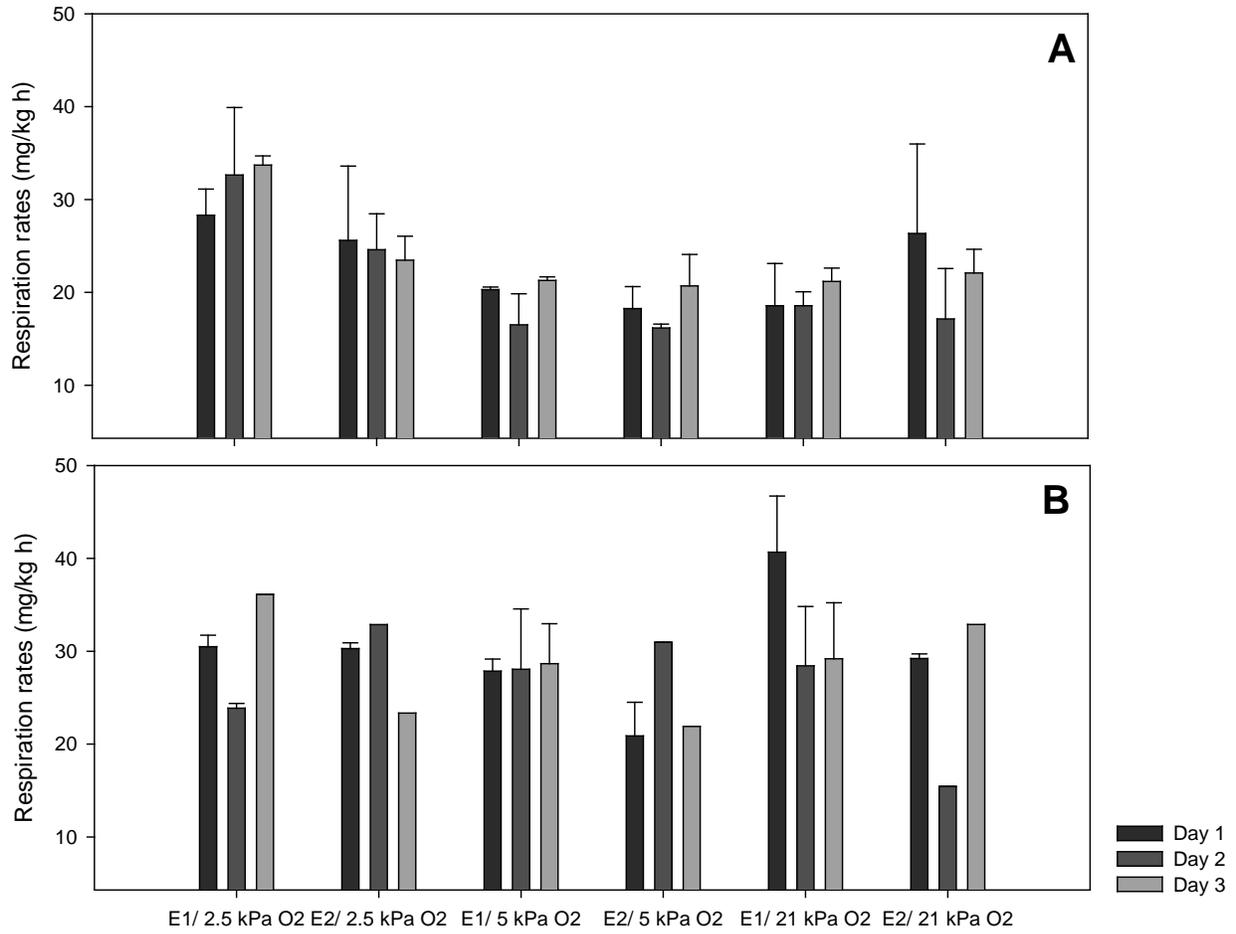


Figure 7-2. Respiration rates of fresh-cut 'Kent' mango slices held in 2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or 21 kPa O₂ for 3 days at 15 °C for E1 and E2.

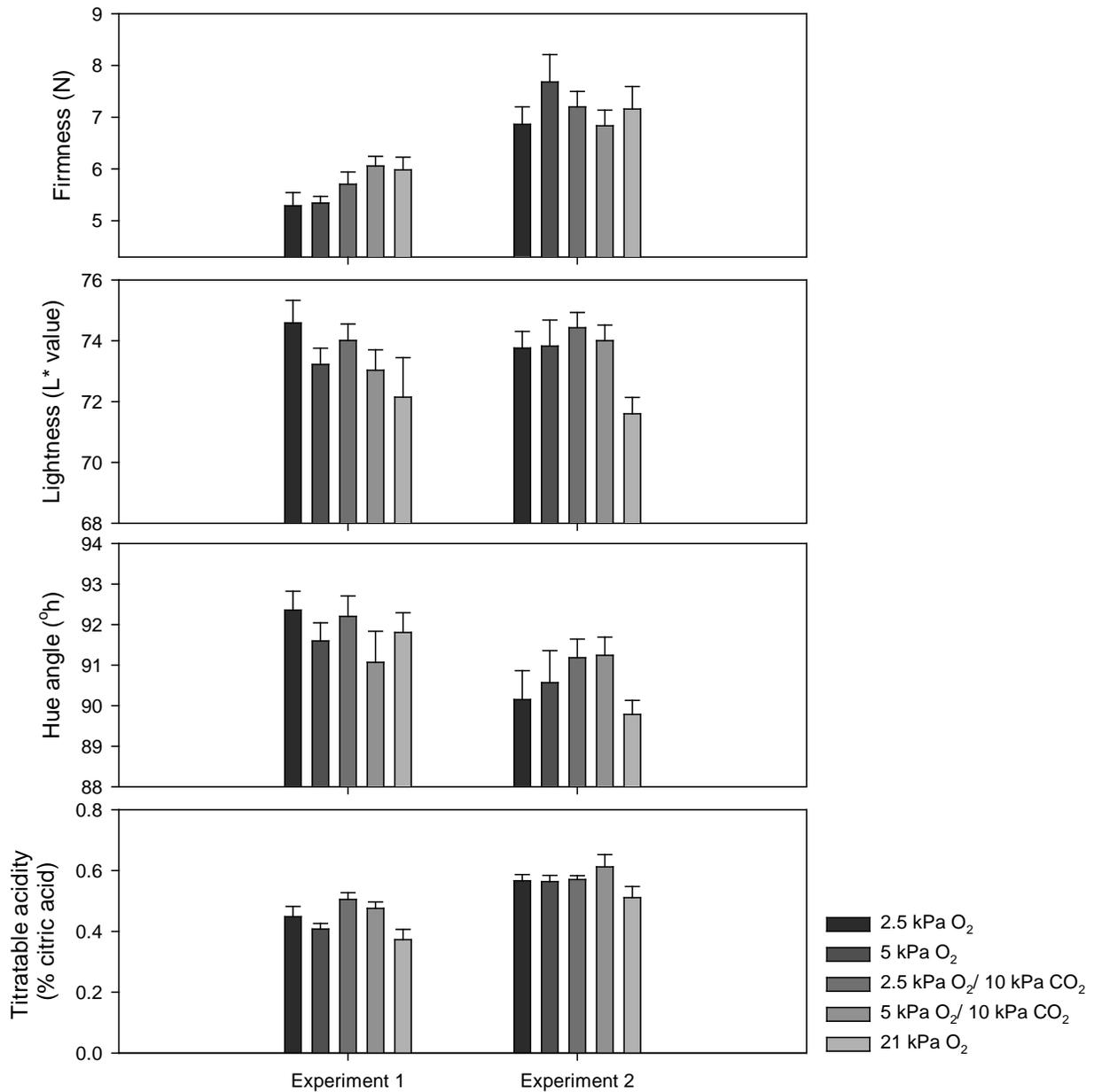


Figure 7-3. Changes in firmness, flesh color (hue angle and L*value) and pH of fresh-cut 'Kent' mango slices held in 2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or 21 kPa O₂ for 3 days at 15 °C for E1 and E2.

