

# Quality Index, Consumer Acceptability, Bioactive Compounds, and Antioxidant Activity of Fresh-Cut "Ataulfo" Mangoes (*Mangifera Indica* L.) as Affected by Low-Temperature Storage

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**ABSTRACT:** To measure bioactive compound losses due to minimal processing, mature green fresh-cut mangoes (*Mangifera indica* L.) cv. "Ataulfo" were subjected to an antioxidant treatment and stored at 5 °C during 15 d. Quality index, total phenols, flavonoids,  $\beta$ -carotene, ascorbic acid, vitamin E, and antioxidant activity were measured during the storage period of fruits. Antioxidant capacity was estimated using ORAC<sub>FL</sub>, TEAC, and DPPH assays. The dipping treatments with ascorbic acid (AA) + citric acid (CA) + CaCl<sub>2</sub> affected positively quality delaying deterioration of fresh-cut mango as compared with whole fruit. However, dipping treatment affected the consumer preferences of fresh-cut mangoes. The highest vitamin C,  $\beta$ -carotene, and vitamin E losses were observed after 10 d, being similar in whole and fresh-cut mangoes. The antioxidant activity was not significantly affected by storage time. We conclude that fresh-cut mangoes retained their bioactive compound content during storage and their antioxidant and nutritional properties make them a good source of these compounds.

**Keywords:** antioxidant activity, bioactive compounds, fresh-cut fruits, *Mangifera indica* L., mango, sensory evaluation

## Introduction

Mango (*Mangifera indica* L.) is one of the most important tropical fruits with a global production exceeding 27 million tons (FAOSTAT 2008), being the 2nd largest tropical crop next to banana, in terms of production, acreage, and popularity. Mango cv. "Ataulfo" is grown in Mexico and it constitutes 12% of the total mango exportations from the last years (Mota 2004). In addition to its attractive color and taste, the high content of ascorbic acid,  $\beta$ -carotene, and phenolics are intrinsic characteristics of this cultivar (Chantanawaragoon 2000; Gil and others 2006; González-Aguilar and others 2008). All these bioactive compounds are good antioxidants and their daily intake in the diet has been related to prevention of degenerative processes, such as cardiovascular diseases and cancer (Block and others 1992; Liu 2003). Thus, consumption of mango could provide significant amounts of bioactive compounds with antioxidant activity to the human diet.

Minimally processed fruits are one of the major growing segments in the food retail market. However, the greatest hurdle to the commercial marketing is the limited shelf life, which is due to ex-

cessive tissue softening and cut-surface browning (Soliva-Fortuny and Martín-Belloso 2003). Great efforts have been made to prevent browning in fresh-cut fruits and vegetables. One approach to achieve this goal is the inhibition of browning reactions by excluding oxygen, adding antioxidants, or inhibiting the activity of the responsible enzyme polyphenol oxidase (PPO) (Saltveit 2003). It has been demonstrated that treatments with calcium salts could be used as firmness stabilizers and to inhibit cell wall-degrading enzymes, such as polygalacturonase (PG) and pectin methylesterase (PME) (Luna-Guzman and Barrett 2000). However, sensorial acceptance of calcium treated fruits has been questioned by some researchers. Studies of dipping treatments with antioxidants such as ascorbic acid and calcium chloride have been shown to affect apple flavor (Rocha and Brochado 1998). Concentrations of 2% of calcium chloride resulted in perception of bitterness in apple chips (Sham and others 2001). Another study also has reported that calcium chloride can cause a bitter aftertaste in fruits (Safner and others 2003). Researchers have reported the effectiveness of dipping treatments containing calcium to delay deterioration of fresh-cut mango (Chantanawaragoon 2000; González-Aguilar and others 2008). However, the effects of dipping treatments on sensorial quality and consumer preference of fresh-cut mangoes have not yet been reported.

Information about changes in bioactive compounds composition and their total antioxidant capacity (TAC) during storage is required to offer consumers nutritionally sound fresh-cut fruits. Evaluation of fruit antioxidant capacity is not an easy task, and several methods are available to determine this property; different substrates, conditions, analytical methods, and concentrations can affect the estimated activity. All methods for determining TAC have their limitations and may appear inconsistent depending on the

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method used (Frankel 1999). Therefore, no single available assay provides all the desired information, so evaluation of overall antioxidant capacity may require multiple methods to generate an “antioxidant profile” (Prior and others 2005).

The goal of this study was to evaluate the effectiveness of dipping treatments on quality indexes and their correlation with cell-wall degrading enzymes (PME and PG) and color (PPO enzyme) of fresh-cut mango as compared with whole fruits. Sensory quality, bioactive compounds losses, and antioxidant capacity of fresh-cut mango and whole fresh fruit during storage were also evaluated.

## Materials and Methods

**Reagents.** Fluorescein (FL) and 6-hydroxy-2,5,7,8-tetramethyl-2-carboxylic acid (Trolox) and 2,2-diphenyl-2-picrylhydrazyl hydrate (DPPH) were purchased from Aldrich (Milwaukee, Wis., U.S.A.). 2,2'-Azobis (2-amidino-propane) dihydrochloride (AAPH) was obtained from Wako Chemicals USA (Richmond, Va., U.S.A.). Randomly methylated cyclodextrin (RMCD) was purchased from Cyclolab R&D Ltd. (Budapest, Hungary). 2,2-Azino-bis(3-thylbenzthiazoline-6-sulfonic acid) (ABTS), potassium persulfate, Folin-Ciocalteu reagent, butylhydroxytoluene (BHT), and hydroquinone (HQ) were obtained from Sigma Chemical Co. (St. Louis, Mo., U.S.A.). All other standards and solvents were of analytical grade and commercially available from Sigma or Aldrich. Deionized and distilled water was used throughout the study.

## Sample preparation

Mature green mangoes (*Mangifera indica* L.) cv. “Ataulfo” were cultivated in Chiapas State and transported to the laboratory in Hermosillo, Sonora, Mexico, during January–March 2007. The mangoes were selected to eliminate damaged, defective or ripe fruits and, then, stored at 15 °C until use. Mangoes with flesh firmness between 15 and 27 N of penetration force were used. Mangoes were submerged in a solution containing 200 ppm sodium hypochlorite (6% NaClO) of a commercial bleach preparation (Cloralex™, NL, Mexico) for 3 min. Next, the mangoes were air-dried at room temperature and divided into 2 batches. Initially, 30 fruits were used for the analysis; samples were chosen and frozen until analysis of the bioactive compounds and antioxidant capacity. Fruits (120) were divided into 2 batches. Batch 1 was maintained as whole fruits (60 fruits) and placed in plastic boxes (15 fruit each) and stored at 12 °C for 15 d. Batch 2 (60 fruits) was peeled with a sharp vegetable peeler, and the flesh was sliced from the seed into halves with a sharp nonserrated knife. Mango slices were cut into 2 × 2 × 2 cm cubes and treated as follows.

