Cutting Shape and Storage Temperature Affect Overall Quality of Fresh-cut Papaya cv. 'Maradol'

JAVIER RIVERA-LÓPEZ, FRANCISCO A. VÁZQUEZ-ORTIZ, J. FERNANDO AYALA-ZAVALA,
ROGERIO R. SOTELO-MUNDO, AND GUSTAVO A. GONZÁLEZ-AGUILAR

ABSTRACT: The effect of cutting shape (cubes or slices) and storage temperature (5 °C, 10 °C, and 20 °C) on overall quality of fresh-cut papaya were investigated. CO_2 production, color, firmness, total soluble solids (TSS), weight loss, overall quality, ascorbic acid, b-carotene, and antioxidant capacity were evaluated as a function of shelf life. CO_2 production was high on day 0 for cubes and slices with an average of 150 and 100 mL/kg/h, respectively. Storage temperature did not affect color changes; however, lower temperatures prevented loss of firmness. Fresh-cut papaya stored at 20 °C showed the lowest TSS value and the highest weight losses. Shelf life based on visual quality ended before significant losses of total ascorbic acid, b-carotene, and antioxidant capacity occurred. In general, quality parameters were not affected by shape. However, slices stored at 10 °C and 5 °C had a shelf life of 1 d and 2 d longer than cubes, respectively.

Key words: fresh-cut, papaya, storage temperature, antioxidant, quality

Introduction

Minimally processed fruit and vegetables have become increasingly popular, due to their convenience to the consumer and the human health benefits associated with eating these foods (Howards and others 1994). Fresh-cut fruits and vegetables are uncooked, peeled, and seeded and are ready to eat (Watada and Qi 1999). Minimal processing of raw fruits and vegetables is intended for keeping the freshness of the products, yet supplying it in a convenient form without losing its nutritional quality (Soliva-Fortuny and others 2002). Their geometry shapes vary widely, depending upon the nature of the vegetable and how is normally consumed.

Papaya (*Carica papaya* L.) fruit is rapidly becoming and important commodity worldwide, both as a fresh fruit and as processed products (Sankat and Maharaj 1997). Mexico is the main exporter and the 3rd-world producer of papaya after Brazil and Nigeria, with a total production of 612558 tons (FAO 2000). Papaya is a very healthy fruit, and it is appreciated because of its attractive pulp color, flavor, succulence, and characteristic aroma (Desai and Wagh 1995). Peeling, removal of the seeds, and slicing before consumption is a time-consuming and effort-consuming activity. Besides, papaya varieties such as 'Maradol' are too big (2.73 to 6.80 kg) for individual consumption. Therefore, papaya is a good candidate to be used as a minimally processed fruit or fresh-cut papaya.

Spoilage of minimally processed foods may result in loss of the physical properties such as color, texture, flavor, aroma, as well as nutritional value. Shelf life is determined as the time required to lose any of these quality characteristics to an unacceptable level. The relative importance of each quality factor varies between products and markets (Huxsoll and Bolin 1989). It seems that in fresh-cut papaya, the more important quality attributes are texture and general appearance, whereas microbial growth does not appear to contribute to spoilage. Fresh-cut papaya does not suffer chilling injury when stored at 4 °C (O'Connor-Shaw and others 1994) and has no flesh-browning problems, although polyphenol oxidase activity has been reported in whole papaya cv. 'Sunrise' and long-term frozen papaya slices (Cano and others 1996, 1998).

Consumer demand of fruits and vegetables is due to their freshness and high content of sugars, organic acids, vitamins, and minerals. Processing of fresh fruits and vegetables included trimming, peeling, cutting, and other physical actions can cause loss of phytonutrients (Watada and others 1990). Therefore, fresh-cut produce is perceived as being more nutritious than canned and frozen foods (Klein 1987). Fresh-cut papaya fruit presented a nutritional interest because it is a good source of carotenoids, as well as vitamin C, and it is believed that this nutritional compounds acts like natural antioxidants and could help to protect cellular components like DNA from oxidative damage (Heinonen and others 1998). Several carotenoids such a β-carotene, lycopene, lutein, and zeaxanthine are known to exhibit antioxidant activity, but β-carotene has been the most thoroughly studied. As a group, vitamin C, E, and β-carotene comprise the so-called antioxidant vitamins (Kaur and Kapoor 2001). Moreover, it is well known that the positive effect on health associated with the consumption of fresh fruits and vegetables is exerted by the pool of antioxidants, with noticeable synergistic effects (Raffo and others 2002). It has been reported that extract from fermented Asian papayas stimulates the immune system and contains antioxidants, which combat oxidative stress that promotes neurodegenerative disorders, such as Parkinson's disease (Kaur and Kapoor 2001). Overwhelming evidence from epidemiological studies indicate that diets rich in fruits and vegetables are associated with lower risks of several degenerative diseases, common cancers, as well as aging (Nicoli and others 1999; Kaur and Kapoor 2001). Therefore, it is important to study these compounds, to assess the changes in nutritional quality for fresh-cut fruits, beside the traditional quality parameters like color, firmness, weight loss, and overall quality.

