

Effectiveness of Calcium Chloride and Calcium Lactate on Maintenance of Textural and Sensory Qualities of Fresh-Cut Mangos

Panita Ngamchuachit, Hanne K. Sivertsen, Elizabeth J. Mitcham, and Diane M. Barrett

Abstract: The effects of calcium chloride (CaCl_2) and calcium lactate on maintaining textural and sensory quality of fresh-cut “Kent” and “Tommy Atkins” mangos and determination of treatments preferred by consumers were investigated. Mango cubes ($1.5 \times 1.5 \times 1.5$ cm) were subjected to different CaCl_2 and calcium lactate concentrations (0 M, 0.068 M, 0.136 M, 0.204 M) and dip times (0, 1, 2.5, 5 min). Instrumental quality parameters (firmness, color, soluble solids, titratable acidity) were analyzed periodically during 9 d of storage at 5 °C. Tommy Atkins mango cubes became more orange, but also had more browning than Kent mango cubes during storage at 5 °C. Firmness retention during storage was greater with mangos cubes treated with CaCl_2 than with calcium lactate, therefore we focused our instrumental analysis only on CaCl_2 -treated cubes. The firmness of Tommy Atkins mango cubes was higher than Kent. Soluble solids content (SSC), titratable acidity (TA), and SSC/TA were higher in fresh-cut Kent mango cubes. Mangos treated with CaCl_2 showed retarded softening during storage, and the retardation was greater at higher calcium concentrations. A consumer test was conducted to cluster consumers based on mango preference in order to correlate consumer liking and calcium treatments, as well as to uncover consumer intentions for in-store fresh-cut mango purchases. Treatment at 10 °C with 0.136 M CaCl_2 for 2.5 min for Tommy Atkins mangos and 1 min for Kent mangos was effective in retaining firmness during storage at 5 °C and was also not disliked by consumers. A cluster analysis divided consumers into 2 preference groups, with Kent mangos significantly preferred over Tommy Atkins.

Keywords: calcium chloride, calcium lactate, color, firmness, *Mangifera indica* L., mango, preference

Practical Application: Fresh-cut mangos often develop tissue softening and discoloration during storage. Short dips (1 to 3 min) in either CaCl_2 or calcium lactate effectively improve fresh-cut mango firmness and color retention after cutting. Mango samples treated with CaCl_2 had higher liking scores compared to those treated with calcium lactate. “Kent” mango variety is more suitable than “Tommy Atkins” for fresh-cut processing in terms of less tissue browning and higher consumer liking.

Introduction

Mangos (*Mangifera indica* L.) are one of the most economically important tropical fruits in the world due to their unique taste, aroma, and nutritional content. However, whole mangos remain a challenge for some processors to ripen and cut. Fresh-cut or minimally processed mangos provide a convenient product for consumers, and have shown great potential for expanding the marketing of mango fruit in retail stores and foodservice operations. However, the shelf life of fresh-cut mangos is limited due to their perishability. The cutting operation enhances water loss, microbial deterioration, and wound responses, which induce ethylene production and higher respiration rate postprocessing. The typical responses to cutting in fresh-cut products are flavor loss, tissue softening, and flesh browning. Dea and others (2010) reported loss of aroma intensity in “Kent” mango slices stored at 5

and 12 °C. Several fresh-cut mango studies have postulated that tissue softening and flesh browning are a consequence of loss of cell compartmentation, whereupon enzymes and related substrates from disrupted cells can interact more easily (Chantanawarangoon 2000; Gonzalez-Aguilar and others 2000; Banjongsinsiri and others 2004; Plotto and others 2004). Loss of aroma intensity and cut edge or tissue damage are thought to be the most critical factors for shelf life of soft-ripe mango cubes (Beaulieu and Lea 2003).

For fresh-cut products, consumers have an expectation that processing and storage will not change the anticipated sensory properties. At the time of purchase, appearance and freshness are the primary criterion for consumers regarding product quality; however, subsequent purchases depend upon the satisfaction with texture and flavor (aroma and taste) quality of the fresh-cut products (Kays 1999; Beaulieu and Baldwin 2002; Kader 2002). Moreover, nutritional value and product safety are also taken into consideration by consumers. Toivonen and Brummell (2008) reported that one of the major mouthfeel textures affecting sensory quality is firmness, which is a product of many interrelated factors. These include cell wall thickness and strength, intercellular adhesion, and cell turgor.

Calcium treatments, either with calcium chloride (CaCl_2) or calcium lactate, have been shown to be effective at maintaining firmness during storage in numerous fresh-cut fruit and vegetable

MS 20131450 Submitted 10/11/2013, Accepted 2/27/2014. Author Ngamchuachit is with Dept. of Food Technology, Faculty of Science, Chulalongkorn Univ., Bangkok 10330, Thailand. Authors Ngamchuachit, Sivertsen, and Barrett are with Dept. of Food Science and Technology, Univ. of California, Davis, CA 95616, USA. Author Mitcham is with Dept. of Plant Sciences, Univ. of California, Davis, CA 95616, USA. Direct inquiries to author Ngamchuachit (E-mail: Panita.N@chula.ac.th).

studies. Examples include pear (Rosen and Kader 1989), mango (Chantanawarangoon 2000), cantaloupe (Luna-Guzman and Barrett 2000), honeydew (Saftner and others 2003), kiwifruit (Beirao-da-Costa and others 2008), melon (Silveira and others 2011), carrot (Rico and others 2007), and lettuce (Martin-Diana and others 2006). Despite these promising studies, application of calcium to fresh-cut mango is not yet used in commercial practice.

Calcium ions passively can diffuse within the cell wall structure because plant cell wall porosity is approximately 3.5 to 9.2 nm (Read and Bacic 1996), while calcium ions are about 0.1 nm (Gillard 1969). In fruit preservation practices, when fruit parenchyma cells are dipped in a calcium salt solution, calcium ions are transported primarily through the apoplast, or intercellular spaces, where they are attracted by negatively charged carboxyl groups in the homogalacturonan that constitutes pectin in the middle lamella and cell wall. The negatively charged chloride or lactate ions remain unbound in solution (Harker and Ferguson 1988; Hasegawa 2006).