## Dipping treatment procedure

The dipping treatment was similar to that reported in a previous study (González-Aguilar and others 2008). Mango cubes were dipped in aqueous solution of 1% AA + CA + CaCl<sub>2</sub> for 3 min and drained. The cubes were distributed in 60 polypropylene plastic trays (150 g each) and covered with lids of the same material. Trays containing the fresh-cut mangoes were stored at 5 °C for 15 d. Quality indexes, bioactive compounds, and antioxidant activity of whole and cube-cut mangoes were evaluated at intervals of 5 d within 15 d. The experiment was repeated twice.

## Quality indexes

**Firmness.** This property was measured using a firmness tester (Texture Analyzer TA-XT2; Arrow Scientific, Lane Cove, NSW, Australia) with a stainless steel spherical probe of 1/4 cc diameter

and a speed of 10 mm/s. Texture was reported as the force in Newton (N) needed to penetrate 10 mm.

**Cell-wall-degrading enzymes.** Polygalacturonase (EC 3.2.1.15) activity was assayed by measuring the reducing groups released from polygalacturonic acid (Gross 1982). The enzyme activity was expressed as milligram of galacturonic acid per milligram of protein. Pectin methylesterase (EC 3.1.1.11) activity was determined by a titration method (Rouse and Atkins 1955), using pectin as substrate. The enzyme activity was expressed as milliequivalents (mEq) of hydrolyzable esters per milliliter of extract.

**Color.** The color was measured with a Minolta colorimeter CR-300 (Minolta Corp., Ramsey, N.J., U.S.A.) using the Hunter Lab scale (*L*<sup>\*</sup>, *a*<sup>\*</sup>, and *b*<sup>\*</sup> values).

**Measurement of PPO.** Specific PPO activity (E.C. 1.14.18.1) was obtained using a colorimetric method (De Ancos and others 1999), using catechol as substrate. One unit of PPO activity (AU) was defined as an increase of 0.001 unit of absorbance per minute per milligram of protein at 420 nm. The protein content was analyzed with a calibration curve made with bovine serum albumin as standard.

## Sensory analysis—consumer test

Testing was carried out in a sensory laboratory equipped with individual booths. Fifty-five consumers, 20 to 50 y old, approximately 50% female and 50% male, who frequently consumed mango fruit, were recruited among personnel of the Centro de Investigación en Alimentación y Desarrollo, Sonora, México. They received 4 cubes of each sample: whole and fresh-cut mango treated with (AA + CA + CaCl<sub>2</sub>) in the same session at zero time and after being stored for 5, 10, and 15 d. A complete block experimental balance design was used to provide to consumer samples from each storage period to score: acceptability of visual aspect, color, texture, taste, and overall quality. For the sensorial attribute evaluation, we used a 9-box scale labeled on the left with “dislike very much,” in the middle with “indifferent” and on the right with “like very much” and answer whether they would consume it in a normal situation with “yes” or “no” having as control fresh-cut mango without dipping and processed at 10 °C 1 h prior evaluation.

## Bioactive compounds

Methanolic extracts (0.2 g/mL) were obtained according to the method of Shivashankara and others (2004). These extracts were used for total polyphenols (Singleton and Rossi 1965) and flavonoids analyses (Dae-Ok and others 2003). Ascorbic acid, β-carotene, and vitamin E were determined as previously described by González-Aguilar and others (2008) and Robles-Sánchez and others (2008).

## Antioxidant activity

**Oxygen radical absorbance capacity assay (ORAC<sub>FL</sub>).** This assay measures the effect of antioxidant components in fruit and other foods based on the decline in FL fluorescence induced by AAPH, a peroxy radical generator (Ou and others 2001; Huang and others 2002). The extraction of lipophilic (L-ORAC<sub>FL</sub>) and hydrophilic (H-ORAC<sub>FL</sub>) components were performed according to the method of Huang and others (2002), Wang and others (2002), and Ayala-Zavala and others (2004).

The reaction mixture contained 1.65 mL of 75 mM phosphate buffer (pH 7), 100 μL of 0.106 μM FL, 150 μL of 0.8 M AAPH, and 100 μL of extracts. Phosphate buffer was used as a blank for L-ORAC<sub>FL</sub> and H-ORAC<sub>FL</sub>, respectively. FL, phosphate buffer, and samples were preincubated at 37 °C for 15 min. The reaction was started by the addition of AAPH, and the fluorescence

was measured and recorded every 5 min until the fluorescence of the last reading declined to < 5%, respect to the initial reading. One blank and a maximum of 12 samples were analyzed at the same time. The excitation and emission wavelength was set at 484 and 515 nm, respectively. All fluorescence measurements were performed on a Perkin-Elmer LS 55 spectrofluorometer (Norwalk, Conn., U.S.A.). Each extract measurement was repeated 4 times. The final L-ORAC<sub>FL</sub> and H-ORAC<sub>FL</sub> values were calculated by using a regression equation between the Trolox concentration and the net area under the FL decay curve and were expressed as Trolox equivalents ( $\mu\text{mol TE}$ ) per 100 g FW. The area under the curve (AUC) was calculated according to the following equation:

$$\text{AUC} = (0.5 + f_5/f_0 + f_{10}/f_0 + f_{15}/f_0 + f_{20}/f_0 + f_{25}/f_0 + f_{30}/f_0 + \dots + f_i/f_0) \times 5$$

where  $f_0$  is the initial fluorescence reading at 0 min and  $f_i$  is the fluorescence reading at time  $i$ . The data were analyzed by applying the equation in a Microsoft Excel spreadsheet to calculate the AUC. The net AUC was obtained by subtracting the AUC of the blank from that of the sample. Total antioxidant capacity (TAC) was calculated by adding the L-ORAC<sub>FL</sub> and H-ORAC<sub>FL</sub>.