Investigations conducted in papaya fruit were primarily devoted to extend the storage of whole papaya fruit, focused on heat treatments to control postharvest decay (Chan and others 1996) or as a

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quarantine treatment to combat fungi rots or fruit fly pests (Couey and Hayes 1986; Lay-Yee and others 1998; Conway and others 1999). Few works have addressed the study of the quality changes of fresh-cut papaya (O'Connor-Shaw and others 1994; Paul and Chen 1997) and *Carica papaya* L. cv. 'Formosa' (Texeira and others 2001). However, published information about *Carica papaya* L. cv. 'Maradol' is scarce and focused on aroma volatiles (Pino and others 2003), and there is no information available regarding the effects of storage condition such as temperature, storage time, and fresh-cut shape on the nutritional components like vitamin C, carotenoids, and antioxidant activity. The objective of this study was to determine the effect of cutting shape and storage temperature on overall quality and antioxidants of fresh-cut papaya cv. 'Maradol.'

Materials and Methods

Plant material

Ripe (3/4 yellow) papaya (*C. papaya* L. cv. 'Maradol') fruit obtained from a wholesale market in Hermosillo (Sonora, Mexico) were used for this study. The initial parameters of fruit were $L^* = 54 \pm 3.5$; $b^* = 25 \pm 3.5$, °Hue = 53±2.5, total soluble solids of 9.5, and pulp firmness of 12 Nw. Fruit were sorted to eliminate damaged or defective fruit, cleaned and washed with water containing 200 ppm of active chlorine, and air-dried. The fruit was peeled, deseeded, and cut with a stainless-steel knife, in cubes (2.5 × 2.5 cm) and slices (halves, 1 cm thick). Papaya cubes and slices (200 to 300 g) were immediately placed in a 1000-mL polystyrene plastic tray covered with a lid and stored during 18 d at 5 °C, 10 °C, and 20 °C. Respiration rate, color, physicochemical attributes (firmness, total soluble solids, and weight loss), overall quality index, vitamin C, β-carotene, and antioxidant capacity were evaluated at different storage intervals.

Respiration rate

To measure this parameter, cubes (40 to 50 g) and slices (50 to 60 g) were placed in a 500-mL plastic jar and sealed with parafilm, stored 15 min at room temperature (25 °C) before gas sampling (1 mL) from headspace. The changes in CO_2 production were measured at 2-d intervals using a gas chromatograph Varian Star 3400 Cx (Varian, Mexico) with a thermo conductivity detector (TCD). Using a 2 m × 1/8-in stainless-steel Hayesep-N Column packed with 80/100-μm mesh Porapak, Chromotographic Specialties Inc., Ontario, Canada) respiration rate was calculated in $mLCO_2/kg/h$.

Color

Fruit flesh surface color was obtained from 24 replicates per treatment using a BYK-Gardener Handy Spec^{TM} colorimeter, model 9300 (BYK-Gardner, Silver Spring, Md., U.S.A.), which provided L^*, a^*, and b^* values. Higher b^* values indicate a more yellow skin color. These values were used to calculate hue degree ($h° = \tan^{-1} [b^*/a^*]$, where 0° = red purple; 90° = yellow; 180° = bluish green, and 270° = blue.

Firmness

Papaya tissue firmness was measured with a Chatillon penetrometer, model DFG-50 (John Chatillon Sons, Inc. New York, N.Y., U.S.A.) with a 5-mm dia flat-head stainless-steel cylindrical probe. Peak high of the force required to shear the sample was recorded. Firmness was expressed as Newton (N) of force required to shear the sample.

Total soluble solids

TSS were measured on expressed fruit juice according to the AOAC method (AOAC 1990) using a handheld refractometer Atago DBX-55 (Atago Co. Ltd., Tokio, Japan) at room temperature (25 °C).

Weight loss

Weight loss was determined with 3 replicates and was recorded initially and daily during storage using a digital balance Mettler P.R. 2003 DR (Mettler Toledo Intl. Inc., New York, N.Y., U.S.A.). Results were reported as percentage of weight loss.

Overall quality index

Twenty-four replicates per treatment were evaluated subjectively on day 0, 2, 4, 6, 10, 14, and 18 during the storage period. Overall quality was evaluated using a hedonic scale (1 to 5) according to the percentage of surface area decayed, 1 = unusable 50% affected), 2 = bad (20% to 50% affected), 3 = fair (5% to 20% affected), 4 = good (up to 5% affected), and 5 = excellent. Results were expressed as an overall quality index.

Ascorbic acid content

Ascorbic acid was determined as described by Donner and Hicks (1981). Three samples per treatment were analyzed with a Varian 9012 (Varian, Mexico) liquid chromatograph equipped with a L-4000 UV detector and a L-6000 pump. Ascorbic acid was detected using a Water-NH_2 type μBondapak analytical column (3.9 × 300 mm, 10 μm) 10-μL loop injector. The mobile phase was acetonitrile:KH_2PO_4 1 *M* (75:25 v/v), at a flow rate of 1.5 mL/min, and the detector wavelength was set at 268 nm.

β-Carotene

β-Carotene was measured using the method described by Mejía and others (1988) with slight modifications. A 5-g papaya flesh sample was mixed with 15 mL of tetrahydrofurane and 0.01 of BHT (Sigma Chemical Co., St. Louis, Mo.) as a carotene stabilizer. The pieces were homogenized 2 min and centrifuged at 10000 g for 15 min using an Eppendorf centrifuge model 5415C (Brinkmann Instruments, Inc. Westbury, N.Y., U.S.A.). The supernatant was filtered through a 0.22-μm membrane. An aliquot of 10 μL was injected into the high-performance liquid chromatography (HPLC) system using an analytical column Microsorb RP-C18 (100 × 4.6 mm, 3 μm). The mobile phase was acetonitrile-methanol-tetrahydrofurane HPLC grade (Sigma Chemical Co.) (58:35:7 v/v), and the run was isocratic at a rate of 1.0 mL/min at room temperature. Detection was performed with an absorbance detector UV-Vis Varian 9050 (Varian, Mexico) at 460 nm.