A second, slower mechanism for uptake of calcium ions relates to their attraction to the phospholipids of the plasma membrane (Demarty and others 1984). Therefore, the initial firming effect of calcium treatments is accounted for by the cross-linking of calcium ions to the homogalacturonan in the middle lamella and cell walls, while the subsequent firming during storage (Mignani and others 1995; Picchioni and others 1996) may be due to the interaction of calcium ions with negatively charged head groups of plasma membrane phospholipids and proteins. In this regard, calcium ions protect the membrane from lipid degradation by stabilizing the plasma membrane. This reduces the chances for degradation by lipolytic enzymes. The calcium bridges formed in cell walls have also been reported to reduce accessibility to fungal or bacterial hydrolases that cause decay (Mignani and others 1995).

Although there are numerous reports about the beneficial effects of calcium on product texture, correlation of this effect with consumer preference has not been previously reported in fresh-cut mango products. In this study, the effects of CaCl_2 and calcium lactate on consumer preference, as well as maintaining textural and sensory quality of fresh-cut Kent and Tommy Atkins mangos were evaluated.

Materials and Methods

Plant material

Kent (9 count, mean fruit weight of 496 g) and "Tommy Atkins" (9 count, mean fruit weight of 492 g) mangos were purchased from a commercial wholesale store in Woodland, California between December 2011 and February 2012. The fruit had been subjected to a hot water quarantine protocol (USDA-APHIS 2012) and were imported from Ecuador. The fruit were transported to the Postharvest Pilot Plant at the Univ. of California, Davis in an air-conditioned vehicle. On the same day, mangos from each cultivar were visually sorted to eliminate damaged and defective fruit and then sorted nondestructively using a compression test (described under firmness below) to measure initial fruit firmness and to divide the mangos into 2 groups: less mature fruit which had firmness levels between 90 to 120 N, and more mature fruit which had firmness levels between 60 to 89 N. The less mature fruit were ripened at 20 °C and the more mature fruit were ripened at 15 °C. All fruit were ripened in rooms with >90% relative humidity to prevent dehydration. For each mango variety, 15 mango fruit from each ripening room were randomly selected every day and flesh firmness was destructively measured using a

penetrometer (described under firmness below) until a sample of 15 fruit reached as close to a mean of 25 N as possible. Firmness of 25 newtons was chosen based on our previous study indicating that consumers preferred both Kent and Tommy Atkins mangos at this firmness stage (unpublished data). For the instrumental quality experiment, once the mangos reached the average firmness according to the penetrometer, further measurements were used to obtain 240 mangos that were approximately 25 N each. For each calcium source (calcium lactate or CaCl_2), 40 mangos per each of 3 replicates (120 mangos in total) were used. These mangos were subjected to fresh-cut processing and calcium treatments and were evaluated by instrumental quality measurements on day 1, 3, 6, and 9 of storage at 5 °C. For the consumer acceptance test, the penetrometer was used to obtain 180 mangos at the average firmness of 25 N, and 30 mangos were used for each of 6 treatments. These mangos were subjected to fresh-cut processing and calcium treatments and were evaluated by 183 consumers on day 1 of storage at 5 °C.

Mango cube preparation

The entire cutting and packing process was conducted in a 10 °C sanitized room. Whole mangos at the 25 N firmness stage were immersed into an antimicrobial solution containing 100 ppm sodium hypochlorite (NaOCl) at pH 7 for 3 to 5 min, and then peeled with nonserrated knives. All cutting equipment, including knives, cutting boards, and stainless steel strainers were immersed in 200 ppm NaOCl solution overnight at 10 °C prior to use. Each mango was sliced from stem to blossom end into 2 slabs on either side of the seed. To obtain more uniform flesh firmness, 2 cm of mango flesh at the stem end, the blossom end, and the sides of each slab were discarded, and the remaining flesh was cut into 1.5×1.5×1.5 cm cubes. All mango cubes from the same treatment were pooled together before being dipped into calcium solutions containing 100 ppm NaOCl (pH 7), as recommended by the International Fresh-Cut Produce Association (2004), at 10 °C, drained, and blotted dry with cheesecloth. The cubes were then transferred to 163 mL polystyrene containers with lids (Solo Cup Co., Highland Park, Ill., U.S.A.). For the instrumental quality experiment, the cubed mangos for each calcium concentration were dipped for 0, 1, 2.5, or 5 min. Sixteen mango cubes each of 3 replicates were sampled on each evaluation day (1, 3, 6, and 9) during storage for instrumental quality measurements. Fifteen of these cubes were evaluated for color, firmness, soluble solids content (SSC), and titratable acidity (TA) and one cube was used for electrolyte leakage measurement. For the consumer acceptance test, the mango cubes for each of 12 treatments were dipped for 5 min. Three mango cubes per treatment were evaluated by each consumer on day 1 of storage at 5 °C.

Calcium treatment

For the instrumental quality experiment, the mango cubes from each variety were subjected to 32 treatment combinations, including 2 calcium sources (CaCl_2 or calcium lactate), 4 calcium concentrations (0, 0.068, 0.136, or 0.204 M), and 4 dip times (0, 1, 2.5, or 5 min). Cubed mangos were then stored at 5 °C in lidded polystyrene containers. For the consumer acceptance test, the cubed mangos from each variety were exposed to 6 calcium treatments including no treatment, distilled water (0 M), calcium lactate (0.068 M and 0.136 M), and CaCl_2 (0.136 M and 0.204 M) treated samples. Prior to calcium dips, these cubed mangos were dipped in 100 ppm NaOCl ; preliminary studies with a focus group determined that no residual aftertaste was detected.

Calcium lactate treatments were used at lower concentrations due to the presence of salt on the cut surface during storage of cubes treated with 0.204 M calcium lactate in preliminary tests.

Color evaluation

A Minolta Colorimeter (model CR-300, Minolta, Ramsey, N.Y., U.S.A.), calibrated with a standard white plate, was used to randomly measure color on the 2 surfaces of each mango cube. Color was measured in the CIE $L^*a^*b^*$ mode and was expressed as lightness (L^*), green to red (a^*), blue to yellow (b^*), and a^*/b^* value, which indicates the intensity of orange coloration (Mitcham and McDonald 1992). Preliminary experiments indicated that the a^*/b^* ratio was a better determinant of color differences than the hue angle. The color of 15 mango cubes was evaluated for each replicate.