### Trolox equivalent antioxidant capacity (TEAC)

This assay is based on the ability of the antioxidants to scavenge the blue-green ABTS<sup>+</sup> radical cation, relative to the ABTS<sup>+</sup> scavenging ability of the water-soluble vitamin E analogue Trolox (Pellegrini and others 1999).

The ABTS<sup>+</sup> radical cation was generated by the interaction of 5 mL of 7 mM ABTS solution and 88  $\mu\text{L}$  of 0.139 mM K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> solution. After the addition of 2970  $\mu\text{L}$  of ABTS<sup>+</sup> solution to 30  $\mu\text{L}$  of methanolic extracts (0.2 g/mL) or Trolox standards (0 to 20  $\mu\text{M}$  range), the absorbance was monitored exactly 1 and 4 min after the initial mixing. The percentage of absorbance inhibition at 734 nm was calculated and plotted as a function of that obtained for the extracts and the standard reference (Trolox). The final TEAC value was calculated by using a regression equation between the Trolox concentration and the inhibition percentage and expressed as micro mol TE per 100 g FW (Re and others 1999).

### Radical scavenging activity using DPPH method

This assay is based on the measurement of the scavenging ability of antioxidants toward the stable radical DPPH (Brand-Williams and others 1995). For it, 3.9 mL of a methanolic solution of 0.063 mM DPPH were added to the test tubes and 0.1 mL of each extract (0.2 g/mL) was added and shaken vigorously. The tubes were allowed to stand at 27 °C for 20 min. A control reaction was prepared as above without any extract, and methanol was used for the baseline correction. Changes in the absorbance of samples were measured at 515 nm. Radical scavenging activity (RSA) was expressed as the inhibition percentage and calculated using the following equation:

$$\% \text{RSA} = (\text{control Abs} - \text{sample Abs} / \text{control Abs}) \times 100$$

### Statistical analysis

A completely randomized blocking experimental design was used for this study. Data were analyzed using SAS statistical software (version 9.0, SAS Inst. Inc., Cary, N.C., U.S.A.). Means separation was performed using Tukey's test at  $P < 0.05$ .

## Results and Discussion

### Quality indexes

Firmness was significantly ( $P < 0.05$ ) affected by storage time and dipping treatment (Table 1). Initial firmness of whole fruit was higher than that of fresh-cut cubes (7.5 and 4.5 N, respectively). However, both samples showed a continuous loss of firmness during storage. After 10 d of storage, firmness losses in whole and fresh-cut cubes were 38% and 25%, respectively. Our results are similar to those reported previously (Chantanawarangoon 2000; González-Aguilar and others 2008), in which dipping treatments with calcium salts had a positive effect on firmness retention. In this study, the delay in fresh-cut fruit softening, as compared with whole fruit, could be associated with enhanced levels of calcium, involving the formation of cation cross-links with pectic acid and other polysaccharides, thus limiting accessibility of the cell wall to degrading enzymes (Luna-Guzman and Barrett 2000).

Pectin methylesterase (PME) and polygalacturonase (PG) have been considered as the primary hydrolases involved in the softening process (Sethu and others 1996). Figure 1A shows the changes in PME activity during storage of whole and fresh-cut mango. A decrease in PME activity was observed during the first 5 d of storage for all treated fresh-cut and whole fruits. Afterwards, PME activity was maintained constant in fresh-cut cubes while a continuous decrease in whole fruits was observed.

The calcium salts added to the dipping solutions maintained a stable PME activity of fresh-cut cubes; however, PME activity of whole fruit decreased in higher extent than fresh-cut during the storage period.

The main hydrolysis product of PME is pectin, the main substrate of PG. Figure 1B shows the changes in PG activity during storage of fresh-cut mango cubes as compared to whole fruits. The PG activity of fresh-cut cubes depicted fluctuations along the whole storage period with slight changes and, at the end of the storage period, a 5% reduction in PG activity was observed in these samples. A slight decrease in PG activity was observed in whole fruits during the first 10 d of storage, remaining stable with a slight increase afterwards. These results were expected, due to the behavior of PME activity during the storage period that precedes the PG activity. In the same way, lower PME and PG activities were correlated with maintenance of firmness of fruit tissues.

The results showed that the dipping treatment containing CaCl<sub>2</sub> maintained the PME and PG activities stable as compared to whole fruit. However, both fruits had the same trend during storage.

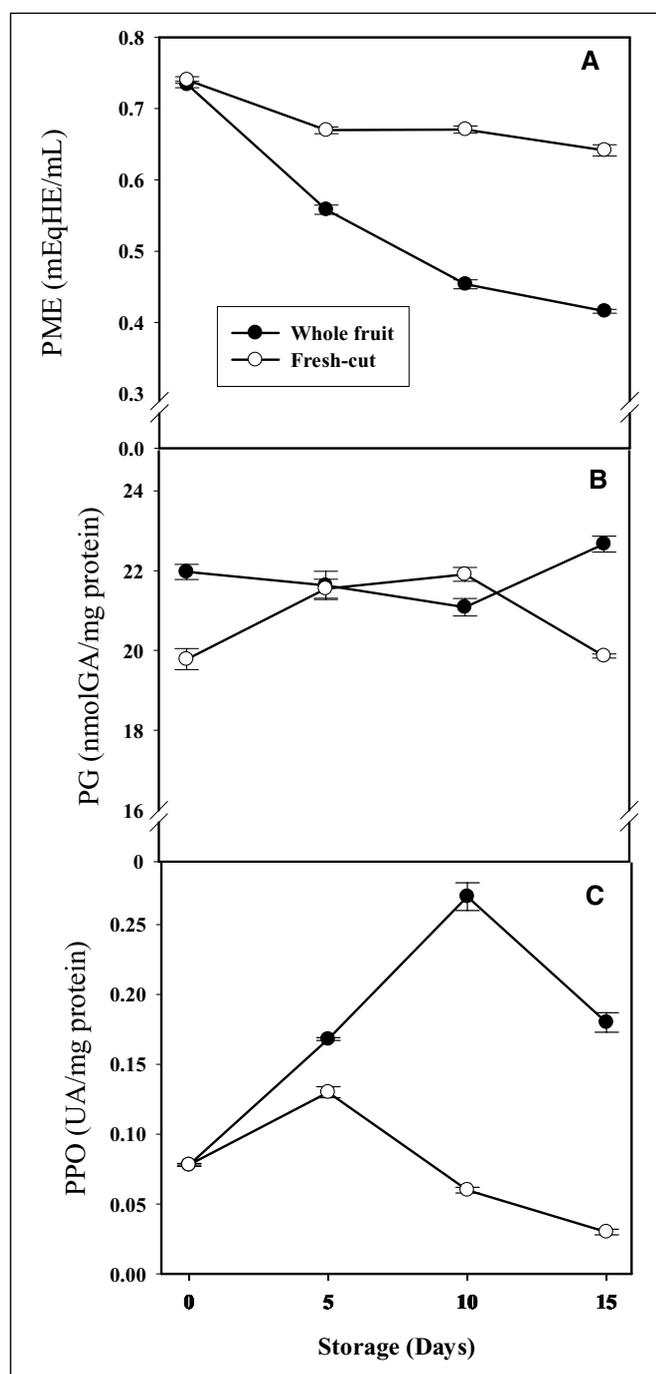
Color parameters are also important quality indexes in fresh-cut fruits. Table 1 shows the color changes ( $L^*$ ,  $a^*$ ,  $b^*$ ) of treated