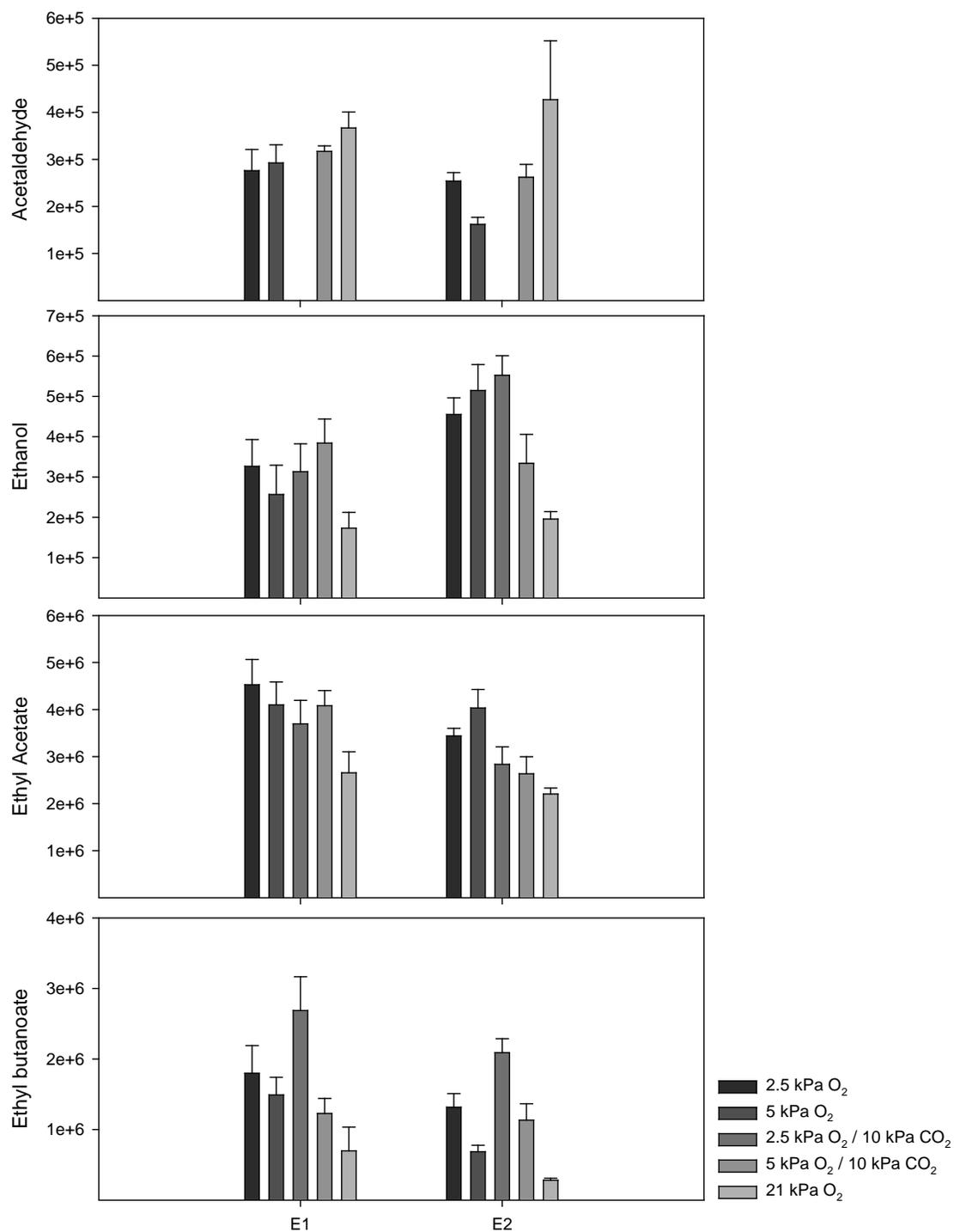


Figure 7-4. Ion target response for acetaldehyde, ethanol, ethyl acetate, and ethyl butanoate obtained by SBSE GC-MS for fresh-cut 'Kent' mango slices held in 2.5 or 5 kPa O₂ plus 0 or 10 kPa CO₂ or 21 kPa O₂ at 15 °C.

CHAPTER 8 MODIFIED ATMOSPHERE PACKAGING FOR FRESH-CUT 'KENT' MANGO

Introduction

The main challenge of designing a modified atmosphere packaging (MAP) system for fresh produce is to find the appropriate polymer film or perforation configuration that can provide the desired concentrations of O₂ and CO₂ inside the package (Eqs. 2-3, 2-4) by matching the package permeability with the respiration rate of the produce when held in the desired modified atmosphere (MA) at a given temperature.

It is known that temperature management, within the recommended temperature range, is more effective in preserving the quality of fresh-cut fruits than the use of MA (Kays, 1991). Therefore, when the temperature is being properly managed, the O₂ and CO₂ levels established at steady state within a MAP system play a secondary or supplemental role to the temperature in reducing the metabolic rate of the tissue and avoiding the effects of ethylene on ripening and senescence. The MAP system also functions as a barrier against microbial contamination, and helps to reduce water loss (Forney, 2007). If the package is exposed to higher temperatures during distribution or when on retail display, the MAP can potentially serve to counter the negative effects of the high temperature by reducing tissue metabolic rates and slowing down quality degradation. But, this benefit can be achieved only if the MAP system is designed to provide O₂ and CO₂ concentrations that avoid the injurious limits of the tissue while it is exposed to high temperatures. Otherwise the tissue is likely to initiate fermentative metabolism at the higher temperature if the respiration rate increases to the point that it overwhelms the capacity of the MAP system to allow sufficient gas exchange to maintain a non-injurious atmosphere.

In the previous chapters, it was determined that an atmosphere consisting of 2-5 kPa O₂ plus 10 kPa CO₂ helped maintain the quality and composition of fresh-cut 'Kent' mango slices at

a temperature higher than 5 °C – the typical handling temperature for fresh-cut mango. It has been documented that fresh-cut fruits are often exposed to temperatures in the range of X to Y °C during retail handling (Nunes et al., 2009). The chilling injury threshold for whole mango fruit is in the range of 12 to 15 °C depending on cultivar and fruit maturity (Abou-Aziz et al., 1976b; Chaplin et al., 1991; Thomas and Joshi, 1988) and it was shown in experiments described in an earlier chapter that fresh-cut mango undergoes chilling stress when held at 5 °C. Therefore, it was determined that an atmosphere of about 3 to 4 kPa O₂ plus a maximum of 10 kPa CO₂ at 15 °C should be targeted for the MAP design.

In order to achieve an atmosphere at steady state of 3 to 4 kPa O₂ plus 10 kPa CO₂ at 15 °C, the MAP system for fresh-cut mango requires a film with relatively low O₂ permeability and very high CO₂ permeability. The ideal film should be 8 times more permeable to CO₂ than to O₂ in order to maintain the desired reduced O₂ concentration and also avoid a CO₂ concentration higher than 10 kPa. Most polymeric films currently available in the market have CO₂/O₂ permeability ratios of 6 or less (i.e., up to six times more permeable to CO₂ than to O₂) (Doyon, 1989), which does not meet the targeted parameters. Nevertheless, even though the desired O₂ and CO₂ transmission rates cannot be simultaneously matched with the selectivity of any commercially available film, the targeted O₂ concentration was given priority since it is not only a physiologically effective factor, but also the most critical in MAP (Exama et al., 1993). Consequently, polyvinyl chloride (PVC) film, which has a permeability ratio of about 6, was selected as coming closest to providing the desired permeability characteristics.

In this study, stretch PVC film was tested to evaluate the effect of a MAP system on the quality and shelf life of fresh-cut ‘Kent’ mango slices held at 5 °C or 15 °C.

In the fresh-cut industry, antioxidant dipping solutions are widely used to preserve the initial color of fresh-cut fruits by inhibiting oxidative browning reactions (Soliva-Fortuny and Martín-Belloso, 2003). In experiments conducted previously, discoloration of fresh-cut mango slices was an important factor limiting the shelf life. Therefore, the synergetic effect of MAP with an antioxidant (Aox) solution applied to the fresh-cut mango slices was also investigated.

Materials and Methods

Plant Material

A total of 244 'Kent' mangoes from Guatemala (twelve boxes of each size 7, 8 and 9, i.e., 7, 8 or 9 fruit per 4.5-kg carton) were received directly from an importer in Pompano Beach, Florida in May, 2009. The fruit were brought to the University of Florida within 5 h. Due to unexpected delays during transportation from Guatemala to Florida, the fruit arrived at the laboratory already at a more advanced ripeness stage than mangoes that were used in previous experiments and the fruit were quite variable in firmness (average fruit firmness \pm standard deviation was $53.8 \pm 19.13\text{N}$ for size 7, 41.0 ± 12.2 for Size 8, and $41.4 \pm 13.7\text{N}$ for size 9). Nevertheless, the most of the fruit were still firmer than the desired firmness for fresh-cut processing of 30 N. The fruit selection for the first experiment (E1) was done upon arrival following the methodology described in Chapter 3. The remaining fruit were stored at 15 °C and allowed to ripen slowly in order to be used a few days later in a second experiment (E2). The average firmness of the mangoes selected for E1 was $34.8 \pm 4.4\text{ N}$ and for E2 the initial firmness was $38.4 \pm 8.0\text{N}$.

The fruit were processed in a sanitized room. Before being peeled, all mangoes were immersed for 3 min in aqueous 100 $\mu\text{L/L}$ NaOCl at 5 °C, adjusted to pH 7 with 2N citric acid solution. For the air-control and the MAP samples, peeled mangoes were submerged in a second 100 $\mu\text{L/L}$ NaOCl at 5 °C chlorinated water bath, left to drain until processed (5 to 15 min), then

cut into slices as described in Chapter 3. For MAP + Aox samples, mangoes were peeled and cut into slices, dipped in a 10 µL/L NaOCl solution for 30 s, drained for 30 sec then dipped in a solution composed of 51 mM (2%) calcium ascorbate and 52 mM (1%) citric acid for 30 s (Plotto et al., 2006). The slices were then drained for 2 min before being distributed into storage containers.

It was determined in previous experiments that the respiration rate (RR; CO₂ production) of fresh-cut mango slices in an atmosphere of 3-4 kPa O₂ plus 10 kPa CO₂ at 15 °C was approximately 30 mg/kg·h. The O₂ permeability of the stretch PVC Omni film (PVC-RMF 61, Goodyear, OH) that was selected for this MAP was 2.3×10^{-2} mL·mil/cm²·h·atm and the CO₂/O₂ permeability ratio was 6.1 (Exama et al., 1993). The required film transmission requirements were established to match the RR of fresh-cut mango slices at 15 °C and to achieve an inner atmosphere 3 to 4 kPa O₂. The film O₂ permeability requirements were calculated with the mass balance equation for O₂ (Eq. 2-3), with the volume of 300g of mango slices in a container of known parameters (591 ml and a surface area of approximately 169 cm²). This necessitated using two layers of the PVC Omni film to cover the opening of the containers holding the mango slices.

For air-control samples, approximately 300 g of fresh-cut slices were placed in 591-ml rigid Ziploc® containers with the lid loosely closed. For the MAP and MAP + Aox samples, approximately 300 g of slices were placed into 591-ml Ziploc® containers and the open container top was covered with two layers of the stretch PVC Omni film and sealed by overlapping and pressing together the sides of the film at the base of the container.

Each container was carefully flushed with nitrogen (N₂) until an atmosphere of 2 kPa O₂ inside the container was obtained as measured with an O₂/CO₂ gas analyzer (Checkmate 9900,

PBI Dansensor, Denmark). The samples were stored at 5 °C or 15 °C, for 10 or 5 days, respectively. The atmospheres inside all of the MAP were measured daily with the O₂/CO₂ gas analyzer.