Oxygen radical absorbance capacity assay

The protocol for the oxygen radical absorbance capacity (ORAC) assay on fresh-cut papaya was modified from a previously described method by Cao and others (1996). This assay measures the effect of antioxidant components in fruit juices of fresh-cut papaya based on the decline in phycoerythrin (R-PE) fluorescence induced by the peroxyl radical generator 2,2′-azobis (2-amidino-propane) dihydrochloride (AAPH). The reaction mixture contained 1.7 mL of 75 m*M* phosphate buffer (pH 7.0) and 100 μL of sample. Phosphate buffer was used as a blank, and 100 μ*M* of Trolox (a water-soluble α-tocopherol analogue) was used as a standard during each run. The final volume of 2 mL was used in 10-mm-wide quartz fluorometer cuvette. R-PE, phosphate buffer, and samples were pre-incubated at 37 °C for 15 min. The reaction was started by the addition of AAPH. Fluorescence emission at 568 nm was measured and recorded every 5 min using an excitation wavelength of 540 nm in a QM-2003 PTI-Photon Technology Intl. spectrofluorometer. The experiment was concluded when the sample fluorescence was less than 5% of the initial reading (approximately 35 min). One blank, 1 standard, and a maximum of 10 samples were analyzed at the same time. Each sample was repeated 3 times. The ORAC value refers to the net protection area under the quenching curve of R-PE in the presence of an oxidant. The results (ORAC values) were calculated and expressed as Trolox equivalents (TE) per gram on a fresh weight basis (Cao and others 1996):

$$\text{ORAC value } (\mu\text{mol TE/g F.W.}) = 20\,K(S_{sample} - S_{blank})/(S_{trolox} - S_{blank}) \qquad (1)$$

where K is the sample dilution factor and S the area under the fluorescence decay curve of the sample, Trolox, or Blank. S is calculated as follows:

$$S = (0.5 + f_5/f_0 + f_{10}/f_0 + f_{15}/f_0 + f_{20}/f_0 + f_{30}/f_0 + \ldots\ldots + f_{60}/f_0 + f_{65}/f_0 + f_{70}/f_0)\ X5 \qquad (2)$$

and where F_0 is the initial fluorescence at 0 min and f_i the fluorescence measure at time *i*.

Statistical analysis

Differences among treatments were analyzed using an analysis of variance (ANOVA) procedure at 5% level. The Fisher Least Significant Difference method was used to determine differences among means. The statistical procedures were performed with NCSS 6.1 (NCSS Co., Kaysville, Utah, U.S.A.).

Results and Discussion

Respiration rate (CO_2 production)

Respiration rate of whole papaya ranges from 15 mL to 35 mL CO_2/kg/h during storage at 20 °C (Lam 1990). It has been observed in several fresh-cut vegetables that peeling and cutting increases the respiration rate from 1-fold to 7-fold, compared with the same fresh whole produce. Increases in ethylene production, quality changes, and synthesis and/or loss of phytochemicals, can also take place. The same trend was observed in this study. Peeling and cutting significantly increased respiration rate to 150 mL and 100 mL CO_2/kg/h for cubes and slices, respectively (Figure 1). The respiration rate of cubes and slices stored at 5 °C and 10 °C decreased after the 2nd day. However, a high increase in respiration rate was observed after the 2nd day of storage at 20 °C, for both shapes. These could be a consequence of an accelerated metabolism at this high temperature or it may be due to the mould growth observed after the 3rd day of storage. A similar behavior was reported on pear slices (Gorny and others 2000) and fresh-cut jicama (Aquino-Bolaños and others 2000). The dramatic increase in respiration rate, even with small increments in temperature storage, demonstrated that fresh-cut papaya cv. 'Maradol' is very sensitive to temperature abuse. However, respiration decreased significantly for those fruits stored at 5 °C and 10 °C ($P \leq 0.05$). Respiration rate of fresh-cut papayas could be controlled by using low temperatures (5 °C) during transportation, storage, and market display.

Previous reports indicated that decreases on respiration rate after the initial period of storage, followed by stabilization after the initial wounding stress, was a normal pattern (Kim and others 1993; Texeira and others 2001). These authors reported that cutting form and size did not affect the respiration rates, although storage temperature did. However, the respiration rate of fresh-cut tomatoes was affected by both storage temperature and cutting shape, in contrast to Kim and others (1993) and Texeira and others (2001). However, this is in contrast with a previous study that demonstrated that respiration rate of fresh-cut tomatoes was significantly affected by type of cut and temperature storage (Aguayo and others 2004). Surjadinata and Cisneros-Zavallos (2003) developed a mathematical model to understand wound-induced respiration and the possible implications in fresh-cut carrots' quality changes and packaging design. The proposed model has the potential to be used as a tool in different fresh-cut produces. In this work, we did not find an effect of cutting shape over respiration rate.