**Table 1 – Changes in color parameters ( $L^*$ ,  $a^*$ ,  $b^*$ ) and firmness of fresh-cut mango fruit stored at 5 °C after dipping treatments (AA + CA + CaCl<sub>2</sub>) compared with whole fruit stored at 12 °C.**

Storage (d)	Samples	Color			Firmness (N)
		$L^*$	$a^*$	$b^*$	
0	Whole	60.0 a	4.62 a	77.0 a	7.50 a
	Fresh-cut	63.0 a	4.02 a	69.0 a	4.53 b
5	Whole	53.0 a	5.39 a	76.0 a	6.73 a
	Fresh-cut	55.0 a	5.86 a	50.0 b	3.35 b
10	Whole	45.0 b	2.93 b	76.0 a	4.61 a
	Fresh-cut	53.0 a	5.65 a	49.0 b	3.14 b
15	Whole	45.0 b	3.88 b	76.0 a	3.80 a
	Fresh-cut	53.0 a	6.59 a	49.0 b	2.43 b

Mean values in each column followed by a different letter at each storage time are significantly different ( $P < 0.05$ ).  $n = 18$ .

fresh-cut and of whole mango fruit during storage. After 5 d of storage,  $L^*$  values decreased drastically in both treated fresh-cut and whole fruit. Afterwards, a gradual reduction in the  $L^*$  value was observed only in whole fruits until the end of the storage period; however, minimal changes were also observed in fresh-cut fruits. The  $L^*$  and  $b^*$  values are indicators of lightness and yellow color in fruits, respectively. Particularly,  $L^*$  value has been used in fresh-cut mango as a good indicator of browning surface in response to peeling or slicing, which facilitates the contact of oxygen and substrates with browning enzymes (PPO) (Soliva-Fortuny and Martín-Belloso 2003). The dipping treatment with AA + CA can be used to prevent



**Figure 1** – Changes in PME (A), PG (B), and PPO (C) activity of fresh-cut mango stored at 5 °C after dipping treatments (AA + CA + CaCl<sub>2</sub>) compared with whole fruit stored at 12 °C. Bars represent standard errors,  $n = 4$ .

browning tissue by inhibiting PPO activity. In this study, the effect of this treatment was very effective reducing the changes of  $L^*$   $a^*$   $b^*$  values, compared with values of whole mangoes. However, prevention of color brightness and deterioration of fresh mango cubes by dipping treatment does not assure that sensorial quality is maintained during storage as is discussed below.

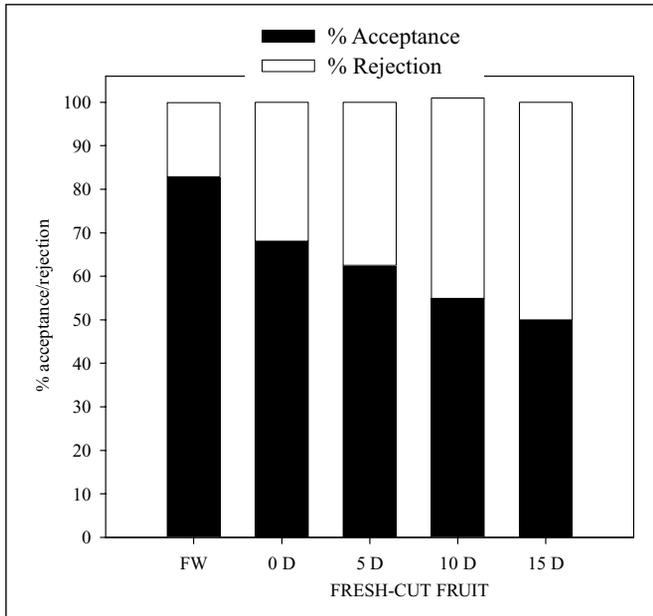
Previously, it has been demonstrated that the use of different antioxidant compounds alone or in conjunction with a modified atmosphere can prevent browning of “Tommy Atkins” fresh-cut mangoes (González-Aguilar and others 2000). In the present study, fresh-cut mangoes did not present any browning symptoms during the first 10 d of storage at 5 °C. However, in another study, fresh-cut mangoes of the “Keitt” and “Kent” cultivars developed severe symptoms of browning after 8 d of storage at 5 °C in comparison to the “Ataulfo” cultivar in which the symptoms developed after 15 d (González-Aguilar and others 2008). No systematic losses of bioactive compounds were evaluated during the storage at 5 °C of these cultivars neither enzymatic activity involved in browning process. The use of controlled atmosphere has been reported to reduce browning and deterioration of fresh-cut “Keitt” mango cubes (Martínez-Ferrer and others 2002); however, bioactive compounds and antioxidant capacity in these fruits were not evaluated during the storage period.

Figure 1C shows PPO activity for whole and fresh-cut mango fruit during storage at low temperature. PPO activity was lower for treated fresh-cut than for nontreated and whole fruit. A slight increase was observed during the first 5 d of storage in treated fresh-cut, but afterwards PPO activity decreased significantly ( $P < 0.05$ ). PPO activity of whole fruit increased with the storage period.