Quality Evaluation

Fresh-cut mango slices were evaluated for visual quality, flesh color, and composition of the tissue as previously described in Chapter 3. For mango slices stored at 15 °C, quality evaluations were performed on samples selected randomly on days 2, 3, 4, and 5 for the samples stored at 15 °C, and on days 3, 5, 8, and 10 for the samples stored at 5 °C.

Microbial Evaluation

To determine the microbial load on the fresh-cut mango slices, 5-g samples of mango tissue were placed in sterile centrifuge vials with 45 ml phosphate buffered saline (PBS) adjusted to pH 7.4 and agitated with a reciprocal shaker (Eberback Corporation, Ann Arbor, MI) set at 60 osc/min for 5 min. Appropriate dilutions of the resulting liquid were spread onto 3M Petrifilm™ Aerobic Count Plates and incubated for 48 h at 30 °C to estimate total aerobic mesophilic microbial population. Yeast and molds populations were estimated on 3M Petrifilm™ Yeast and Mold Count Plates incubated for 120 h at 25 °C. Microbial analyses were performed on day of preparation of the fresh-cut mango slices, immediately after cutting, after holding the fresh-cut mango for 3 d at 5 °C or 15 °C, and then at the end of the shelf life for each treatment, as determined by the visual subjective evaluation.

Statistical Analysis

Analysis of variance (ANOVA) was performed using the General Linear Model to identify significant main effects due to the experiment replicates, MAP treatments, and storage duration, using the PC-SAS software package (SAS-Institute, 1985). Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. The

visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. For the microbial analysis, means \pm standard deviations were used.

Results

Modified Atmosphere

Once all of the MAP containers were sealed and flushed with N₂ (within 4 h), an atmosphere of approximately 2.4 kPa O₂ was measured in all samples for both experiments (Figure 8-1). The initial CO₂ concentration inside the MAP containers varied from 1.0 to 1.8 kPa. During storage at 5 °C, the O₂ concentration increased slowly to reach a steady state beginning on day 6 of approximately 6 kPa and 5 kPa for E1 and E2, respectively. The CO₂ concentration increased within 3 d at 5 °C to reach a maximum of 8.7 kPa (E1) or 7.4 kPa (E2). The CO₂ concentration then decreased slowly during the rest of the storage period, and by day 10, the O₂ and CO₂ concentrations were both about 6 kPa in E1 or 5 kPa in E2.

For the samples stored at 15 °C, the O₂ concentration reach a steady state on day 1 of 3.5 or 4 kPa for E2 and E1, respectively. The CO₂ increased within 2 d to 16.5 (E1) or 18.0 kPa (E2), and remained near those concentrations for the rest of the storage period.

Visual Evaluation

During storage at 5 °C and regardless of the treatment, more edge damage, spoilage, and desiccation, and less off odor were noticed for slices from E1 than from E2 (Figure 8-2). At 5 °C, MAP + Aox slices had better color retention, and developed less edge damage, off odor development, and desiccation than the slices in MAP without Aox treatment. Slices held in air had the lowest scores for those attributes among the treatments at 5 °C (Figure 8-2). Moreover, less indications of microbial spoilage (development of slimy and gooey surface) were noticed for slices in the MAP and MAP + Aox treatments than in the air control.

The visual quality decreased with increased time at 5 °C. The shelf life at 5 °C was limited to 8 d for both the MAP and the control samples. Appearance of whitish color and desiccation on the surfaces of the slices were the limiting factors for the air-control samples. Also, browning was observed on the riper slices, with easily bruised edges and mushy tissue. No off odor was perceived, but the overall aroma was bland with no characteristic mango aroma. For the slices in MAP, the shelf life was limited by edge tissue damage and desiccation. The slices had also no fruit aroma, but no-off odor was perceived. On the other hand, slices in MAP + Aox had a shelf life of 10 days that was limited in E1 by edge bruising, some browning, and soft texture, and by desiccation that caused the slices to stick together in E2.

Better overall color, along with less edge damage, spoilage, and desiccation were noted for slices from E1 compared with E2 at 15 °C. Overall, as noted for 5 °C, the MAP + Aox slices retained better color and developed less edge damage, off odor development, spoilage, and desiccation than the MAP slices without Aox, followed by the air control. The visual quality decreased rapidly at 15 °C. The shelf life was limited to 4 d for both the control and the MAP samples. Control samples were showing evident signs of spoilage (microbial colonies apparent) on day 4. The slices were agglomerated and a musty odor was perceived. For the samples in MAP, the development of browning, edge bruising, and mushy tissue were the limiting shelf life attributes. The MAP + Aox treatment extended the shelf life to 5 d at 15 °C, and was compromised by desiccation, which caused the slices to stick together in the container, a sign of lack of freshness.

Firmness

The slice firmness at 5 °C in E1 was lower than in E2, reflecting the difference in initial whole fruit firmness (Table 8-1). Firmness was not significantly affected by the MAP (with or without Aox treatment) (Figure 8-4).

Similarly, at 15 °C the slice firmness was lower in E1 than E2, and the firmness decreased significantly by the end of the storage period (Table 8-2). Overall, slices held in MAP were less firm than slices from the MAP + Aox treatment or the air control (Figure 8-5).

Flesh Color

The L* value of fresh-cut mango slices at 5 °C was higher in E1 than in E2, and slices from the air-control had lower L* value than those from the MAP treatments (Table 8-1, Figure 8-4). Moreover, the lightness decreased over time, indicating that browning was developing on the slice surfaces at 5 °C. The hue angle value at 5 °C was not affected by the MAP treatments or by the storage duration (Table 8-1). However, slices from E1 had larger hue angle than those from E2 (Figure 8-2).

At 15°C, the fresh-cut mango slices in E1 had higher L* values than the slices in E2, and the L* value of slices from the air-control was lower than for slices from the MAP treatments (Table 8-2, Figure 8-5). The hue angle was smaller in E1 than in E2, and the hue angle of slices from the air control was smaller than for slices from MAP and MAP + Aox.

pH, TA and SSC

Slices at 5 °C in E1 had higher pH than slices in E2 (Table 8-1, Figure 8-6). MAP + Aox slices had lower pH than the MAP and air-control slices, which had similar pH levels (Table 8-1, Figure 8-6). The TA of the slices in E1 was higher than in E2, but TA was not significantly affected by MAP or MAP + Aox (Figure 8-6). The SSC at 5 °C did not differ among the fruit in E1 and E2 (Table 8.1). The SSC was, however, lower in the MAP + Aox slices than in MAP and air-control slices, which had similar SSC (Figure 8-6).

The pH of the mango slices at 15 °C in E1 was higher than those in E2 (Table 8-2). Slices in MAP + Aox at 15 °C had lower pH than slices in MAP or air control slices, which had similar pH (Figure 8-7). Also, pH tended to increase over time at 15 °C, regardless of treatment (Table

8.2; Figure 8-7), however, when the treatments were analyzed separately, pH increased only for the MAP + Aox treatment, while no significant effect of treatment duration was found for the other treatments. TA at 15 °C declined slightly over time in both experiments with no significant differences among the treatments (Table 8-2; Figure 8-7).

Microbial Evaluation

Immediately after processing, the total aerobic mesophilic microbial population on the fresh-cut mango slices was 4.2 ± 0.3 log CFU/g in E1 and 4.5 ± 0.5 log CFU/g in E2 (Table 8-3). The aerobic microbe population increased to 7.1 ± 1.0 log CFU/g in E1 and 7.4 ± 0.7 log CFU/g in E2 for the air control treatment and increased to 6.6 ± 0.8 log CFU/g in E1 and 8.3 ± 1.2 log CFU/g in E2 for the MAP treatment after 8 d at 5 °C; the aerobic microbe population in the MAP + Aox treatment increased to 5.9 ± 1.0 log CFU/g in E1 and 6.7 ± 0.1 log CFU/g E2 after 10 d at 5 °C (Table 8-3). No differences were observed among the treatments.

The increase in the total aerobic mesophilic microbial population was higher at 15 °C than at 5 °C. The aerobic microbe population reached 8.6 ± 0.2 log CFU/g in the air control after 4 d at 5 °C (Table 8.4). The aerobic microbe populations in the MAP and MAP + Aox treatments were slightly lower than the air control, with the MAP treatment reaching 7.9 ± 0.2 log CFU/g in E1 and 7.4 ± 0.1 log CFU/g in E2 after 4 d, while the MAP + Aox treatment reached 7.9 ± 0.1 log CFU/g in E1 and 8.0 ± 0.7 log CFU/g in E2 after 5 d (Table 8.4).

The yeast and mold populations on the fresh-cut mango slices were initially 3.0 ± 0.0 log CFU/g in E1 and 2.2 ± 0.3 log CFU/g in E2. The count increased to 6.0 ± 0.6 log CFU/g in E1 and 6.4 ± 1.1 log CFU/g in E2 for the air control, and to 6.3 ± 0.5 log CFU/g in E1 and 5.7 ± 0.3 log CFU/g in E2 for the MAP treatment after 8 d at 5 °C. The yeast and mold populations for the MAP + Aox treatment increased to 5.8 ± 0.6 log CFU/g in E1 and 5.1 ± 0.2 log CFU/g in E2 after 10 d at 5 °C. There were no significant differences in yeast and mold populations among the

treatments for E1, but in E2, lower yeast and mold counts were observed in the MAP + Aox treatment than in the air-control and MAP treatments.

At 15 °C, the yeast and mold population in MAP increased to 6.4 ± 0.7 log CFU/g in E1 and 6.5 ± 0.2 log CFU/g in E2. In MAP + Aox, the yeast and mold increased to 6.6 ± 0.3 log CFU/g in E1 and 6.4 ± 0.8 log CFU/g in E2 (Table 8.4). Results for yeast and mold populations in the air control treatment at 15 °C were missing.