Firmness

Nondestructive and destructive firmness measurement of mangos were made using a Texture Analyzer (Model TA.XT plus, Texture Technologies Corp., Scarsdale, N.Y., U.S.A.) equipped with a 5-kg load cell, and using a test speed of 5 mm/s. During nondestructive and destructive firmness measurements of whole mangos, an individual fruit was supported with an 8.5-cm diameter aluminum cradle, manufactured at the Univ. of California, Davis. For the compression test, firmness was recorded when a 35-mm flat-tipped cylindrical probe reached 2.5-mm deformation. For the penetrometer test, firmness of whole mangos or fresh-cut mango cubes was measured as the maximum force required to penetrate 5 mm into the cut surface with an 8-mm (whole mango) or a 3-mm (mango cubes) flat-tipped cylindrical probe.

Electrolyte leakage

Three fresh-cut mango cubes from each treatment were cut into disks (7 mm diameter \times 10 mm) using a cork borer. The tissue disks were rinsed gently with deionized water before being incubated with gentle mixing in 30 mL of 0.65 M isotonic mannitol solution at room temperature for 4 h. The electrical conductivity measurements were made using a conductivity meter (Model Accumet portable AP65, Fisher Scientific, Singapore). Total electrolytes were determined after 2 cycles of freezing at -20°C and thawing to room temperature before electrical conductivity was remeasured. Electrolyte leakage was calculated as a percentage of the conductivity of total tissue electrolytes.

Soluble solids content (SSC) and titratable acidity (TA)

After penetrometer firmness measurements of mango cubes, the 15 cubes from each replicate were juiced together through 2 layers of cheesecloth with a manual juicer (Hamilton Beach Model 932, Hamilton Beach Brands, Inc., Southern Pines, N.C., U.S.A.) for SSC, TA, and pH determination. A few drops of juice were used to measure SSC using a refractometer (Reichert AR6 Series, Depew, N.Y., U.S.A.), and 4 g of juice was diluted in 20-mL deionized water for determination of TA (citric acid equivalents) using an automatic titrator (Radiometer Tim850 titration manager connected to an SAC80 sample changer, Radiometer TitraLab, Lyon, France).

Calcium content

Freeze-dried mango samples were sent to the UC Davis Analytical Laboratory for calcium analysis. Calcium content was quan-

tatively determined using a nitric acid/hydrogen peroxide microwave digestion (Sah and Miller 1992) and inductively coupled plasma atomic emission spectrometry (ICP-AES) (Meyer and Keliher 1992).

Consumer acceptance test

A hedonic liking test on the mango cube samples was performed on the Univ. of California, Davis campus. A total of 183 participants (120 females and 63 males, ages 19 to 65) were recruited from the campus. The consumers were asked to complete a questionnaire about their liking of the 2 sets of 6 fresh-cut mango samples using a 9-point hedonic scale (1 = "extremely dislike," 5 = "neither like nor dislike," 9 = "extremely like") as well as their purchase intentions and demographics. Each sample set was from one mango variety (Kent or Tommy Atkins). The 6 samples in each set represented 6 different treatments (untreated, distilled water (0 M), 0.136 M CaCl_2 , 0.204 M CaCl_2 , 0.068 M calcium lactate, and 0.136 M calcium lactate). The solutions were applied as a dip for 5 min, and each sample was blotted dry before placing in a 59-mL polystyrene plastic cup with a lid (Solo Cup Co.). The mango samples were prepared 1 d before the consumer testing and refrigerated overnight. A randomized block design was used for sample presentation sequences and samples were labeled with random 3-digit numbers within each set. The order in which the Kent and Tommy Atkins sets were served was also randomized. The consumers were served one set at a time. Consumers were given a cup of water and unsalted saltine crackers as palate cleansers. Percentage of acceptance was calculated as the number of consumers liking the sample (score $>$ 5.0) divided by the total number of consumers tasting that sample (Lawless and Heymann 2010).

Statistical analysis

The effects of calcium treatments on firmness, electrolyte leakage, flesh color (CIE $L^*a^*b^*$, chroma, and hue angle), SSC, TA, and SSC/TA ratio were analyzed using analysis of variance for each variety and calcium type. The variety and calcium type were analyzed separately because of the dissimilarity of treatment response in each variety and calcium type. Concentration, dipping time, days after cutting, and all interactions were included in the model; replicate and interactions of replicate with all other terms were also included. Fisher's least significant difference (LSD) was used to compare means of calcium content, dip time, days after cutting and combinations of dipping time, concentration, and days after cutting at $P < 0.05$ (SAS version 9.0, Cary, N.C., U.S.A.).

A principal component analysis of the covariance matrix was performed to investigate the relationship between consumer liking and fresh-cut mango treatments (XLSTAT version 2010, Addinsoft, Paris, France), using the variables of calcium treatment and consumer liking score. Cluster analysis was carried out on the mean consumer liking scores to identify clusters of consumers that shared similar preferences. Pearson's dissimilarity matrix and the flexible linkage agglomerative hierarchical clustering technique were used (XLSTAT). Fisher's LSD was used to determine the difference in liking scores among treatments within the clusters at $P < 0.05$.

Internal preference mapping, showing the preference of consumers for each mango sample, was carried out on the hedonic ratings of mango samples by the 183 consumers. The preference data of each consumer were also shown in cluster based on cluster analysis.

Table 1—Means of instrumental quality of fresh-cut Kent mangos treated with different CaCl₂ treatments.