Color

*L** value of fresh-cut papaya slices cv. 'Maradol' was notably influenced ($P \leq 0.05$) by the storage temperature (Figure 2a and 2b). We found significant differences in *L** values between shapes stored at 5 °C or 10 °C, but not with storage period at these temperatures. We found a large decrease in color associated with the storage period in the *L** value, for cubes and papaya slices stored at 20 °C ($P \leq 0.05$). Changes in the *L** value in mango cubes were attributed to a slight browning on the surface and loss of water (Rattanapanone and others 2001). However, fresh-cut papaya did not present severe browning (data not shown), mostly appearing only on a few slices and cubes stored at 20 °C and probably because of microbial growth. In other fresh-cut produces (for example, apples, pears, or bananas), browning is a serious problem and could affect flesh appearance (Wiley 1994). Previous work with fresh-cut mangoes reported that variety plays an important role in shelf life. 'Kent' and 'Keitt' mango varieties were more susceptible to browning compared with 'Ataulfo.' In addi-

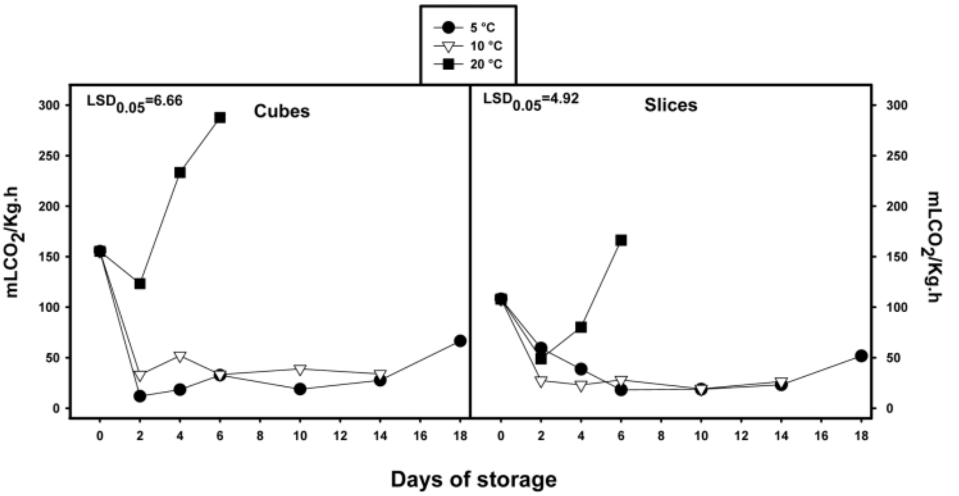

Figure 1—CO_2 production changes of papaya 'Maradol' cubes and slices during storage at 5 °C, 10 °C, and 20 °C

tion, shelf life of the later variety was 7 d longer compared with 'Kent' and 'Keitt,' after being stored at 5 °C (Celis-Salas 2003).

Changes in color expressed as hue angle (°Hue) are shown in Figure 2c and 2d. No effect ($P \leq 0.05$) on color was observed at different temperatures and during the day of storage of papaya cubes and slices. However, temperature significantly affected color changes. Hue values (52 to 58) obtained in this work showed that fresh-cut papaya conserved its natural yellow-red color during the storage period. This results confirm that neither temperature nor storage time significantly promote oxidative or enzymatic browning of fresh-cut papaya. Lower changes in °Hue values have been reported to be a good indicator of absence of oxidative browning of flesh pulp (Rocha and Morais 2000). Hue angle did not change during storage when the measure was done on the ends of the pieces from either cutting treatment. Portella and Cantwell (2001) evaluated the effect of sharpness of the blades on fresh-cut cantaloupe and reported that °Hue increased similarly during 12 d of storage in air at 5 °C, independently of the cutting treatment, when this value was measured in the longitudinal side of the blunt pieces. Gorny and others (1998) reported that storage temperature had an effect on °Hue of fresh-cut peach and nectarine slices at 3 ripeness stages, mature-green, partially ripe, and ripe fruit. Other studies on fresh-cut revealed the importance of color changes on pulp, which contrast with those obtained on fresh-cut papaya cv. 'Maradol.'

Weight loss

This parameter was affected ($P \leq 0.05$) by temperature and d of storage (Figure 3a and 3b). Papaya cubes and slices stored at 5 °C presented the lowest weight loss during the storage period. Papaya slices stored at 20 °C showed higher weight loss (24%) than papaya cubes (15%), whereas, papaya cubes showed higher weight loss at 10 °C (13%), than papaya slices (8%). There was no difference in percentage of weight loss ($P \leq 0.05$) between papaya cubes (4%) and slices (5%) stored at 5 °C at the end of the storage period. Weight loss is principally due to high storage temperatures, skin removal, and cutting that exposes interior tissues and drastically increases the water evaporation rate (Brecht 1995). Some of this weight loss (10% to 20%) could be due to loss of carbon by respiration, as is reported in fresh-cut carrots (Izumi and others 1996). The use of sharp blades and good practices reduces the physiological damage of fresh-cut produce. These recommendations are important because they have a strong effect in weight loss and visual appearance scores (Barry-Ryan and O'Beirne 1998; Portella and Cantwell 2001). It has been reported that weight losses of 4% to 8% had negative effect in general appearance of fresh-cut fruits and consumer acceptance (Wiley 1994; Watada and others 1996).