Discussion

Oxygen and Carbon Dioxide Concentrations in MAP

When exposed to 15 °C, the MAP system containing fresh-cut mango slices maintained the desired level of 4 kPa O₂, however, due to the film selectivity ratio of 6.0, higher than desired CO₂ levels built up inside the packages, reaching approximately 17 kPa. In contrast, at 5 °C, the CO₂ increased to 8 kPa but, by the end of storage, it had decreased to 5 to 6 kPa. Since the MAP was designed based on the RR of mango slices exposed to 15 °C, exposure to the lower temperature of 5 °C resulted in lower RR that led to maintenance of higher O₂ in the package. Thus, O₂ concentrations inside the MAP at 5 °C ranged from 5 to 6 kPa O₂. Since, in general, the effect of low temperature is greater than the effect of a modified atmosphere (Rattanapanone et al., 2001), in this study the effect of low temperature most likely mitigated the effects of reduced O₂ concentration and elevated CO₂.

Moreover, the effect of adverse high CO₂ levels on the fresh-cut mango quality may be similar to that of the whole fruit. It is known that elevated CO₂ that is above the tolerance limit of the fruit may cause injury in whole mango that involves irreversible inhibition of ripening upon transfer to air at 20 °C. The symptoms are characterized by abnormal, grayish epidermal coloration, inhibition of normal aroma development, and development of off flavors (Bender et al., 2000a, b).

Fresh-cut Mango Slice Quality

During storage at 5 °C, a small difference was observed in visual quality of the mango slices in MAP compared to air stored samples. Samples from both treatments had a maximum shelf life of 8 d, which was limited by the development of browning and desiccation. The Aox treatment extended the shelf life of mango slices to 10 d, after which edge bruising, soft texture, and some browning and desiccation developed and rendered the product unacceptable for sale. Moreover, the MAP and MAP + Aox treatments limited the development of microbial spoilage on the slice surface compared to the samples stored in air, which showed more spoilage.

After 4 d, mango slices samples stored in air at 15 °C developed severe spoilage (obvious microbial colonies), while MAP samples developed surface browning and mushy tissue. Shelf life of mango slices stored at 15 °C was extended by 1 day (to 5 d) when MAP + Aox was used.

Loss of firmness in MAP samples, as indicated by lower firmness measurements and development of mushy tissue may be attributed to the supraoptimal CO₂ concentration measured inside the MAP at 15 °C (16 to 18 kPa CO₂). The effect of elevated CO₂ on firmness varies among fresh-cut products. For example, a 5 to 40 kPa CO₂ atmosphere promoted gradual tissue softening of 'Kensington' mango slices, stored at 3 °C (de Souza et al., 2006). Similar effects have been observed in fresh-cut 'Carabao' when exposed to elevated CO₂ but not in 'Nam Docmai' mangoes (Poubol and Izumi 2005a, b). Exposure of kiwifruit slices to 10 kPa CO₂ resulted in higher slice firmness than air-control slices (Agar et al. 1999). Furthermore, texture of pear, peach and persimmon slices was not affected by exposure to 20 kPa CO₂ during storage at 5 °C (Gorny et al, 2002; Wright and Kader, 1997a, b). The CO₂ concentration of 10 kPa was chosen for MAP development because, in Chapter 6, it was reported that firmness was greater in 'Kent' mango slices stored in air or reduced O₂ plus 10 kPa CO₂, compared with slices stored in reduced O₂ plus 0 or 20 kPa CO₂. It was therefore suggested that 20 kPa CO₂ was not suitable for

'Kent' fresh-cut mango slices. In addition, visual quality of slices exposed to 20 kPa CO₂ was poor and no different from the control samples stored in air.

Calcium ascorbate used in the Aox treatment helped maintain slice firmness even though the CO₂ was too high (17 kPa) in the MAP. Calcium and its salts have been successfully used to decrease softening of a great variety of minimally processed fruit (Soliva-Fortuny and Martín-Belloso, 2003).

Unexpectedly, an off- aroma was perceived in mango samples stored in MAP during storage at 5 °C. When the MAP containers were opened, the mango slices briefly released a plastic-like odor that was detectable for 1 to 2 h. It is known that MAP may directly impact the aroma of the product due to the likely interactions between aroma compounds and packaging materials (Mattheis and Fellman, 2000). Plastic polymers used in packaging can reduce or enhance the loss of flavor volatiles depending on their chemical properties (Forney, 2007). Volatile loss can occur through sorption (i.e., scalping) of the volatile compounds onto the film or permeation through the film (Brody, 2002). At the typical low temperature and high humidity environment created by the MAP, loss of flavor can be enhanced since the rate of sorption of gaseous flavor volatiles, unlike liquids, increases with lower temperature (Paik and Wagner, 2001). Moreover, polymer films differ in their rates of transmission for volatiles compounds, just like for the O₂ and CO₂ (Mount and Wagner, 2001). The interaction between fruit aroma volatiles and the packing material used in this study needs further investigation.

The fresh-cut mango slices in MAP had no fruity notes at the end of shelf life at 5 °C compared to the slices stored in air, which maintained the characteristic aroma of mango fruit. The altered atmosphere could have inhibited ripening processes and thus inhibit the aroma

volatile biosynthesis during storage at 5 °C or 15 °C although no such loss of aroma was perceived in the CA experiments (Chapter 6 and 7).

Compared to storage in air, MAP or MAP + Aox better maintained the color of fresh-cut mango slices stored at 15 °C. In general, air-control samples had lower L* and higher hue values, corresponding to more browning and watersoaked appearance compared to samples in MAP.

MAP treatments affected the pH of mango slices during storage at 5 or 15 °C. MAP + Aox samples had lower pH compared to MAP and air-control samples. This difference in pH can be attributable to the use of citric acid in the anti-browning dip solution, which has been widely accepted as effective in reducing superficial pH of cut fruits (Soliva-Fortuny and Martín-Belloso, 2003).

Microbial Evaluation

Typically, products become spoiled once microbial population levels increase to the 7 to 8 log CFU/g range (Martínez-Ferrer et al., 2002). In this study, an initial aerobic microbial population of 4.2 to 4.5 log CFU/g was measured, and spoilage became evident when the microbial count reached levels above about 7 log CFU/g.

Bai et al. (2001) reported that active MAP (4 kPa O₂ plus 10 kPa CO₂), combined with low temperature storage (5 °C) slightly reduced the bacterial and yeast and mold counts in fresh-cut cantaloupe. Under the same conditions, Rattanapanone (2001) showed that the marketable period of mango cubes could be extended by 1 to 2 d compared with samples stored in air due to a significant decrease of both mesophilic aerobic and yeast and molds counts.

During this study, large variations among the samples (large standard deviations) were measured, leading to an uncertain conclusion regarding the effect of the MAP on the microbial load of fresh-cut mango slices. Nevertheless, a beneficial effect of MAP on the total aerobic counts was observed during storage at 15 °C, in which lower counts were present in the MAP

and MAP + Aox samples than in the air-controls versus no differences among the treatments during storage at 5 °C. The yeast and mold count was not affected by any treatment in E1, but was lower in MAP + Aox at 5 °C in E2. No significant differences among the treatments were observed at 15 °C for the yeast and mold count.

Conclusion

This study evaluated the effect of a MAP system with or without an antioxidant dip treatment at 5 and 15 °C on the quality of fresh-cut 'Kent' mango slices. The MAP system used was efficient in maintaining a suitable 3 to 4 kPa O₂ concentration at 15 °C. However, during storage at 15 °C an atmosphere with greater than 10 kPa CO₂ developed inside the packages, resulting in mango slices that were softer than samples stored in air. The development of a polymeric film tailored to the required CO₂/O₂ selectivity of 8 would most likely enhance the positive effect of MAP on fresh-cut mango when exposed to non-chilling temperatures. An antioxidant dip applied to 'Kent' fresh-cut mango slices in combination with MAP resulted in better visual quality and extended the shelf life of the product by 1 d at 15 °C and by 2 d at 5 °C.

Finally, the loss of characteristic mango aroma and the plastic-like odor that developed during storage at 5 °C, due most likely to the interaction between the film and the aroma volatiles, suggests that the type of film used might not be suitable for use in a MAP system for mango fruit.

Table 8-1. ANOVA table - Firmness, color (L* and hue angle), pH, titratable acidity (TA), and soluble solids content (SSC) of fresh-cut 'Kent' mango at 5 °C

Source of variations	d.f.	F-value					
		Firmness (N)	Lightness (L*)	Hue angle (H°)	pH	TA (% citric acid)	SSC (%)
Experiment (E)	1	48.09***	88.81***	61.05***	14.65**	9.38**	3.93 ns
Treatment (T)	2	0.68 ns	30.60***	0.88 ns	6.25**	1.75 ns	5.35**
Treatment duration (D)	4	6.58***	3.32*	1.56 ns	1.10 ns	5.92**	0.16 ns
E*T	1	4.98**	5.65**	0.50 ns	0.63 ns	0.69 ns	0.04 ns
E*D	2	1.47 ns	0.97 ns	1.66 ns	1.94 ns	2.02 ns	2.50 ns
T*D	4	1.05 ns	3.80**	0.60 ns	0.84 ns	1.17 ns	1.47 ns
E*T*D	6	0.43 ns	0.97 ns	0.56 ns	1.57 ns	0.82 ns	0.78 ns

Fresh-cut mango slices from E1 and E2 (E) were held in MAP, MAP +Aox or in air (T) at 5 °C for 5 days (D); ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 8-2. ANOVA table - Firmness, color, pH, titratable acidity (TA), and soluble solids content (SSC) of fresh-cut 'Kent' mango at 15 °C

Source of variations	d.f.	F-value					
		Firmness (N)	Lightness (L*)	Hue angle (H°)	pH	TA (% citric acid)	SSC (%)
Experiment (E)	1	29.92***	29.07***	33.30***	7.39**	2.14 ns	0.17 ns
Treatment (T)	2	12.51***	21.73***	6.99**	0.49 ns	0.84 ns	0.93 ns
Treatment duration (D)	4	7.58***	1.95 ns	1.84 ns	6.04***	9.82***	2.93 ns
E*T	1	5.62**	2.25 ns	4.46*	0.98 ns	0.72 ns	5.47**
E*D	2	1.39 ns	0.96 ns	3.05 ns	1.44 ns	1.16 ns	2.25 ns
T*D	4	0.68 ns	3.74**	1.66 ns	0.75 ns	2.12 ns	0.46 ns
E*T*D	6	1.17 ns	0.64ns	2.71*	0.47 ns	0.30 ns	2.98*

Fresh-cut mango slices from E1 and E2 (E) were held in MAP, MAP +Aox or in air (T) at 15 °C for 5 days (D); ns, *, **, or *** = non-significant or significant at P< 0.05, 0.01, or 0.001, respectively.