	Firmness (N)		Ion leakage (% total conductivity)		Lightness (L*)		Flesh color (a*/b*)		SSC ¹ (%)		TA ¹ (%)		SSC/TA ¹	
Concentration (C)														
0M	2.34	d ²	30.02	a	78.36		-0.068	a	12.68	a	0.53	c	24.35	a
0.068M	2.68	c	28.14	b	78.96		-0.073	b	12.17	bc	0.58	b	21.52	b
0.136M	2.93	b	27.85	b	79.14		-0.074	b	12.06	c	0.60	a	20.65	c
0.204M	3.23	a	26.62	c	79.31		-0.081	c	12.27	b	0.60	a	20.91	bc
Dip time (T)														
0 (untreated)	2.34	b	33.93	a	78.51		-0.071	a	12.13	b	0.56		21.87	
1	3.00	a	27.32	b	79.42		-0.074	b	12.42	a	0.59		21.72	
2.5	2.90	a	25.10	d	78.99		-0.078	c	12.39	a	0.58		21.95	
5	2.93	a	26.29	c	78.84		-0.074	b	12.24	b	0.57		21.89	
Days after cutting (D)														
1	2.89	a	28.40	a	79.26		-0.081	c	12.14	c	0.61	a	20.30	b
3	2.85	a	27.57	b	79.42		-0.078	b	12.19	c	0.59	a	20.99	b
6	2.79	a	28.67	a	78.44		-0.069	a	12.35	b	0.54	b	23.13	a
9	2.64	b	27.99	ab	78.66		-0.069	a	12.50	a	0.55	b	23.00	a
Significance														
C	***,3		***		ns		***		***		***		***	
T	***		***		ns		***		***		ns		ns	
D	***		*		ns		***		***		***		***	
C × T	***		***		ns		***		***		**		***	
C × D	ns		***		ns		ns		ns		ns		ns	
T × D	ns		***		ns		**		***		ns		*	
C × T × D	ns		***		ns		ns		ns		ns		ns	

¹SSC, soluble solids content; TA, titratable acidity. ²Within each main effect, values with the same letter are not significantly different across treatment variables ($P > 0.05$). ³ns = not significant or *, **, *** significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 2—Means of instrumental quality of fresh-cut Tommy Atkins mangos treated with different CaCl₂ treatment.

	Firmness (N)		Ion leakage (% total conductivity)		Lightness (L*)		Flesh color (a*/b*)		SSC ¹ (%)		TA ¹ (%)		SSC/TA ¹	
Concentration (C)														
0M	2.65	d ²	36.01	a	67.80		-0.069		10.09		0.48	b	21.23	a
0.068M	3.01	c	33.78	b	67.25		-0.069		10.07		0.48	b	21.67	a
0.136M	3.42	b	35.06	ab	67.95		-0.068		10.06		0.51	a	20.21	b
0.204M	3.74	a	35.39	a	68.14		-0.066		10.04		0.50	a	20.40	b
Dip time (T)														
0 (untreated)	2.85	c	36.35	a	67.73		-0.068		10.33	a	0.50	a	21.25	a
1	3.25	b	35.77	a	67.51		-0.067		9.85	c	0.50	a	19.89	b
2.5	3.43	a	34.94	a	67.94		-0.068		10.05	b	0.49	ab	21.18	a
5	3.30	b	33.18	b	67.96		-0.067		10.03	b	0.48	b	21.20	a
Days after cutting (D)														
1	3.52	a	33.38	c	70.36	a	-0.072	c	9.98	b	0.51	a	20.01	b
3	3.29	b	33.88	bc	69.48	b	-0.069	bc	10.17	a	0.49	b	21.00	a
6	3.03	c	35.06	b	65.83	c	-0.067	b	10.08	ab	0.49	b	21.02	a
9	2.99	c	37.92	a	65.48	c	-0.063	a	10.02	b	0.48	c	21.48	a
Significance														
C	***3		*		ns		ns		ns		***		***	
T	***		***		ns		ns		***		*		***	
D	***		***		***		***		*		***		**	
C × T	***		**		ns		ns		*		***		***	
C × D	ns		**		ns		ns		ns		ns		ns	
T × D	*		**		ns		ns		ns		**		*	
C × T × D	ns		*		ns		ns		ns		ns		ns	

¹SSC, soluble solids content; TA, titratable acidity. ²Within each main effect, values with the same letter are not significantly different across treatment variables ($P > 0.05$). ³ns = not significant or *, **, *** significant at $P < 0.05$, 0.01, or 0.001, respectively.

Results

Firmness

The firmness of mangos treated with calcium was generally higher relative to the untreated controls (Table 1 and 2, Figure 1). In fresh-cut Kent mango, all of the calcium treatments

increased the calcium content more than 2-fold. Higher calcium contents were found in fresh-cut mangos treated with higher calcium concentrations for longer dip times, in both calcium CaCl₂ and calcium lactate dips (Figure 2). In this study, fresh-cut mangos with higher flesh calcium concentration (Figure 2) also tended to have firmer texture (Figure 1). After 1 d of storage at 5 °C, both

calcium sources provided a similar firming effect, but firmness tended to be higher in CaCl₂-treated samples than calcium lactate treated ones after 9 d storage in both Kent and Tommy Atkins mangos (Figure 1). After 9 d, Kent mangos treated with calcium lactate showed no significant differences across concentrations or dip times (Figure 1A).

Due to the greater effect of CaCl₂ on firmness retention in fresh-cut mango as well as the less consistent effect of calcium lactate during storage, we focused our analysis in the remainder of this study on the CaCl₂ treatments. For both mango cultivars, treatment with a higher concentration of CaCl₂ produced a firmer fresh-cut mango texture ($P < 0.001$) (Table 1 and 2). There was no difference in firmness between the 1, 2.5, and 5 min dip times in Kent (Table 1), therefore the shortest dip time (1 min) is sufficient. The highest firmness for Tommy Atkins mango cubes was obtained with a 2.5-min dip time (Table 2). A decrease in firmness during storage at 5 °C was also found in both cultivars.

Electrolyte leakage

In general, Tommy Atkins mango cubes had higher electrolyte leakage than Kent for both untreated and treated samples (Table 1 and 2). For Kent mangos, the higher the calcium concentration applied, the lower the electrolyte leakage. The 0.204 M CaCl₂ treatment showed the most pronounced reduction in electrolyte leakage. For Tommy Atkins, there was not a consistent trend in electrolyte leakage among the CaCl₂ concentrations, and little reduction in electrolyte leakage took place, despite the firming effect of the CaCl₂ treatments. Both cultivars had lower electrolyte leakage with longer dip times ($P < 0.001$). An increase in electrolyte leakage was observed in Tommy Atkins mangos during 9 d of storage at 5 °C ($P < 0.001$), but not in Kent.