Firmness

Storage temperature affected ($P \leq 0.05$) the firmness loss of fresh-cut papaya 'Maradol.' Firmness loss was observed as a result of higher storage temperatures (Figure 3c and 3d). Firmness of papaya slices decreased significantly ($P \leq 0.05$) close to 67% (9.8 N to 3.2 N), whereas firmness of papaya cubes decreased 57% (7.5 N to 3.2 N) after 16 d of storage at 5 °C. The higher the storage temperature, the higher the firmness loss. Firmness loss has been reported to decrease considerably with storage on other fresh-cut produces such as peaches and nectarines (Gorny and others 1998), mangos, pineapples, and bell pepper (González-Aguilar and others 2000, 2004a, 2004b). It is well known that texture loss is influenced by temperature and storage when enzymatic hydrolysis of cell wall components takes place (Watada and others 1990; Agar and others 1999, Beaulieu and Gorny 2002). Fruit cell walls consist of pectin, hemicellulose, and

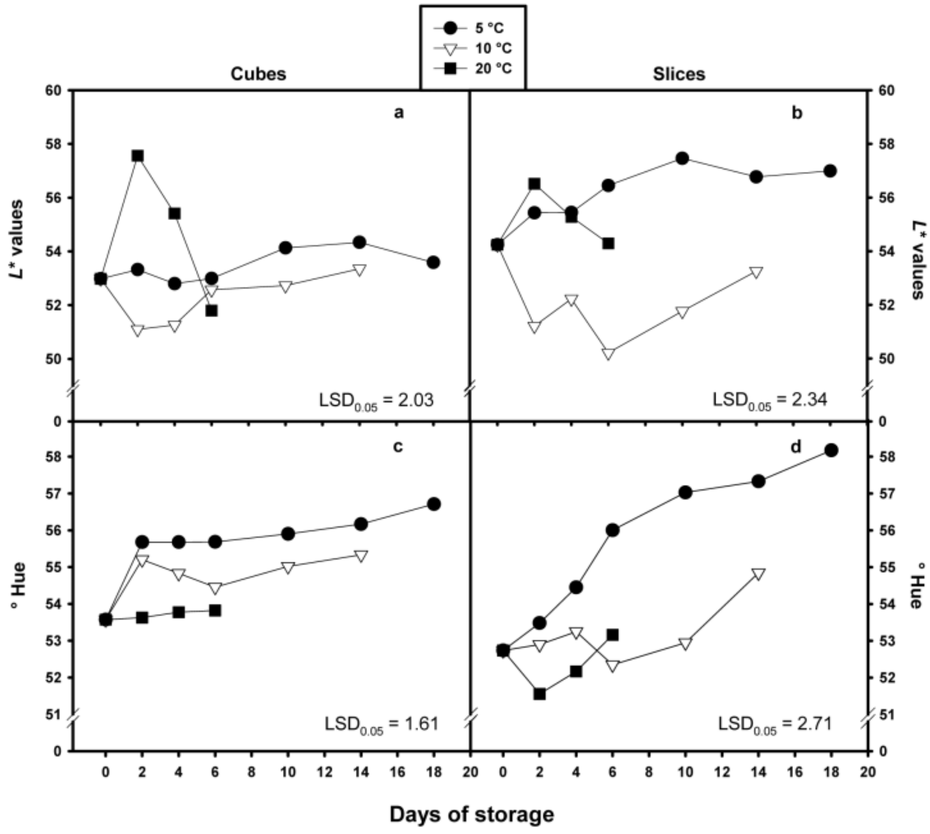

Figure 2—Color changes of papaya 'Maradol' cubes and slices during storage at 5 °C, 10 °C, and 20 °C

cellulose polysaccharide polymers (Owino and others 2004). The rapid softening and deterioration of fresh-cut papaya has been attributed to hydrolytic enzymes, which lead to accelerated senescence and rapid softening and deterioration of fresh-cut papaya fruit (Karakurt and Hubber 2003). Although these enzymes were not evaluated in this study, recent work done in our laboratory show that firmness loss was related with high polygalacturonase, pectinmethylesterase, and β-galactosidase activity, in fresh-cut papaya cv. 'Maradol' (Monroy-Garcia 2004) (data not shown).

Total soluble solids (TSS)

Soluble solids content was affected by temperature and storage period ($P \leq 0.05$). Papaya cubes and slices stored at 20 °C had the lowest soluble solids content after 6 d of storage (Figure 3e and 3f). TSS in papaya cubes and slices stored at 5 °C and 10 °C also decreased in a lesser extent. The difference in TSS loss between papaya cubes stored at 5 °C and 10 °C was larger compared with papaya slices stored at the same temperature. A high TSS depletion in papaya cubes and slices stored at 20 °C could be explained by a higher respiratory rate when papaya was stored at 20 °C, whereas the produce stored at 5 °C and 10 °C had lower respiration rates and showed a smaller decrease in the TSS content. It has been reported by several authors that correlation between TSS reduction decrease in sugar content and high metabolic activity occurs when fruits are stored at high temperatures (Chan 1979; Agar and others 1999; Lamikanra and others 2000; Ayala-Zavala and others 2004). The 1st substrates used during respiration are sugars, and this could be the main reason that cause depletion of TSS content observed in the produce stored at higher temperatures.

Overall quality index

Shelf life period of fresh-cut papaya, determined as an overall quality index was affected ($P \leq 0.05$) by temperature and the storage period (Figure 4). Papaya cubes and slices stored at 20 °C showed a shelf life of only 2 to 3 d. Those cubes and slices stored at 10 °C presented a good overall quality index until 6 to 8 d, overpassing the limit of shelf life at 10 d. However, a score of 3 (acceptable) was assigned for papaya slices and a score of 2 (bad) for papaya cubes. Storage of fresh-cut papaya at 5 °C lead to a good overall quality index (ranking with a score of 4 = good) kept for up to 10 d.