The “Ataulfo” mango is one of the most important cultivars produced in Mexico. Its intense yellow color and good taste make this one of the most accepted cultivars by consumers. The PPO activity found in the “Ataulfo” mango did not promote important changes in color values. In our study, the whole fruit showed high PPO activity but minor changes in  $b^*$  values. Another important characteristic of the “Ataulfo” mango that can contribute to the color retention in its flesh is its high vitamin C content, this compound can indirectly inhibit PPO action because it reduces the o-quinones produced from the oxidation of diphenols by PPO (Soliva-Fortuny and Martín-Belloso 2003), leading to less production of pigmented products. AA and CA solutions inhibited browning of fresh-cut mango. Additionally, CA reduced the pH and consequently inhibited PPO action that works at pH close to neutrality (Pilizota and Sapers 2004).

### Sensory analysis

Application of dipping treatment (AA + CA + CaCl<sub>2</sub>) affected initially the sensory attributes of fresh-cut mangoes compared with nontreated samples (data not shown). Figure 2 shows the percentage of acceptance/rejection (yes/no) of the samples when consumers were asked whether they would normally consume the samples of fresh-cut mangoes offered at different storage periods. It is important to point out, that percentage of acceptance of samples at zero time was lower than 100%. This result suggests that panelists, even they use an established scale for evaluation, considered that fresh-cut mangoes were not in optimal conditions based in the percentage (close to 20% of panelist) that rejected initial samples. At this time, it is clear that fresh-cut mango treated with AA + CA + CaCl<sub>2</sub> in combination with low temperatures experiences less changes in quality indexes at least after 5 d of storage as compared with whole fruit, being inevitable the impact exerted by the peeling and slicing during the 1st days of storage. Rejection of treated samples significantly increased with storage

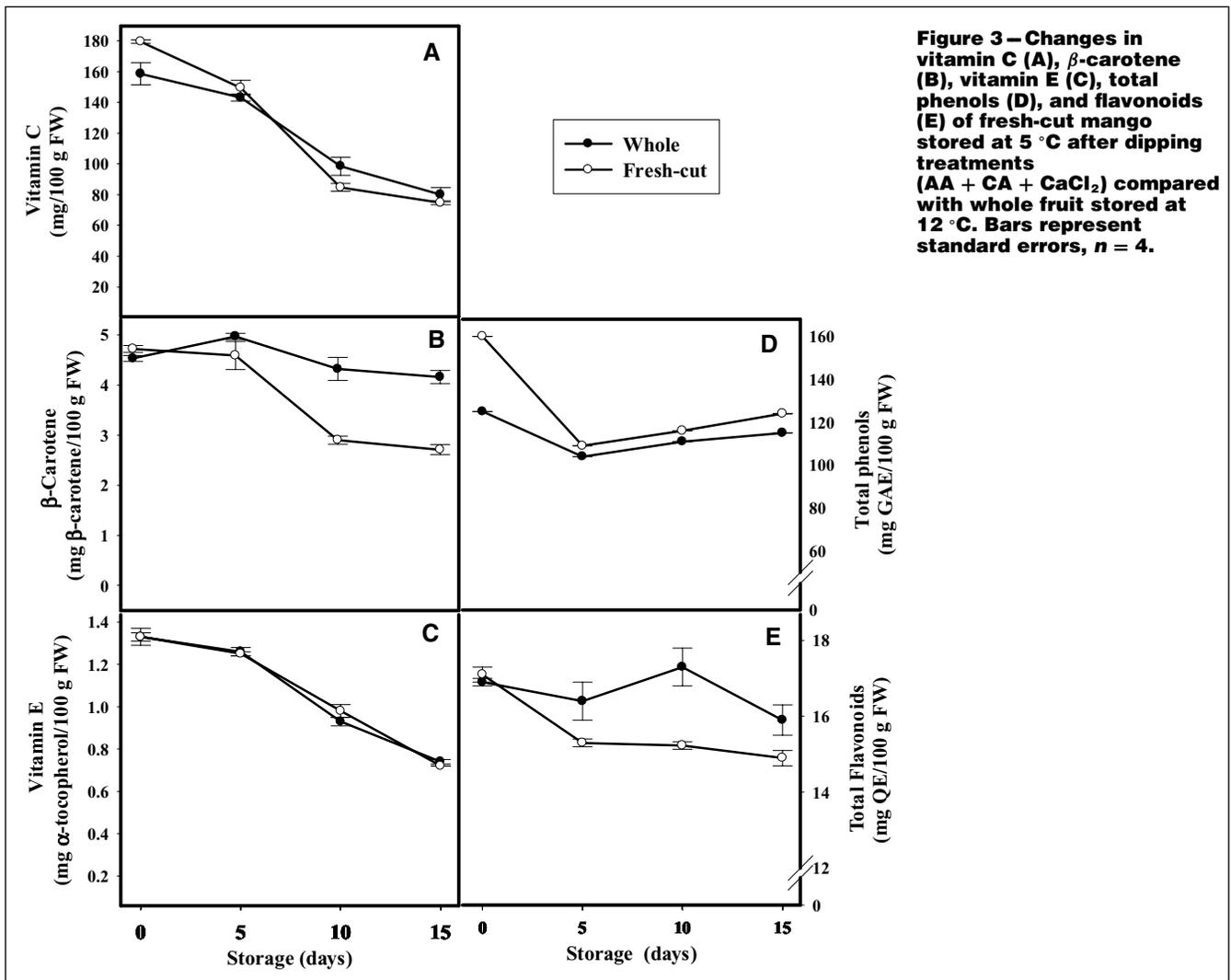


**Figure 2—Acceptance/rejection percentage of fresh-cut mango (FCM) treated with AA + CA + CaCl<sub>2</sub> stored at 5 °C as compared with fresh-whole fruit (FWM) stored at 12 °C. n = 55.**

period. After 10 d of storage, about 46% of the panelists rejected the fresh-cut mangoes. Furthermore, at the end of storage (15 d), close to 50% of panelists rejected fresh-cut mangoes. Even the treatment offers great advantages such as prevention of surface browning and deterioration of fresh-cut mangoes, it is clear that when fruit are evaluated by a group of people that commonly consume mangoes, they are able to detect the negative effect of the treatment. We observed that sensorial attributes were significantly affected, according the consumer test performed (data not shown). Results obtained in this study are in accordance with those reported previously by various researchers that dipping treatments containing calcium affected sensorial acceptance of fruits (Rocha and Brochado 1998; Sham and others 2001; Saftner and others 2003). It is necessary to evaluate if lower Ca concentrations affect in less extent sensory attributes, without disturbing the beneficial effects of treatment.