Flesh color

For both mango cultivars, the higher the CaCl₂ concentration applied, the higher the L* value, but the differences were

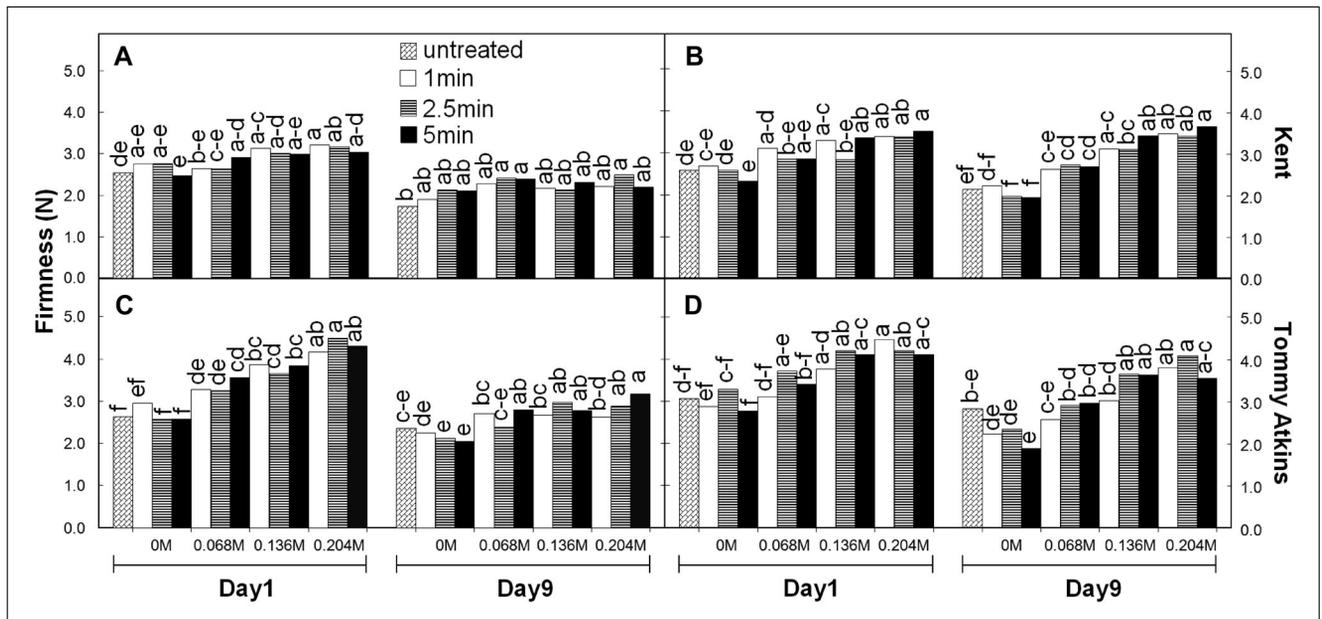


Figure 1—Changes in firmness of fresh-cut Kent (A,B) and Tommy Atkins (C,D) mangos that were untreated or dipped in calcium lactate (A,C), or in CaCl₂ (B,D) at 0.068, 0.136, or 0.204 M for 1, 2.5, or 5 min and stored at 5 °C for 1 or 9 d. For each evaluation day, values with the same letter were not significantly different ($P > 0.05$).

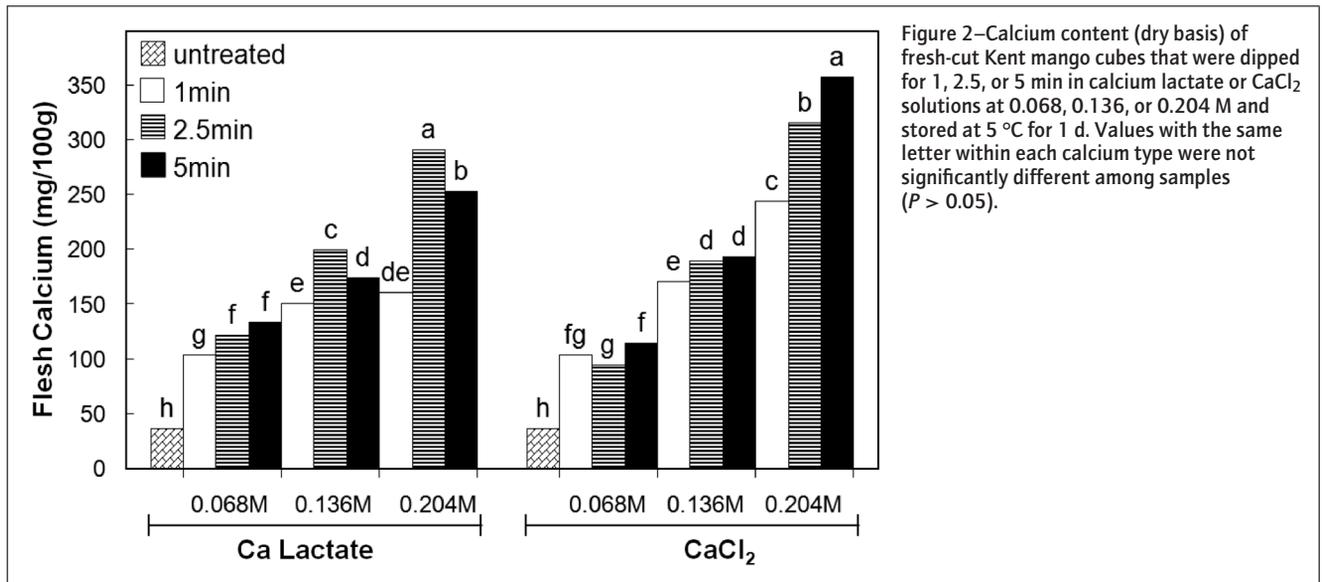


Figure 2—Calcium content (dry basis) of fresh-cut Kent mango cubes that were dipped for 1, 2.5, or 5 min in calcium lactate or CaCl₂ solutions at 0.068, 0.136, or 0.204 M and stored at 5 °C for 1 d. Values with the same letter within each calcium type were not significantly different among samples ($P > 0.05$).

not significant (Table 1 and 2). There was a significant decrease in L^* value of fresh-cut Tommy Atkins mangos during storage ($P < 0.001$) (Table 2). Both mango cultivars also showed a significant increase in a^*/b^* value throughout storage ($P < 0.001$). Tommy Atkins mangos had higher a^*/b^* values, but had a smaller increase in a^*/b^* storage as compared to Kent. Kent mangos had lower a^*/b^* values with higher calcium concentrations and shorter dip times, whereas there was no significant difference in a^*/b^* value among concentrations and dip times in Tommy Atkins mangos.