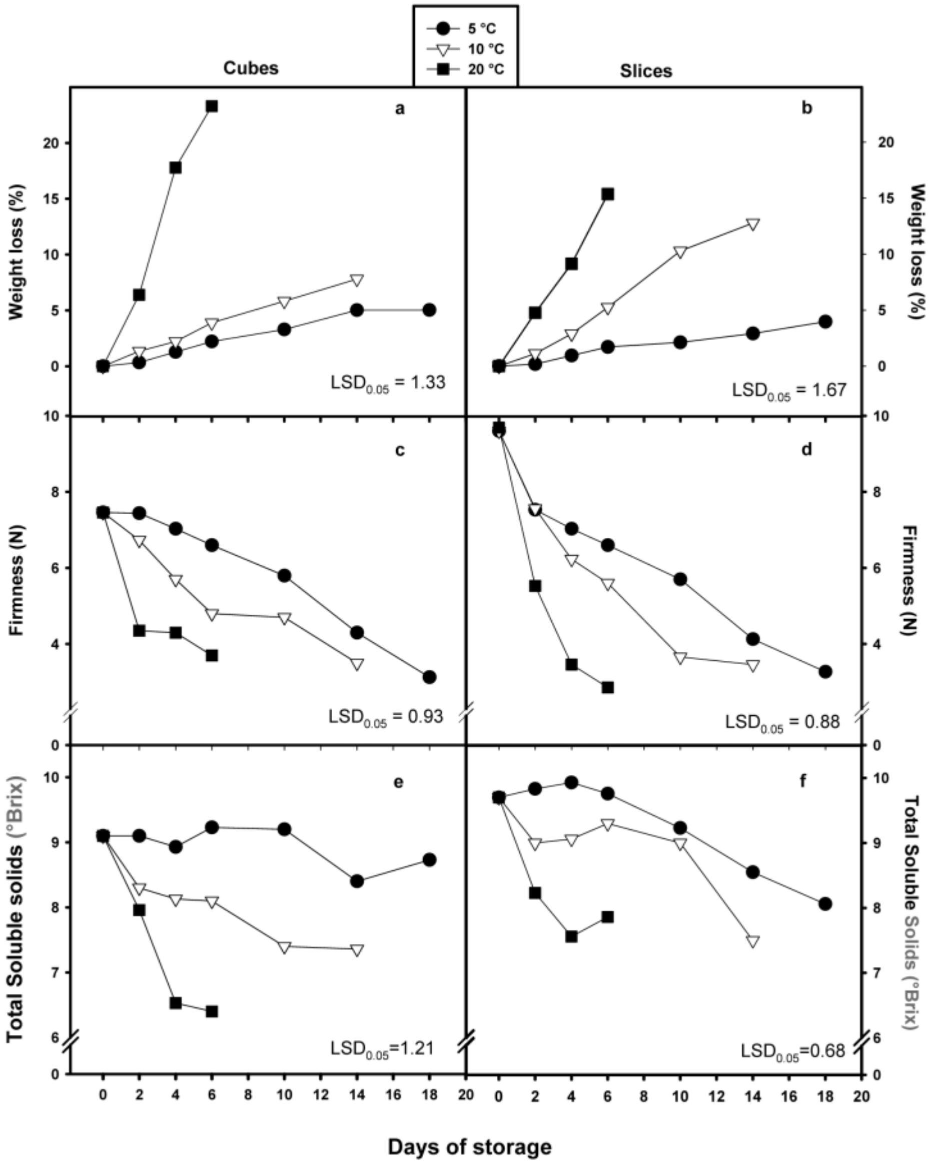

Figure 3—Changes in weight loss, firmness, and total soluble solids of papaya 'Maradol' cubes and slices during storage at 5 °C, 10 °C, and 20 °C

At this temperature, papaya cubes at day 14 pass the limit of shelf life, whereas papaya slices ranked over the limit. Overall quality index was highly correlated with firmness and weight loss, with R^2 values of 0.89 and 0.97, respectively. The shelf life for fresh-cut papaya cv. 'Formosa' was only 7 d, after being stored at 3 °C, 6 °C, or 9 °C (Texeira and others 2001). Other authors reported that shelf life of fresh-cut papaya was 2 d when stored at 4 °C (Chan and others 1996). According to these results, it appears that 'Maradol' papaya variety can withstand better minimal processing. Therefore, it could be more suitable for marketing as a fresh-cut product.

Ascorbic acid content

Ascorbic acid content was significantly affected by temperature and storage period and had a similar trend for both cubes and slices of fresh-cut papaya (Figure 5a and 5b). Cubes and slices contained 65.47 mg/100 g (FW) of vitamin C at day 0. After 6 d of storage, no changes in vitamin C content were observed in cubes and slices stored at 5 °C, whereas those fruits stored at 10 °C and 20 °C presented an average of 5% and 63% lower vitamin C content, respectively, within the same period. Vitamin C content of cubes and slices stored at 5°C decreased by 29.6 and 26.38 % after 18 d of storage, respectively. Cubes and slices stored at 10 °C decreased by 27.30% and 38.92%, respectively, of their initial vitamin C content after 14 d of storage. The effect of the storage temperature in ascorbic acid retention has been reported in kiwi fruits slices at 5 °C and 10 °C (Agar and others 1999) and a few citrus species, such as fresh-cut mandarin and Satsuma oranges (Palma and others 2003). Oxidation of ascorbic acid due to high temperatures has been found in other produces. For example, in minimally processed lettuce, total ascorbic acid levels were 25% lower between 8 °C and 3 °C after 10 d. González-Aguilar and others (2004a) reported that fresh-cut peppers under modified atmosphere packaging (MAP) and vacuum packages showed the highest values of ascorbic acid during storage at 5 °C than at 10 °C. Our results are in agreement with these authors because fresh-cut papaya cubes and slices stored at 5 °C kept the highest ascorbic acid levels during the entire storage period. Okuse and Ryugo (1981) reported that kiwi fruit did not exhibit browning due to low tannin content and polyphenoloxidase activity and high ascorbic acid. We hypothesize that the fact that the fresh-cut papaya fruit did not present any browning problems could be due to its high ascorbic acid content and low polyphenoloxidase activity (data not shown).