Table 8-3. Total aerobic and yeast and mold count on fresh-cut mango slices at 5 °C for two replicate experiments.

		Total aerobic count (log CFU/g)		Yeast and mold (log CFU/g)	
		Experiment 1	Experiment 2	Experiment 1	Experiment 2
Initial		4.2 ± 0.3	4.5 ± 0.5	3.0 ± 0.0	2.2 ± 0.3
Day 3	Control	5.3 ± 0.2	4.2 ± 0.6	3.4 ± 0.5	4.2 ± 0.6
	MAP	6.0 ± 0.5	3.5 ± 0.2	2.8 ± 0.3	3.6 ± 0.3
	MAP+ Aox	4.4 ± 2.0	3.3 ± 0.5	2.9 ± 0.1	3.0 ± 0.0
Day 8	Control	7.1 ± 1.0	7.4 ± 0.7	6.0 ± 0.6	6.4 ± 1.1
	MAP	6.6 ± 0.8	8.3 ± 1.2	6.3 ± 0.5	5.7 ± 0.3
Day 10	MAP+Aox	5.9 ± 1.0	6.7 ± 0.1	5.8 ± 0.6	5.1 ± 0.2

Table 8-4. Total aerobic and yeast and mold count on fresh-cut mango slices at 15 °C for two replicate experiments.

		Total aerobic count (log CFU/g)		Yeast and mold (log CFU/g)	
		Experiment 1	Experiment 2	Experiment 1	Experiment 2
Initial		4.2 ± 0.3	4.5 ± 0.5	3.0 ± 0.0	2.2 ± 0.3
Day 3	Control	8.7 ± 0.0	7.5 ± 0.7	6.4 ± 0.3	6.6 ± 0.7
	MAP	7.0 ± 0.7	5.8 ± 0.5	5.6 ± 0.3	5.9 ± 0.6
	MAP + Aox	6.5 ± 1.0	5.0 ± 0.6	4.8 ± 0.7	4.0 ± 0.0
Day 4	Control	8.6 ± 0.2	-*	-	-
	MAP	7.9 ± 0.2	7.4 ± 0.1	6.4 ± 0.7	6.5 ± 0.2
Day 5	MAP + Aox	7.9 ± 0.1	8.0 ± 0.7	6.6 ± 0.3	6.4 ± 0.8

*Data missing

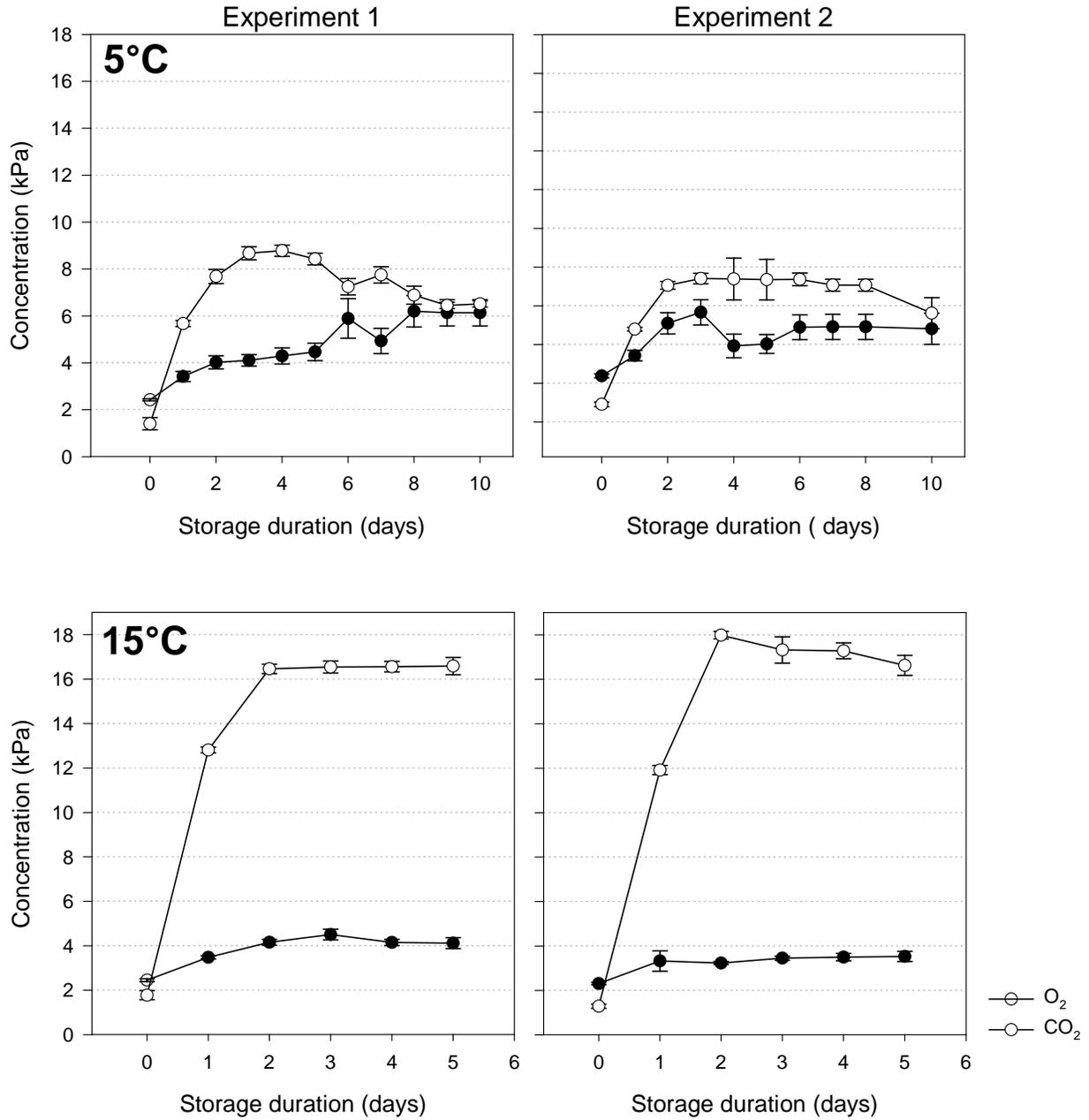


Figure 8-1. Oxygen (O₂) and carbon dioxide (CO₂) concentrations measured in MAP containers of fresh-cut mango slices at 5 °C and 15 °C for two replicate experiments. Day 0, number of samples = 28; days 1-10 (5 °C) or 1-5 (15°C), number of samples = 8.