Soluble solids content (SSC) and titratable acidity (TA)

In general, Kent mangos had higher SSC, TA, and SSC/TA than Tommy Atkins mangos (Table 1 and 2). Treatment with CaCl_2 had no effect on the SSC of Tommy Atkins mangos, but it reduced SSC in Kent. In both cultivars, treatment with higher concentrations of CaCl_2 maintained higher TA and thus lowered the SSC/TA ($P < 0.001$). SSC and SSC/TA increased significantly after 6 d of storage in Kent, while TA significantly decreased in both cultivars ($P < 0.05$). There was no consistent trend due to dip time in either cultivar.

Sensory evaluation

A cluster analysis was carried out on the liking scores to determine consumer-liking groups for fresh-cut mango. Two consumer clusters were identified (Figure 3 and 4). The internal preference mapping of the consumer clusters revealed that 44.7% of the variation in consumer liking was described by the 1st 3 principal components (PC1 = 20.4%, PC2 = 13.5%, PC3 = 10.8%). The observations from the internal preference mapping were confirmed by an examination of the mean liking scores and the percentage of consumer acceptance within the 2 consumer clusters (Figure 5).

For consumer liking of fresh-cut mango products, cluster 1, the largest cluster ($n = 130$), had higher liking scores (5.8) and a greater percentage of consumer acceptance (63%) for Kent mangos over Tommy Atkins (liking score 5.1, 48% consumer acceptance). Treatments with lower calcium concentrations were also liked better by this cluster. Additionally, at a similar calcium concentration (0.136 M), this cluster significantly preferred ($P < 0.05$) the CaCl_2 -treated mangos (liking score 5.8, 61% consumer acceptance) over the calcium lactate treated samples (liking score 4.7, 42% consumer acceptance). Cluster 2 ($n = 53$) showed a clear liking for fresh-cut Tommy Atkins mango (Figure 5), and had high acceptance for all fresh-cut Tommy Atkins products over Kent, with the exception of those mango

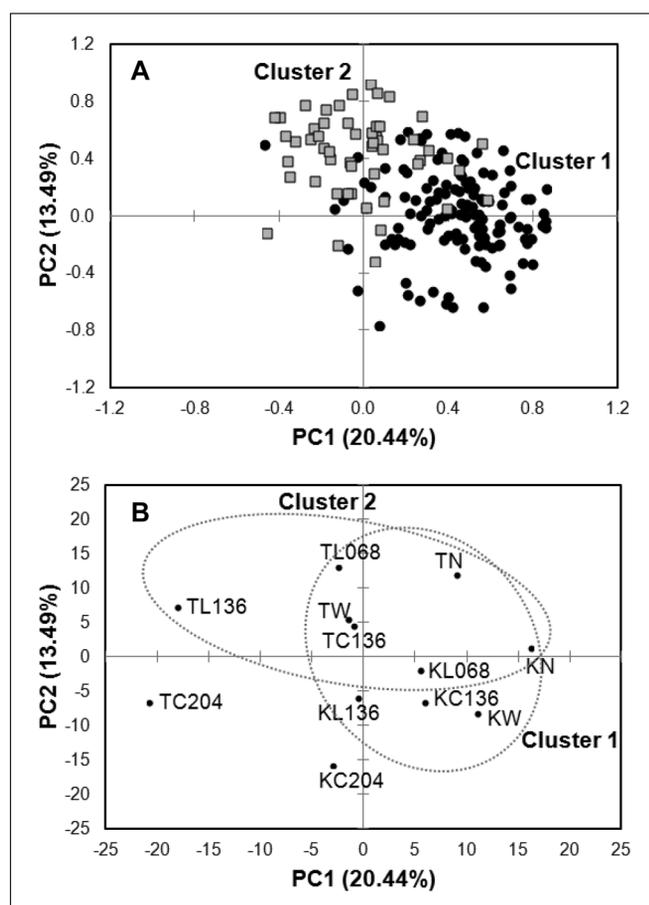


Figure 3—Principal component analysis of consumer liking (A) and of (B) of fresh-cut Kent (K) and Tommy Atkins (T) mangos treated at different concentrations (N = no treatment, W = water dipped, 068 = 0.068 M, 136 = 0.136 M, and 204 = 0.204 M) with calcium lactate (L) or CaCl_2 (C) on PC1 and PC2. Cluster 1 = closed circles; Cluster 2 = shaded squares.

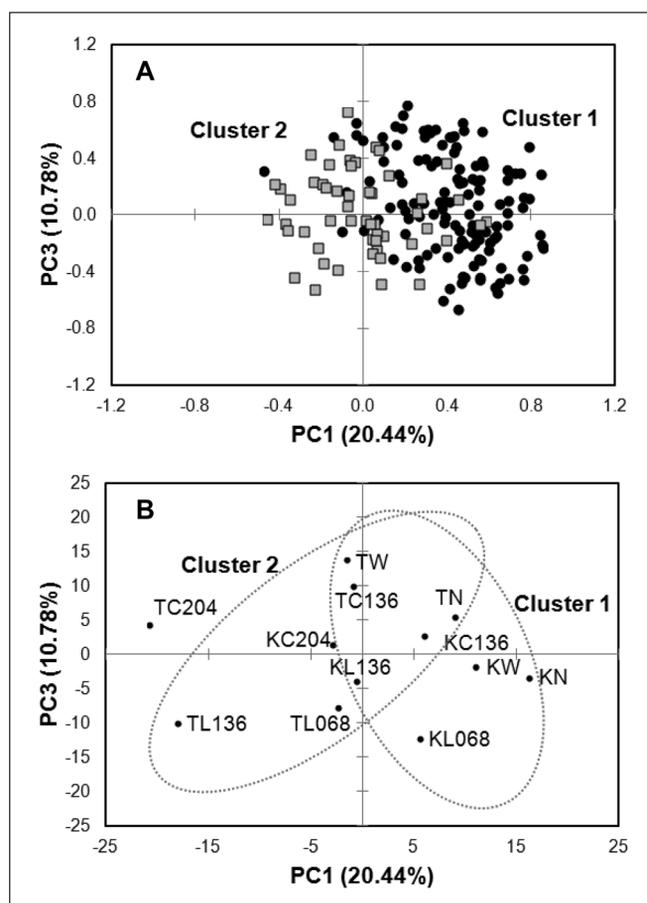


Figure 4—Principal component analysis of consumer liking (A) and of (B) of fresh-cut Kent (K) and Tommy Atkins (T) mango treated at different concentrations (N = no treatment, W = water dipped, 068 = 0.068 M, 136 = 0.136 M, and 204 = 0.204 M) with calcium lactate (L) or CaCl_2 (C) treated on PC1 and PC3. Cluster 1 = closed circles; Cluster 2 = shaded squares.