β-carotene levels

Fresh-cut papaya cubes and slices stored at 5 °C did not present any change in β-carotene content during 10 d of storage (Figure 5c and 5d). Carotenoids appear to be less adversely affected by processing compared with the other major fruit and vegetable antioxidant such as vitamin C (Kalt 2005). Noticeable changes were found at 14 d and 18 d of storage, where β-carotene decreased by an average of 18% and 22% for both cubes and slices, respectively. No changes were observed in β-carotene content after 6 d of storage at 10 °C; however, after 14 d of storage, there was a depletion of 62% for cubes and 63.4% for papaya slices. Fresh-cut papaya cubes and slices stored at 20 °C showed the highest β-carotene losses. At this temperature and after 6 d of storage, cubes and slices decreased by 57.4% and 60.63%, respectively. Palmer-Wright and Kader (1997) reported that there were no significant changes in the β-carotene content of sliced peach fruit over the time of storage, with the exception of fruit stored under air + 12% CO_2; the treatment resulted in a lower concentration of β-carotene. Persimmon fruit slices stored under air showed a decrease in β-carotene over the course of the study; however, overall, there was no significant difference among treatments. According to Weichmann (1986), carotene retention is better when O_2 levels are decreased, and CO_2 levels of 7.7% to 10.0% are maintained. It is well known that β-carotene is somewhat less thermolabile than vitamin C but is rapidly oxidized when exposed to light and oxygen. Enzymatic carotene degradation is mediated by lipoxygenase and is lost through secondary reactions or co-oxidation during fatty acid oxidation (Klein 1987). Besides, when high temperature and low humidity prevail, rapid transpiration occurs and vegetables wilt. With these in mind, it is likely that losses of β-carotene showed in fresh-cut papaya, especially in the last days of storage, could be due to losses by wilting or oxidation instead of thermal damage.

Antioxidant capacity (ORAC)

The storage temperature significantly affected the ORAC value of fresh-cut papaya fruit. Fresh-cut papaya cubes and slices changed slightly during storage at 5 °C (Figure 6). However, significant reduction of ORAC values were found in fresh-cut papaya at 10 °C and 20 °C, primarily during final storage stage for cubes, whereas only at 10 °C were ORAC differences significant ($P < 0.05$) for slices. Operations such as peeling, cutting, and slicing are expected to induce a rapid enzymatic depletion of several natural antioxidants. Unfortunately, few data are available on the changes of natural occurring antioxi-

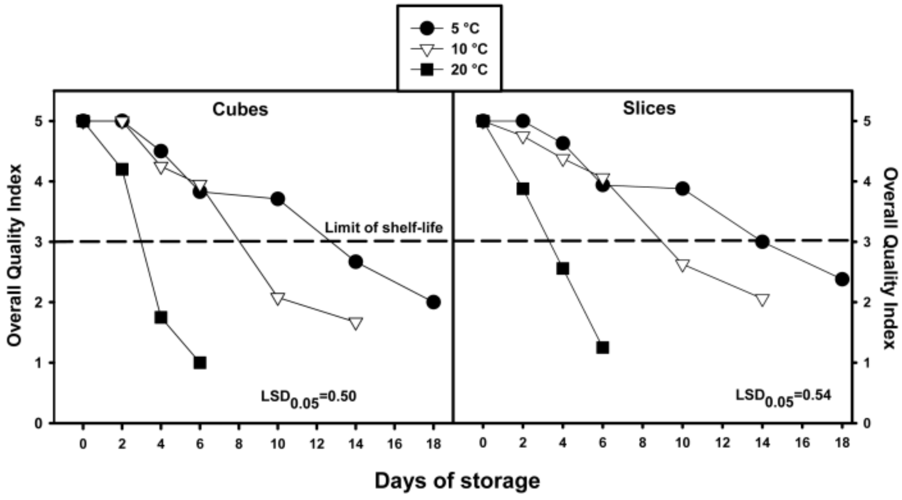

Figure 4—Overall quality index of papaya 'Maradol' cubes and slices during storage at 5 °C, 10 °C, and 20 °C

dants in minimally processed fruit and vegetables (Nicoli and others 1999). The total antioxidant capacity of whole strawberries showed that water-soluble and water-insoluble total antioxidant capacity trend to decrease during 2 d of storage during the 1999 season, but this change was not consistent in fruits harvested during the 2000 season (Olson and others 2004). Recent study with strawberries reported that ORAC value increases with the increment of storage temperature and could be due to the increase in total phenolic and anthocyanin content (Ayala-Zavala and others 2004). In this study, depletion of ORAC was associated with depletion of both ascorbic acid and β-carotenes, but in general, the highest loss of these important nutrients was reached before the product was unacceptable or spoiled. A recent report revealed that colored antioxidant reach their highest levels when fruits are at their optimal ripeness and is accompanied by fruit softening and a decline in astringency and in an improvement of overall quality (Kalt 2005).