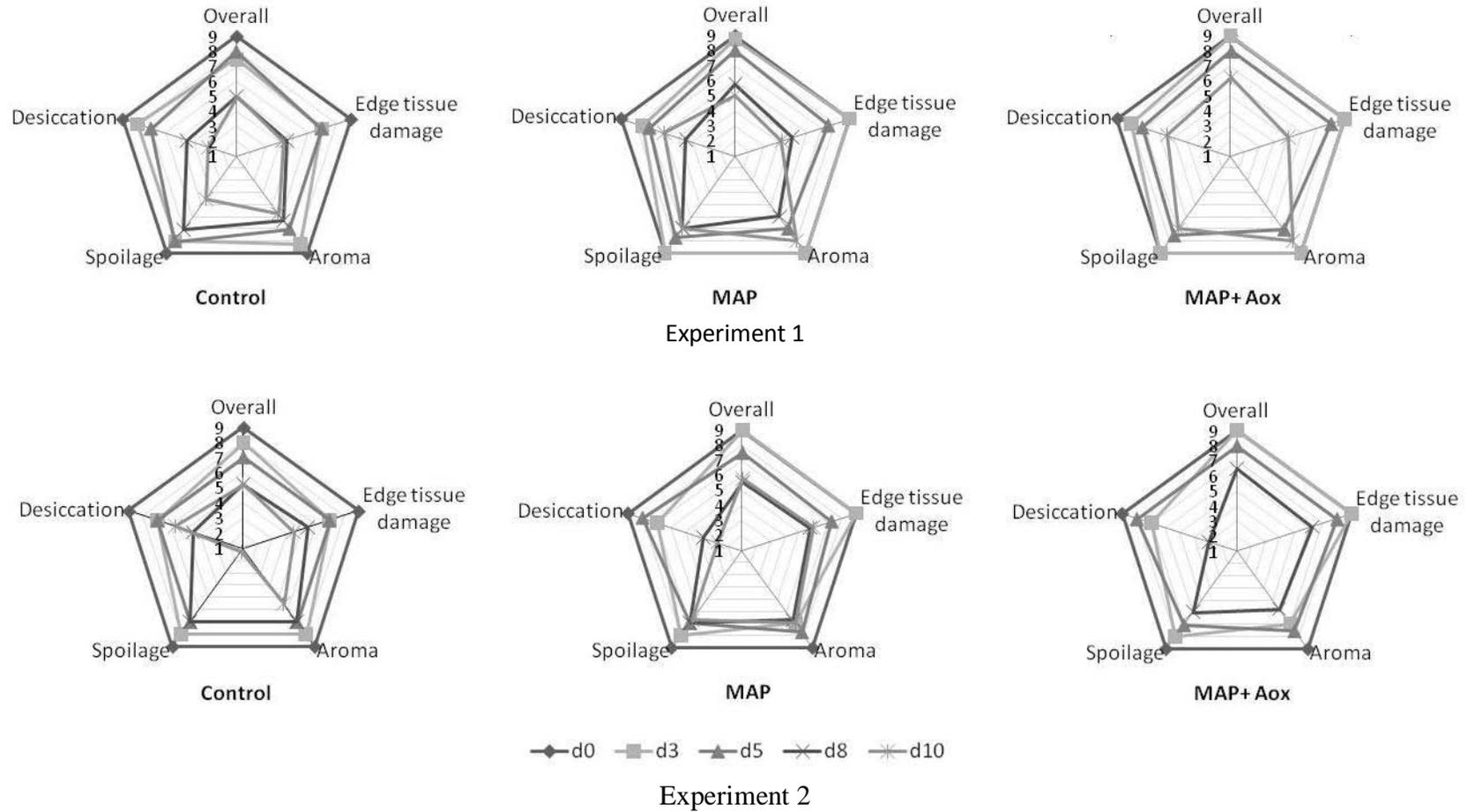


Figure 8-2. Subjective visual evaluation of fresh-cut 'Kent' mango slices at 5 °C from air, or from MAP with or without antioxidant (Aox) treatment for two replicate experiments. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1 = poor, inedible. A score of 5 represents the minimum subjective score (limit) for marketing.

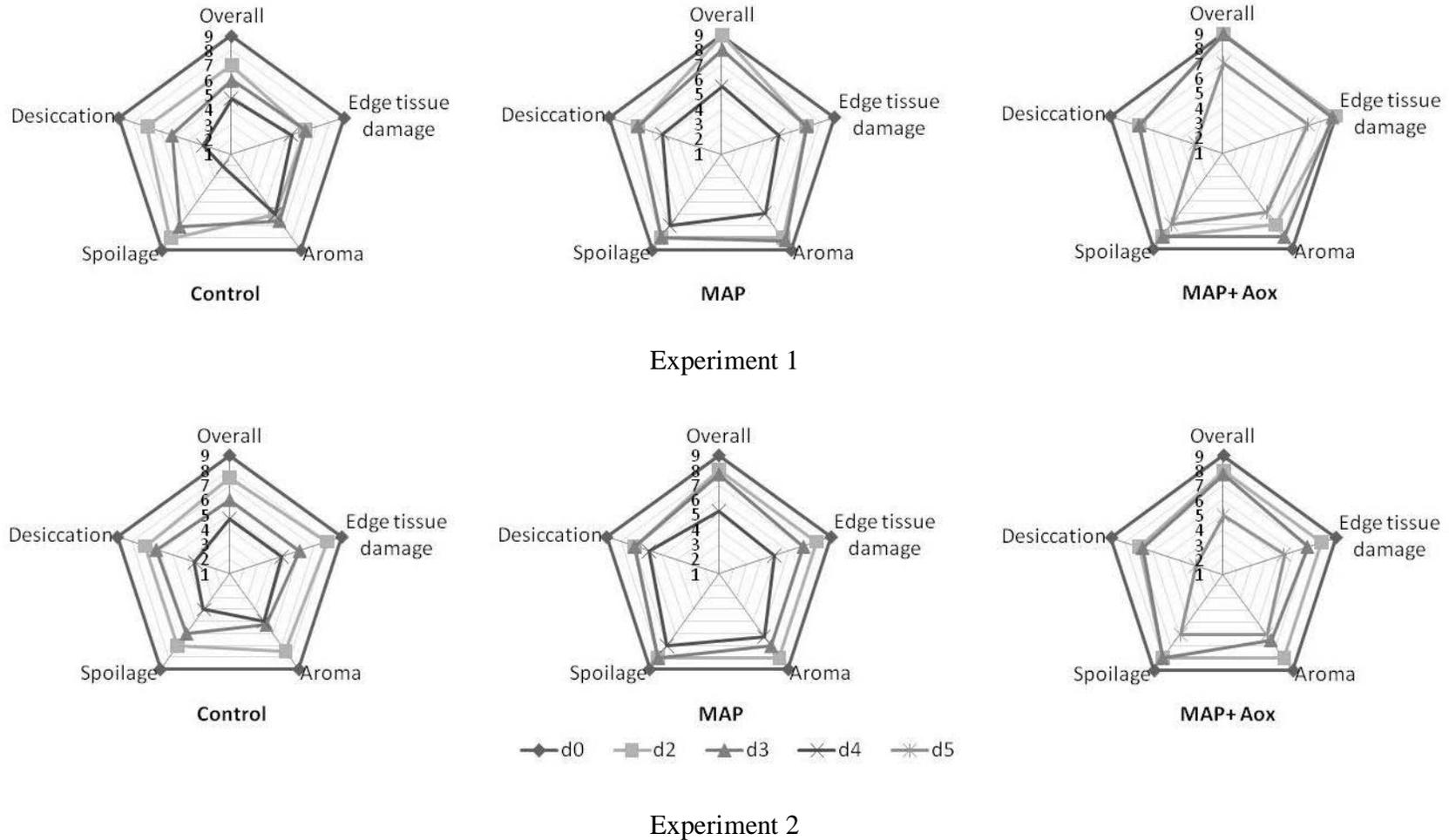


Figure 8-3. Subjective visual evaluation of fresh-cut 'Kent' mango slices at 15 °C from air, or from MAP with or without antioxidant (Aox) treatment for two replicate experiments. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1 = poor, inedible. A score of 5 represents the minimum subjective score (limit) for marketing.

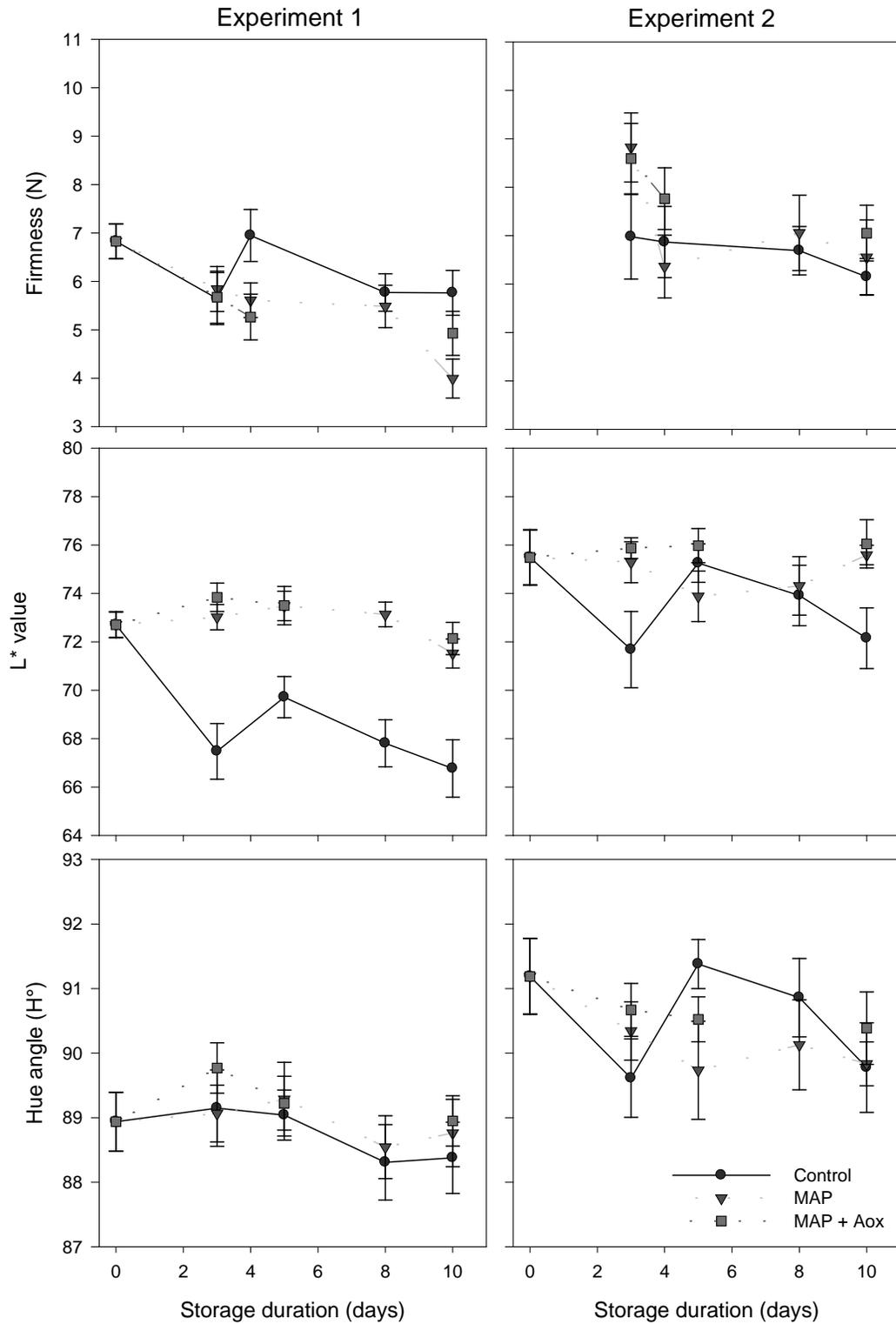


Figure 8-4. Firmness and flesh color (L* value and hue angle) of fresh-cut 'Kent' mango slices at 5 °C, in air, or in MAP with or with antioxidant (Aox) treatment for two replicate experiments.