**Bioactive compounds**

Figure 3A shows the ascorbic acid (AA) changes of whole and fresh-cut mangoes during their storage. Ascorbic acid is the main biologically active form of vitamin C. The initial ascorbic acid content of whole “Ataulfo” mangoes was 158.5 mg per 100 g FW, whereas in fresh-cut mangoes it was higher (179.9 mg per 100 g FW), which is attributed to the dipping treatments. In



**Figure 3—Changes in vitamin C (A), β-carotene (B), vitamin E (C), total phenols (D), and flavonoids (E) of fresh-cut mango stored at 5 °C after dipping treatments (AA + CA + CaCl<sub>2</sub>) compared with whole fruit stored at 12 °C. Bars represent standard errors, n = 4.**

fresh-cut mangoes, ascorbic acid content has been previously reported to be in the range of 75 to 115 mg per 100 g FW (Gil and others 2006).

In this study, no significant differences in ascorbic acid were observed between whole and fresh-cut mangoes during cold storage. However, the storage period affected significantly the ascorbic acid content. A sharp decrease in ascorbic acid content was observed along the whole storage period. At the end of the storage period, the ascorbic acid losses were about 50% and 58%, for whole and fresh-cut fruit, respectively. Although ascorbic acid losses were considerably high, the final values were higher than those reported by the USDA Nutrient Database (USDA 2008) for other mango cultivars (30 to 35 mg per 100 g FW). It appears that the intrinsic high content of vitamin C present in "Ataulfo" mangoes could be related to the length of storage when this cultivar is maintained in good conditions. Contrary to other organic acids, vitamin C is quite unstable. This instability is mainly due to the activity of ascorbic acid oxidase and the reaction with oxygen in the presence of heavy metal ions and light (Bode and others 1990); therefore, vitamin C is taken as an indicator of fruit freshness and retention of other components. In addition to the longer shelf life of this cultivar ("Ataulfo"), the dipping treatment prevented deterioration of this produce; however, it was insufficient to prevent losses of vitamin C. However, losses of ascorbic acid are common in different fresh-cut fruits. It has been observed that in pineapple slices the losses can be as high as 20% and 60% of ascorbic acid after 9 and 14 d of storage at 5 °C, respectively (González-Aguilar and others 2004; Gil and others 2006). In papaya cubes, 30% losses of ascorbic acid have been reported after 18 d of storage at 5 °C (Rivera-Lopez and others 2005).

Total carotenoid content of different mango cultivars has been reported to be in the range of 0.9 to 9.20 mg per 100 g FW (Litz 1997). The major carotene present in the "Ataulfo" cultivar was  $\beta$ -carotene, whereas  $\alpha$ -carotene was present only in small amounts (data not shown). Figure 3B shows the changes in  $\beta$ -carotene for either whole or fresh-cut mangoes during storage. The initial content of  $\beta$ -carotene was 4.53 and 4.72 mg per 100 g FW for whole and fresh-cut mangoes, respectively. Lower  $\beta$ -carotene content has been observed in mangoes of the same cultivar with initial values of 1.30 mg per 100 g FW (Gil and others 2006). This difference could be attributed to different mango maturation stages used in each study.

The  $\beta$ -carotene content of whole mangoes was quite stable during fruit storage and no significant changes were observed when compared with the initial contents. Apparently, the oxidation of carotenoids starts at an advanced maturity stage of the mangoes (Thompson and others 1987). For this reason, this aspect should be considered to avoid oxidation processes in "Ataulfo" mangoes in advanced maturity stages when deteriorative processes are more active. Preliminary studies (Robles and others 2006) revealed that advanced maturity stages enhance losses of bioactive compounds; hence, it was helpful to choose correctly the maturity stage of the mangoes used in the present study.

Fresh-cut mangoes preserved their initial  $\beta$ -carotene content during the first 5 d of storage. However, afterwards,  $\beta$ -carotene contents decreased significantly in fresh-cut as compared to whole mangoes, which did not present noticeable changes in its content. At the end of the storage period, the fresh-cut mangoes had a  $\beta$ -carotene reduction of 40% with respect to the initial value. Similar losses (30%) in fresh-cut "Ataulfo" mangoes without dipping treatment, were found (Gil and others 2006), therefore the storage time and cutting were the factors that affected the  $\beta$ -carotene content rather than the dipping treatment. Losses in  $\beta$ -carotene content for other products like fresh-cut carrots are of 33% after 21 d at 5 °C (Ruiz-Cruz and others 2007); pineapple, 16%; and strawberry,

2% after 9 d at 5 °C (Gil and others 2006), whereas sliced papaya reached losses of 40% after 18 d at 5 °C (Rivera-Lopez and others 2005).

Vitamin E occurs naturally in 4 forms of tocopherol ( $\alpha$ -,  $\beta$ -,  $\lambda$ -, and  $\gamma$ -T) and the corresponding tocotrienols ( $\alpha$ -,  $\beta$ -,  $\lambda$ -, and  $\gamma$ -T3), which contain unsaturated side chains. Among these compounds,  $\alpha$ -tocopherol is the most biologically active form. Plant foods, especially fruits and vegetables, contain from low to moderate levels of vitamin E; and the large amount of plant-derived foods in our diets provide a significant and consistent source of vitamin E (Chun and others 2006). Figure 3C shows the vitamin E values found in whole and fresh-cut mangoes during storage. The initial content of vitamin E for both whole and fresh-cut mangoes was 1.33 mg per 100 g FW. This value is higher than that reported by the USDA Nutrient Database (USDA 2008) for other mango cultivars. In our study, no significant differences in vitamin E were observed between whole and fresh-cut mangoes during the storage period. However, the storage period affected significantly vitamin E to a similar extent in both presentations.

Figure 3 also shows the total content of phenols and flavonoids of fresh-cut "Ataulfo" mangoes during cold storage. At initial storage total phenol content of fresh-cut treated cubes was significantly higher than that observed in whole fruit (160 and 125 mg per 100 g FW, respectively) (Figure 3D). Overestimation in total phenol content was expected because the Folin-Ciocalteu assay includes contribution from L-ascorbic acid, reducing sugars, soluble proteins, and other substances (Prior and others 2005). This pattern was maintained relatively constant during the whole storage period, with a sharp reduction on day 5 of storage. At the end of storage the losses were of 8% and 22% with respect to the initial values for whole and fresh-cut fruit, respectively. As recommended in other studies, the Folin-Ciocalteu assay is not a good marker to evaluate total phenols in fruits with high ascorbic acid content.