Conclusions

Comparing the 2 cutting shapes, cubes and slices, the latter presented a slight advantage in TSS content, weight loss, and overall quality index when stored at 5 °C and 10 °C. The temperature that best conserved nutriments, shelf life, and quality of papaya cubes

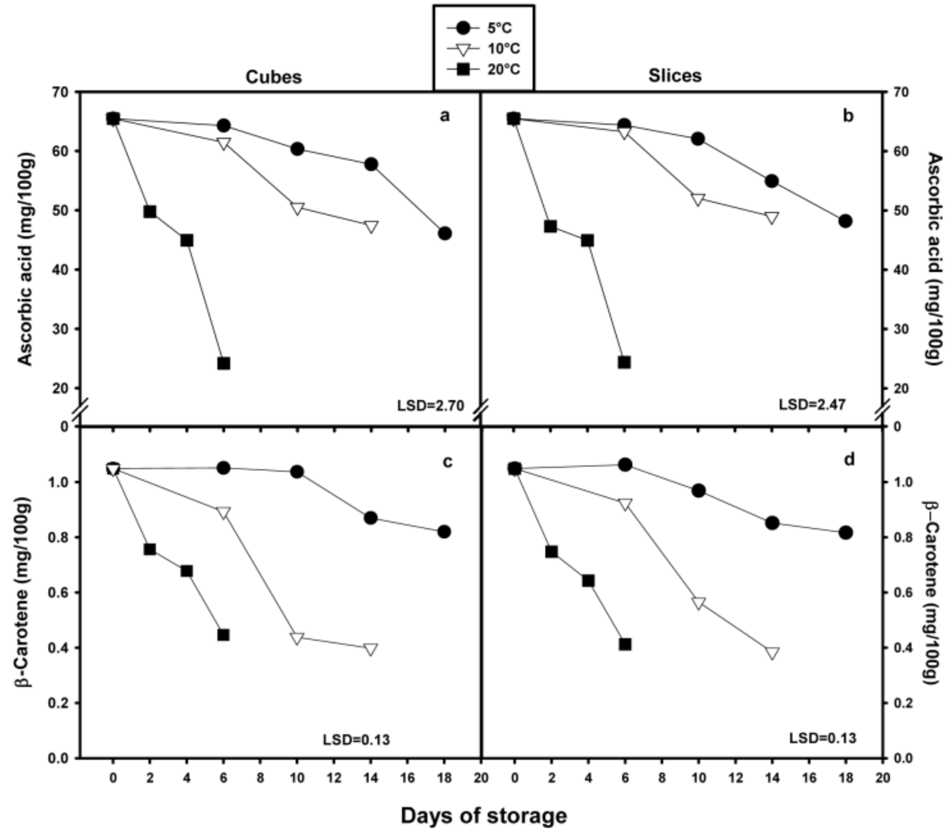

Figure 5—Ascorbic acid and β-carotene content of papaya 'Maradol' cubes and slices during storage at 5 °C, 10 °C, and 20 °C

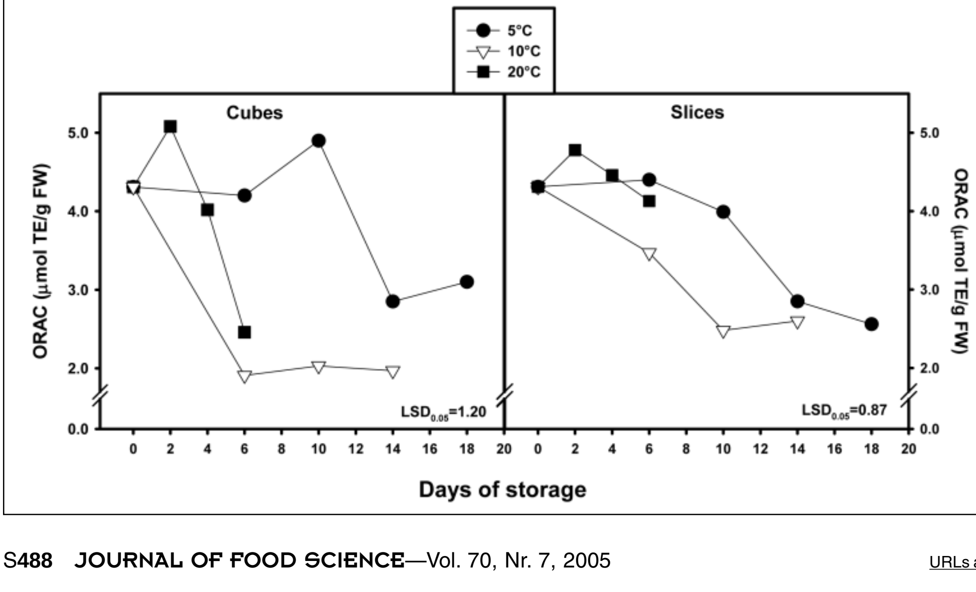

Figure 6—Antioxidant capacity of fresh-cut papaya 'Maradol' cubes and slices during storage at 5 °C, 10 °C, and 20 °C

and slices during all the storage period was 5 °C. Storage temperature of 10 °C could be used to preserve fresh-cut papaya for only 6 d; higher temperatures are not recommended at all because the produce had a very short shelf life (<5 d). For commercial purposes, 5 °C provides good maintenance of nutrients and quality attributes. Papaya cv. Maradol seemed to be more suitable for fresh-cut processing because it had a longer shelf life than other cultivars and it offers an alternative of commercialization of this produce.

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