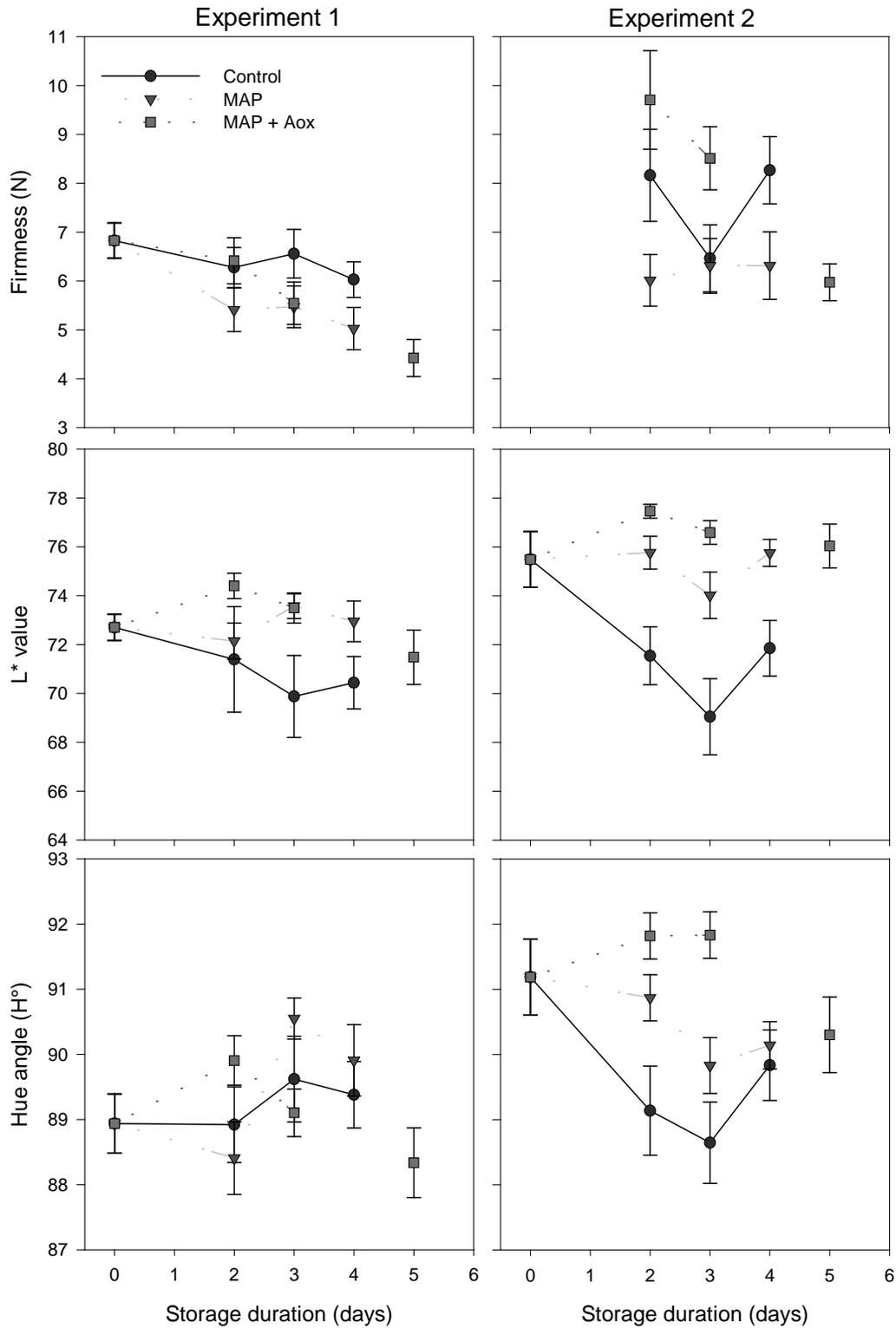


Figure 8-5. Firmness and flesh color (L*value and hue angle) of fresh-cut 'Kent' mango slices at 15 °C, in air, or in MAP with or with antioxidant treatment (Aox) for two replicate experiments. (Note, data missing for initial firmness measurement for Experiment 2)

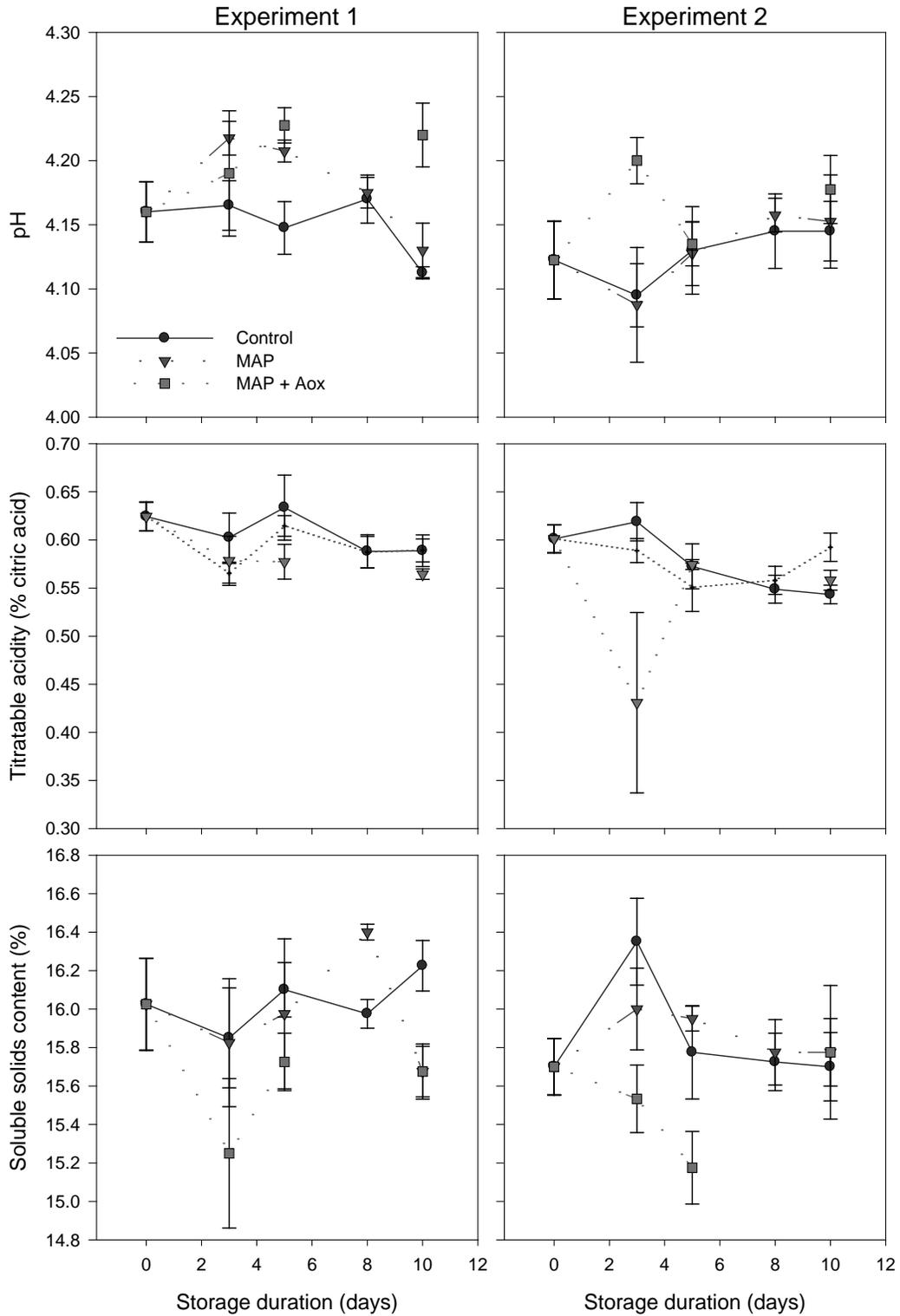


Figure 8-6. pH, titratable acidity, and soluble solids content of fresh-cut 'Kent' mango slices stored at 5 °C, in air, or in MAP with or with antioxidant treatment (Aox) for two replicate experiments. (Note, data missing for initial firmness measurement for Experiment 2)