There are very few studies in fresh-cut mangoes that evaluate losses of phenolic compounds during storage. A similar study estimated total phenolic content in fresh-cut mango through HPLC, finding similar losses as in whole mango, after 9 d of storage at 5 °C (Gil and others 2006). However, no treatment was applied in the last study and deterioration of mango cubes was observed before significant changes in bioactive compounds occurred.

Phenolics are degraded when they become exposed to oxygen, light, high temperatures, and enzymes. Most of these conditions take place as a consequence of peeling and cutting processes and as a result of cellular content mixing. Oxidation of phenolic compounds, which is often catalyzed by the polyphenol oxidase enzyme to form colored melanins, results in browning of surface tissue and loss of quality (Vámos-Vigyázó 1981). In previous studies, it has been observed that cutting increases PPO activity with the subsequent browning of surface tissue of fresh-cut mangoes treated with UV-C (González-Aguilar and others 2001). It has also been observed that dipping treatments with antioxidants are useful to prevent cut surface browning and to retain vitamin C content in fruits; however, changes in phenol content were not reported.

In the "Ataulfo" mango, the initial content of flavonoids was about 17 mg QE per 100 g FW (Figure 3E). The total phenol content decreased to different extents during the first 5 d of storage, with lower values in the fresh-cut with respect to whole fruit. This value showed a slight decrease during the first 5 d for both whole and fresh-cut fruit. Afterwards, no significant losses of flavonoids were observed for both presentations. In fresh-cut mangoes, losses of flavonoids were about 10% at the end of the storage period. Quercetin and catechin are the main flavonoids present in mango,

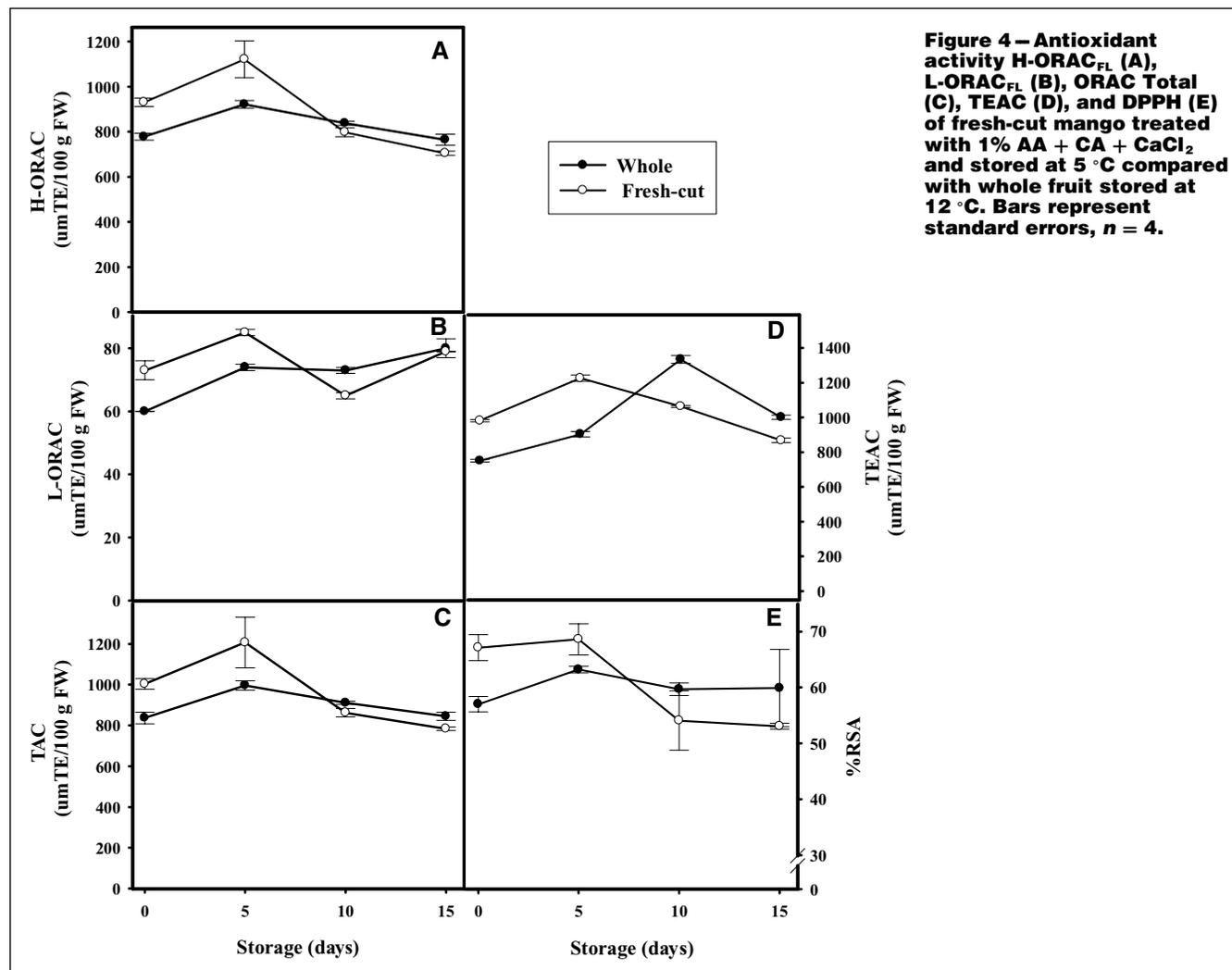
with values of 0.0172 (USDA 2008) and 0.014 mg/g (Shivashankara and others 2004), respectively. These flavonoids are considered as potent antioxidants with beneficial health effects (Pietta 2000). Future studies must be focused on the evaluation of changes and preservation of these compounds in fruits. Flavonoid contents correlate with the reduction of deteriorative reactions (Crozier and others 2000; Ross and Kasum 2002). The higher flavonoid content present in "Ataulfo" mangoes could be associated with their long shelf life, as has been reported in other important produces (Tomas-Barberan and Espin 2001).