cubes treated with 0.204 M CaCl₂, the highest concentration of calcium, which were liked the least.

The factors that influenced fresh-cut mango consumers the most in their in-store buying decisions regarding fresh-cut mango were appearance and price, followed by mango variety, nutrition, organic, and packaging, respectively (Figure 6).

Discussion

Firmness

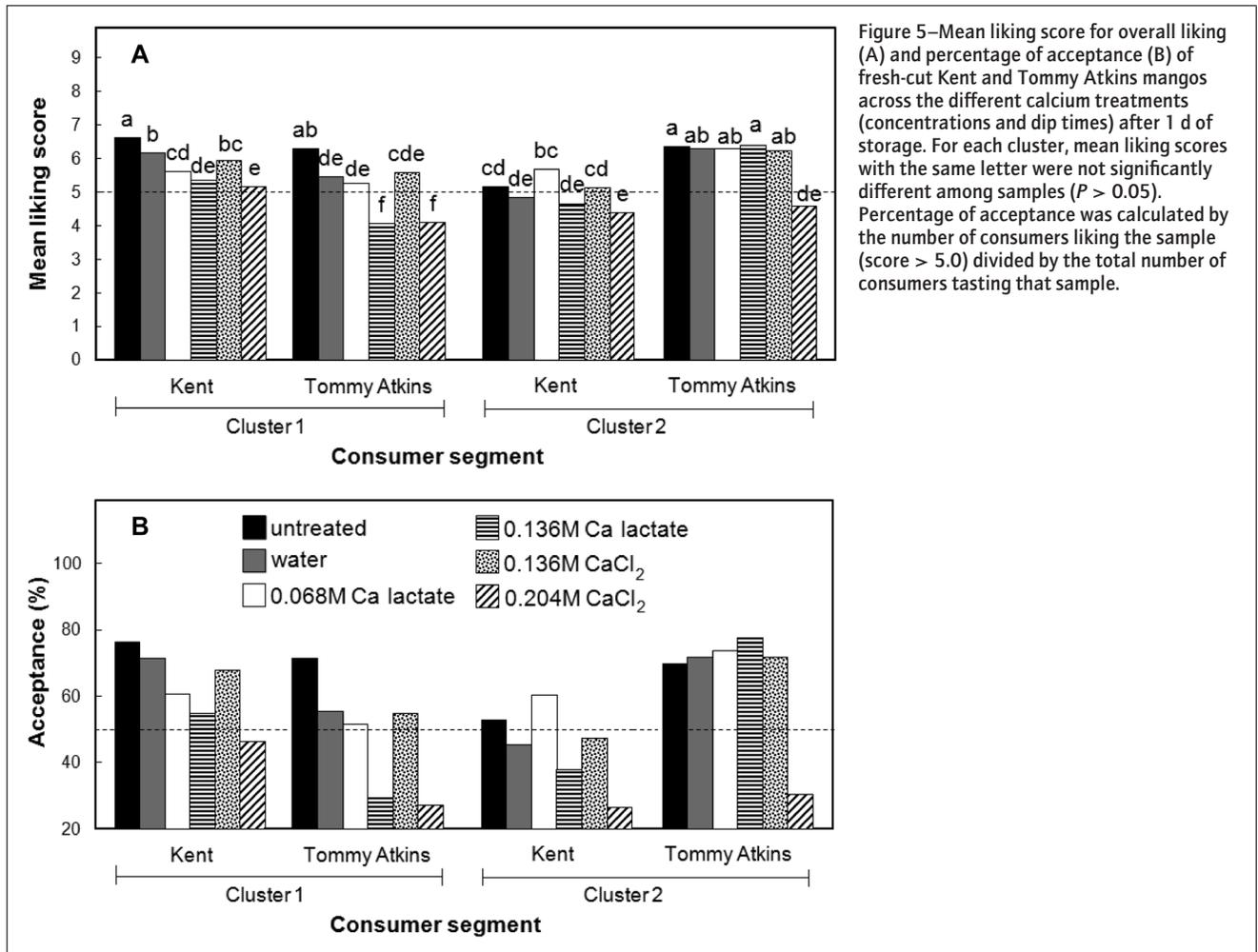
The 30 N firmness level of whole mango, measured by compression test, was recommended by Dea (2009) as an initial whole fruit firmness for fresh-cut Kent mango slice due to best overall quality and maximum shelf life under refrigerated conditions. However, we used initial firmness of 25 N, measured by penetration test, for Tommy Atkins and Kent mango in our experiment because it was preferred by mango consumers from our unpublished study.

The higher firmness and calcium content of mangos treated with higher calcium concentrations and longer dip times confirms the role of calcium in maintaining cell wall structure (Chantanawaragoon 2000; Soliva-Fortuny and Martin-Belloso 2003; Banjongsiniri and others 2004; Toivonen and Brummell 2008; Plotto and others 2010) and membranes (Demarty and others 1984; Mignani and others 1995; Picchioni and others 1996) suggested in previous reports.

In general, the firming effect of calcium can likely be explained by the cross-linking of negatively charged carboxyl groups in the de-esterified pectin of the middle lamella and cell wall to calcium ions in the calcium solutions (Harker and Ferguson 1988; Hasegawa 2006). The calcium ions may also improve mango firmness by stabilizing the plasma membrane by binding to phospholipids and proteins at the membrane surface, contributing to an increase in membrane integrity and maintenance of cell turgor pressure (Mignani and others 1995; Hirschi 2004).