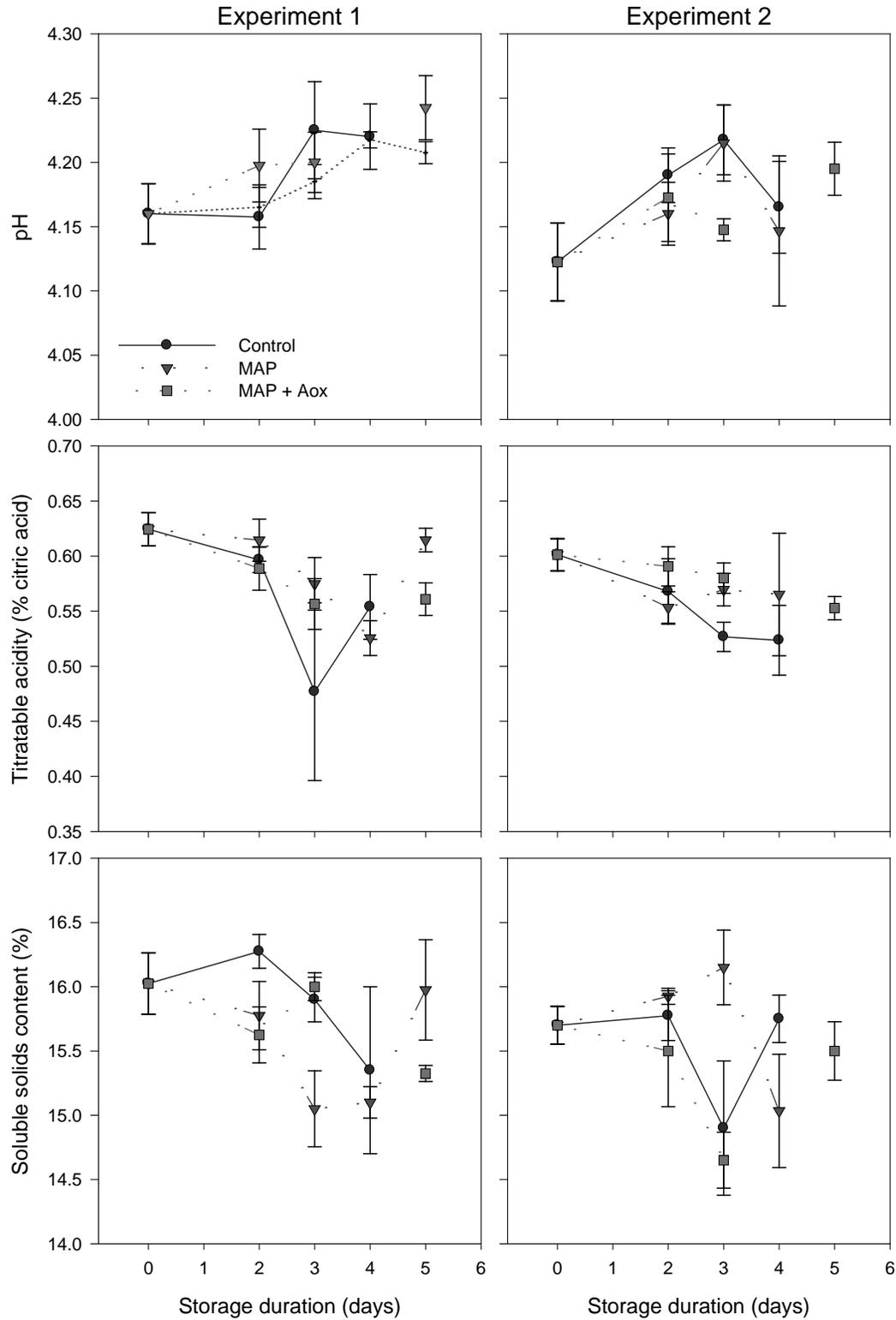


Figure 8-7. pH, titratable acidity, and soluble solids content of fresh-cut 'Kent' mango slices stored at 15 °C, in air, or in MAP with or with antioxidant treatment (Aox) for both experiments.

CHAPTER 9 CONCLUSIONS

The main objective of this study was to develop optimum procedures for preparing and handling fresh-cut mango slices to maintain maximum total product quality (i.e., aroma, appearance, texture, and nutritional value).

In the first objective, the optimal ripeness stage for processing 'Kent' mango into a fresh-cut product and marketing it with best quality and maximum shelf life in terms of visual, compositional, and sensory quality was determined. An initial ripeness stage selection was based on whole fruit firmness, which was more reliable than flesh color or soluble solids content (SSC) in predicting shelf life. The visual quality differed among the ripeness stages and deteriorated during storage. The shelf life duration, based on the subjective visual evaluation, was 10, 7, and 5 d for ripeness stages corresponding to average flesh firmness of 35 N, 30 N, and 25 N, respectively, and was mainly limited by desiccation and the development of off odor for the two firmer ripeness stages, or edge tissue damage and spoilage for the least firm stage. The slices with the highest initial firmness remained firmer during shelf life, had the lowest pH and SSC to titratable acidity (TA) ratio, and the highest contents of ketones and esters. The least firm slices had the highest pH, SSC/TA ratio, and ascorbic acid (AA) content, as well as the lowest TA and highest aldehydes and alcohol contents. Intermediate firmness slices had intermediate pH, SSC/TA ratio, color, and AA content. Also, the intermediate slices had less alcohols and aldehydes than slices from the riper fruit, but had similar content of esters as slices from the less ripe fruit. Therefore, an initial firmness of 30 N is recommended to process 'Kent' mangos into fresh-cut slices, to assure maximum shelf life based on textural, visual, and compositional attributes.

The effects of the USDA-APHIS hot water (HW) quarantine treatment (46.1 °C for 65 to 110 min) applied to whole mangoes on the visual, and compositional quality attributes, aroma volatile production, respiration rate, and electrolyte leakage of fresh-cut 'Kent' mango slices during subsequent storage at 5 °C was assessed in the second part of this study. In general, the visual quality, electrolyte leakage, firmness, and aroma volatile production (based on the quantification of 16 aroma volatiles) did not differ between the fresh-cut slices prepared from HW- and non-HW-treated fruit. The fresh-cut slices from non-HW-treated fruit had higher SSC than the HW-treated samples. There were also differences between the treatments for respiration rate, TA, and pH; but, the results were contradictory between the two harvests. Overall, the results suggest that the HW quarantine treatment applied to whole mangoes does not significantly affect the quality of fresh-cut 'Kent' mango slices stored at 5°C.

The third part of this project investigated the occurrence of chilling injury (CI) in fresh-cut 'Kent' mango, using fresh-cut mango slices and whole mango fruit controls stored at a putative chilling (5 °C) versus non-chilling (12 °C) storage temperature. The shelf life of the fresh-cut mango slices in this experiment was about 5 to 6 d at 5 °C versus 3 to 4 d at 12 °C. The shelf life of the slices was limited by slight sogginess of the slice edges or watersoaking and darker color of the tissue, or darkening of veins, slight softening, and desiccation; aroma intensity declined in slices stored at 5 °C while off odors related to fermentative metabolism developed in slices stored at 12 °C. The overall difference in the quality of whole fruit versus fresh-cut slices was more important than the effect of storage temperature for electrolyte leakage, respiration rate, firmness, total AA, and SSC. However, the effect of temperature on the overall quality was more important than the effect of whole fruit versus fresh-cut for pH, TA, color (hue angle) and AA. Nevertheless, CI of fresh-cut 'Kent' mango slices resulting from exposure to 5 °C, if at all, was

apparently less significant than the rapid, natural deterioration and off odor development of the fresh-cut slices stored at 12°C. Thus, fresh-cut mango slices maintained better quality and thus had a longer shelf life when stored at 5 °C than at 12 °C.

The optimal reduced O₂ and/or elevated CO₂ concentrations that optimize the development of aroma and the overall sensory quality while inhibiting the symptoms responsible for reducing the shelf life, such as browning, water-soaking, and tissue softening in fresh-cut mango slices was determined in the fourth part of this project. When considering an atmosphere with only reduced O₂ and no modification of CO₂, an atmosphere of 0 or 2.5 kPa O₂ was found to be the most suitable for storage of fresh-cut 'Kent' mango at 15 °C. However, a complete anaerobic atmosphere is not recommended since it may result in tissue damage during long periods at lower temperature. When reduced O₂ atmosphere (2.5 kPa) was compared with reduced O₂ combined with elevated CO₂ levels of 10 or 20 kPa CO₂ and an air control at 15 °C, the 2.5 kPa O₂ plus 10 kPa CO₂ atmosphere was found to best maintain fresh-cut 'Kent' mango quality. In contrast, an atmosphere of 2.5 kPa O₂ plus 20 kPa CO₂ did not show any beneficial effect on the quality of fresh-cut 'Kent' mango. Higher levels of fermentative aroma volatiles (i.e., acetaldehydes and ethanol) occurred in slices held in reduced O₂ atmospheres compared with air, but no objectionable aroma was detected subjectively. During this study, information regarding the effects of different reduced O₂ plus elevated CO₂ on the respiration rate (RR) of fresh-cut mango slices was questionable due to the great variation of replicated sample measurements.

Nevertheless, the RR of fresh-cut mango slices stored in reduced O₂ atmospheres with or without elevated CO₂ at 15 °C, was measured using two different methods, GC or gas analyzer in another set of experiments. Despite the significant differences between the RR measured by the two methods (higher RR were measured by gas analyzer), the RR were not significantly

affected during storage by the reduced O₂ levels compared to holding in air. The total RR average of fresh-cut mango slices stored at 15 °C in reduced O₂ and in air for the overall storage duration was 33.4 ±17.8 mg/kg·h when measured by gas analyzer approximately and 27.1 ± 14.6 mg/kg·h when measured by GC. The RR of the slices stored in reduced O₂ and elevated CO₂ could not be accurately measured due to negative differences between the initial and final readings for several measurements. Even though the range of RR measured in this study was large, the data collected provides valid information that can be used as starting point for the development of a MAP system that will be capable of maintaining the overall quality of fresh-cut mango slices when exposed to non-chilling temperatures.

The last part of this project attempted to design a MAP system using the optimal atmosphere that was determined in the previous objective to be suitable for the commercialization of fresh-cut ‘Kent’ mango slices. Moreover, the synergetic effect of an antioxidant treatment (combination of calcium ascorbate and citric acid) was investigated. Mango slices were packed with a polyvinyl chloride (PVC) film and store at 5 and 15 °C. The MAP system used was efficient in maintaining a suitable 3 to 4 kPa O₂ concentration when exposed to 15 °C. However, during storage at 15 °C a CO₂ concentration greater than 10 kPa was measured inside the packages, resulting softer slices compared to samples stored in air. An antioxidant dip applied to ‘Kent’ fresh-cut mango slices in combination with MAP contributed to a better visual quality and extended the shelf life of the product by 1 day when stored at 15 °C and by 2 d when stored at 5 °C. Finally, the loss of characteristic mango aroma and the plastic-like odor that developed during storage at 5 °C, due most likely to the interaction between the film and the aroma volatiles, suggests that the type of film used might not be suitable to use in a MAP system for mango fruit.

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BIOGRAPHICAL SKETCH

Sharon Dea was born in 1979 in Québec, Canada. She attended Laval University in Québec where she received, in 2003, a Bachelor of Science in food science and technology and a Master of Science in food engineering two years later. In the winter of 2005, she began her work towards a Doctorate of Philosophy in the horticultural sciences department at the University of Florida under the direction of Dr. Jeffrey K. Brecht and Dr. Cecilia do Nascimento Nunes. Along the years, she has been working on several projects regarding postharvest quality of fruits and vegetables and on the cold chain management of perishables and temperature sensitive pharmaceutical products.