It is well known that phenolic compounds have a role as antioxidants promoting health benefits. Their effect on the inhibition of oxidation of low-density lipoproteins (LDL) has been widely studied (Paganga and others 1999; Eberhardt and others 2000). However, phenol compounds have different antioxidant capacity, depending on their structure, number of hydroxyl groups, as well as the matrix where they are embedded (Heo and others 2007). We analyzed the antioxidant activity of the standard phenols that occur naturally in fruits and found that gallic, protocatechuic, chlorogenic, ferulic, caffeic acids, and quercetin and catechin flavonoids at the same concentration showed higher antioxidant activity than vitamin C, vitamin E,  $\beta$ -carotene, and trolox (unpublished data). For this reason, studies about individual phenol content in the "Ataulfo" mango are needed to recommend this fruit as part of a healthy diet.

### Total antioxidant capacity

ORAC<sub>FL</sub>, H-ORAC<sub>FL</sub> measures the antioxidant capacity of water-soluble antioxidants, such as ascorbic acid and phenolic compounds. Figure 4A shows changes in H-ORAC<sub>FL</sub> for whole and fresh-cut mangoes stored at low temperature. Initial values for whole fruit were of 778  $\mu\text{mol TE}$  per 100 g FW while for fresh-cut cubes the H-ORAC values were of 931  $\mu\text{mol TE}$  per 100 g FW. It appears that the addition of AA and CA is responsible of the increase in the antioxidant activity observed in fresh-cut mangoes. An increase in H-ORAC<sub>FL</sub> values was observed in mangoes during the first 5 d of storage and a gradual decrease during the rest of the storage period. At the end of storage, the total H-ORAC<sub>FL</sub> losses were about 9% and 17% for whole and fresh-cut mangoes, respectively. These results imply that cutting does not substantially affect the antioxidant capacity as commonly assumed by consumers.

L-ORAC<sub>FL</sub> measures the antioxidant capacity of lipophilic antioxidants, such as vitamin E. It is necessary to clarify that the L-ORAC<sub>FL</sub> assay does not measure the antioxidant activity of carotenoids, since carotenoids are not chain-breaking antioxidants. Instead, they may act as singlet oxygen scavengers and therefore follow a different reaction mechanism (Huang and others 2002). The antioxidant activity measured as L-ORAC<sub>FL</sub> can be attributed to the antioxidant activity of vitamin E in mango fruit. In this study, L-ORAC<sub>FL</sub> values increased during the first 5 d either in whole or fresh-cut mangoes with respect to the initial values



(Figure 4B). At the beginning of the storage period, the fresh-cut mangoes showed higher values of antioxidant capacity than those of whole fruits. Afterwards, L-ORAC<sub>FL</sub> values of whole and fresh-cut fruits were quite stable.

Total antioxidant activity (TAC) was measured by adding H-ORAC and L-ORAC. Figure 4C shows the effect of low-temperature storage on TAC values in whole and fresh-cut mangoes; TAC values followed a pattern similar to that presented by H-ORAC<sub>FL</sub>, this is expected since L-ORAC<sub>FL</sub> contributed just with 1% of the TAC. These results are comparable to those of others (Wu and others 2004), who reported 988  $\mu\text{mol TE}$  per 100 g FW and 14  $\mu\text{mol TE}$  per 100 g FW for H-ORAC<sub>FL</sub> and L-ORAC<sub>FL</sub>, respectively. However, in this latter study, the analyzed mango cultivar was not specified. In the present study, the total antioxidant capacity (TAC) was measured for the 1st time using ORAC<sub>FL</sub> combining both lipophilic and hydrophilic antioxidant components in "Ataulfo" mangoes.

Based on the fresh weight of fresh-cut mango, the antioxidant activity against peroxy radicals measured as TAC (ORAC<sub>FL</sub>) was similar to other results observed in whole fruit, such as apricot (1340  $\mu\text{mol TE}$  per 100 g FW), green and red grapes (1118 and 1260  $\mu\text{mol TE}$  per 100 g FW, respectively), and nectarines (749  $\mu\text{mol TE}$  per 100 g FW) (Wu and others 2004).

**TEAC.** The results of the determination of total antioxidant potential in whole and fresh-cut mango measured as TEAC during storage are shown in Figure 4D. As can be seen, the initial antioxidant potential of fresh-cut was significantly higher than that of the whole fruit ( $P < 0.05$ ), this pattern was maintained until day 5 of storage. At the same time a slight increase in TEAC values was observed; thereafter, the values decreased only in the fresh-cut mangoes. At the end of the storage period, the TEAC values were 868  $\mu\text{mol TE}$  per 100 g FW. This is the 1st report on the antioxidant potential of mango measured as TEAC. We found only 1 report (Kuskoski and others 2005) in which the antioxidant activity of frozen mango pulp was estimated using TEAC and the results were 1320  $\mu\text{mol TE}$  per 100 g.

**DPPH.** Figure 4E shows the percentage of the DPPH radical inhibited by antioxidants present in whole and fresh-cut mangoes during storage. The percentage of inhibition at the beginning of the storage was of 56% and 67% for whole and fresh-cut fruit. This percentage remained relatively stable during the first 5 d of storage, a noticeable reduction was observed after this time, particularly for fresh-cut mangoes. For whole fruit, an increase was observed at the end of the storage period.

To date, no standardized assay is available to estimate the antioxidant activity in food. The nature of the food sample, the antioxidant components, the reaction mechanism of the oxidants, and the measurement of end point oxidation make this task difficult (Sánchez-Moreno 2002). In small fruits with high content of phenolic compounds, it has been observed that the latter correlates well with the values reported for antioxidant activity. In apples, it has been observed that vitamin C contributes just with 0.4% of the total antioxidant activity (Eberhardt and others 2000).

## Conclusions

**F**resh-cut fruits are a good alternative to whole fruit consumption if several aspects are by the technological process involved. In this study, a dipping process with citrates and calcium, plus low temperatures led to a product with good nutritional quality and acceptable to the consumers. In terms of the browning, softening and color, the AA + CA + CaCl<sub>2</sub> dipping treatment and storage at 5 °C allowed maintenance of a good quality index by 15 d. In terms of consumer acceptability, the acceptance level was 54% by the panelists after 10 d, probably because of the development of off-flavors. More

study is also necessary to evaluate lower concentrations of calcium that does not negatively affect sensory attributes. Further analytical study would be useful to understand the mechanisms and origins of development of these components.

From the marketing and consumer education point of view, it is critical to emphasize the content of antioxidants and bioactive compounds in the nutritional labeling. In this regard, the dipping treatment plus low-temperature storage were able to reasonably keep the nutritional quality of fresh-cut mangoes compared with whole-fresh mangoes during the storage period.

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