In our study, mangos with higher calcium contents, for example, those treated with higher calcium concentration and longer dip times, may contain more available calcium ions to interact with the binding sites in the cell wall and plasma membrane. The firming effect of calcium-treated cubed mangos results primarily from the interaction with the cell wall and middle lamella. There was only minimal change observed in electrolyte leakage (indicating maintenance of membrane integrity) among the various calcium-treated samples, despite the firming effect, while the subsequent firming during storage may have resulted from the stabilization of calcium in plasma membrane. Similar results showing use of calcium treatments to prevent loss in membrane integrity and subsequent maintenance of textural quality during storage has also been reported in shredded carrots by Picchioni and others (1994).

A similar firming effect was found initially following both CaCl₂ and calcium lactate, but during the course of storage, a higher rate of softening was found in calcium lactate treated mangos,



as compared to CaCl_2 -treated samples. This was also found by Aguayo and others (2008) in fresh-cut "Amarillo" melons. However, other researchers (Luna-Guzman and Barrett 2000) found that calcium lactate improved the firmness of fresh-cut melon better than CaCl_2 .

Electrolyte leakage

Leakage of electrolytes, or cellular content, has been used as an index of membrane integrity during ripening, stress damage, or mechanical injury in plant tissues by previous investigators (Nyanjage and others 1999; Saltveit 2002; Dea and others 2010). The lower electrolyte leakage in calcium-treated fresh-cut mangos at higher calcium concentrations and dip times signifies a membrane stabilizing effect imparted by the exogenous calcium ions. The higher electrolyte leakage observed in CaCl_2 -treated Tommy Atkins mangos, as compared to Kent, may be due to inherent membrane permeability properties of Tommy Atkins mango, or may be due to mechanical damage during the cutting process of the higher fiber Tommy Atkins cultivar. We note that Tommy Atkins mangos have 1.6 times more crude fiber than Kent mangos (Abourayya and others 2011). An increase in electrolyte leakage in Tommy Atkins mangos during storage may also be attributed to ripening of Tommy Atkins mangos (Marangoni and others 1996) or could indicate faster deterioration of the tissue after cutting this cultivar.

Flesh color

A decrease in the L^* value (darker) of fresh-cut mangos can be used as an indicator of flesh browning (Chantanawarangoon 2000), and a higher a^*/b^* value indicates a deeper orange color (Mitcham and McDonald 1992). For both mango cultivars, a lighter flesh color was found in the CaCl_2 -treated mango cubes, indicating that CaCl_2 inhibited browning of mango flesh. This could be due to inhibition of polyphenol oxidase (PPO) activity by the chloride ion, accompanied by reduced loss of subcellular compartmentalization and subsequent leakage of PPO and its substrates due to the firming action of calcium (García and Barrett 2002). During storage at 5 °C, mango cubes of both cultivars became more orange. Tommy Atkins mangos were deeper orange at the start of the experiment and developed more browning than Kent. In addition, there was less orange color development in Kent mango cubes with higher CaCl_2 concentration and longer dip times, indicating the ability of CaCl_2 to retard ripening and maintain tissue integrity. A similar effect was not observed in Tommy Atkins mangos.

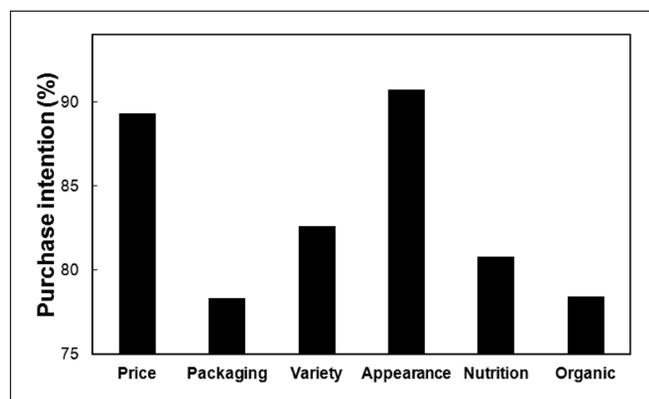


Figure 6—Influence of various factors on consumer's intent to purchase fresh-cut mango.

Soluble solids content (SSC) and titratable acidity (TA)

The higher SSC, TA, and SSC/TA in Kent mangos compared with Tommy Atkins mangos was in agreement with the findings of Rattanapanone and others (2001). The lower levels of SSC in Kent mangos and higher TA in mangos treated with higher CaCl_2 concentrations are likely due to reduced ripening. However, the increased SSC and SSC/TA during storage and decreased TA was likely due to the continued ripening during storage at 5 °C. Dea and others (2010) and Tovar and others (2001) reported that TA decreased slightly and SSC increased in whole and fresh-cut Kent mangos during storage at 5 °C. These results suggest that the fruit continues ripening after cutting; however, Dea and others (2010) found that fresh-cut mangos did not reach the same SSC level as the whole fruit.

Sensory evaluation

Mango consumers were inclined to strongly respond to mango variety, and tended to accept Kent mangos over Tommy Atkins, with greater preference for fruit treated with lower calcium concentrations or no calcium. Preliminary tests found that trained panelists could detect saltiness in the samples treated with 0.204 M CaCl_2 . In addition, mango cubes treated with CaCl_2 were favored over mango cubes treated with calcium lactate at similar calcium concentration. Because appearance and price were the most important considerations for mango consumers when making a decision for in-store purchase, maintenance of product appearance is key to improve sales of fresh-cut mango products. However, the sensory quality of the product will likely influence repeated purchases.

Conclusions

Although treatment with CaCl_2 more effectively and reliably improved fresh-cut mango firmness and color over untreated samples, calcium treatment did not improve product liking compared to untreated controls or water-treated fresh-cut mangos. However, product liking was higher in CaCl_2 compared to calcium lactate treated samples at 0.136 M calcium solution. The optimal treatment for Tommy Atkins mango cubes was a 2.5-min dip in 0.136 M CaCl_2 and for Kent a 1-min dip in 0.136 M CaCl_2 . Kent mango was more suitable than Tommy Atkins for fresh-cut processing in terms of less tissue browning and higher consumer liking.

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