Edible Coatings as Carriers of Antibrowning Compounds to Maintain Appealing Appearance of Fresh-cut Mango

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SUMMARY. Fresh-cut mango (*Mangifera indica*) slices and chunks garner an exotic image and are highly appreciated for their unique flavor and nutritional value. However, processors tend to use firm unripe mangoes to achieve shelf life of 10 to 14 days, which compromises eating quality. The post-processing life of ripe fresh-cut mangoes is limited by tissue softening, translucency, and browning. The current study was undertaken to investigate whether edible coatings can extend the shelf life of fresh-cut mangoes processed at an eating-ripe stage. Three edible coatings, carboxymethylcellulose (1% w/v), aloe (*Aloe vera*) powder (2% w/v), and whey protein isolate (2% w/v), supplemented with calcium ascorbate 2% w/v (firming agent) and the antioxidants citric acid (0.8% w/v) and acetyl-*N*-cysteine (0.4% w/v), were used. The mixture of antibrowning agents, whether applied alone or with the edible coatings, was the most effective at reducing slice browning up to 10 and 11 days at 5 °C for ‘Tommy Atkins’ and ‘Kent’, respectively. In general, there were no differences in firmness and flavor among the three edible coatings. Calcium ascorbate alone did not suppress browning consistently, whereas citric acid appeared to be the ingredient having the greatest antibrowning effect on slice quality. Citric acid can easily be used by processors of fresh-cut mangoes to prevent browning.

Mangoes (*Mangifera indica*) represent a small part of the fresh-cut industry but their popularity is growing, as reflected by the increase in sales by 8% between 2013 and 2017 in the United States

(National Mango Board, 2017), and recently ranking seventh among fresh-cut fruit sales in 2019 (Van Den Broek, 2020). Their appealing flavor and texture, and the added convenience that ready-to-eat fresh-cut products offer compared with whole fruit, are some of the main contributing drivers (Brecht et al., 2017).

The process of wounding whole fruit tissue to obtain fresh-cut fruit stimulates the development of undesirable color changes, due to enzymatic browning, and tissue softening. It also provides a

substrate for microbial growth, increasing the risk of developing pathogens (Baldwin, 2007). Therefore, fresh-cut fruit shelf life is considerably shorter than for whole fruit. To delay fresh-cut fruit deterioration, processors tend to cut mangoes on reception without pre-ripening to avoid overripe, soft, bruised, and decayed fruit (Brecht et al., 2017). Furthermore, fresh-cut mangoes must be maintained at no higher than 5 °C, both to prolong shelf life and to reduce the risk associated with potential proliferation of microbial food-borne human pathogens (U.S. Food and Drug Administration, 2017). Under these conditions, unripe fresh-cut mangoes do not fully develop their desirable sensory attributes, which may negatively affect repeat purchase by consumers. In this context, the fresh-cut mango industry needs to reach a balance between acceptable shelf life and appealing organoleptic features, to offer a high-quality product that meets the expectations of all stakeholders involved. Processing riper fruit might be a way to achieve this goal, but at the same time can increase susceptibility to wounding during processing and shorten shelf life (Beaulieu and Lea, 2003; Brecht et al., 2017; Ngamchuachit et al., 2015).

The use of edible coatings (ECs) for the purpose of extending shelf life and improving quality of fresh-cut fruit is an extensively reviewed strategy (Baldwin and Brecht, 2020; Dea et al., 2012; Ghidelli and Pérez-Gago, 2018; Yousuf et al., 2018). Delay of flesh browning and tissue softening are some of their most notable benefits. Antibrowning and/or firming agents such as calcium ascorbate, citric acid, and *N*-acetyl-L-cysteine are

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Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
1	%	g/100 mL	1
29.574	fl oz	μL	3.3814 × 10 ⁻⁵
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
4.4482	lbf	N	0.2248
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
1	ppm	μL·L ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

frequently used in the fresh-cut industry, and their incorporation into ECs is known as an effective tool to improve their efficacy. Polysaccharide-based ECs have been widely reported as good matrices to incorporate compounds with antibrowning properties in fresh-cut mango and other fruit (Benítez et al., 2015; Plotto et al., 2010; Robles-Sánchez et al., 2013; Saba and Sogvar, 2016), whereas the application of coatings based on proteins is more limited, and only a few studies with apple (*Malus domestica*) and persimmon (*Diospyros kaki*) fruit can be found in the literature (Alves et al., 2017; Ghidelli et al., 2010; Pérez-Gago et al., 2006).

This study aimed at determining how the shelf life of fresh-cut mangos processed at an eating-ripe stage could be extended by treatments with antioxidants and/or firming compounds incorporated into ECs to offset the expected shelf life limitations caused by using riper fruit. For that purpose, the influence of ECs on physico-chemical and sensory properties of fresh-cut mango were analyzed during storage at 5 °C for 14 d.

Materials and methods

PREPARATION OF THE ANTI-BROWNING COATING SOLUTIONS. All solutions were prepared with sterile deionized water and all ingredients were food grade (Table 1). Calcium ascorbate [CaAS (Sigma-Aldrich, St. Louis, MO)] was diluted to 2% (w/v) for 20 min at room temperature. The antioxidant solution (ANTIOX), was a mixture consisting of CaAS (2%), citric acid [0.8% w/v (Sigma-Aldrich)], and *N*-acetyl-L-cysteine [0.4% w/v (Sigma-Aldrich)] dispersed at room temperature for 20 min. The ANTIOX solution was applied alone or in combination with ECs. Carboxymethylcellulose sodium salt [CMC

(Sigma-Aldrich)], was dissolved (1% w/v) in warm water for 2 h, and after cooling, dextrin [0.5%, w/v, dextrin Type II from corn (*Zea mays*) (Sigma-Aldrich)] was added and the mixture was stirred for an additional 5 min. Aloe powder [ALOE (S.W. Basics, Brooklyn, NY)] was dissolved at 2% (w/v) for 20 min. Whey protein isolate [WPI (The Isopure Co., Downers Grove, IL)] was dissolved (2% w/v) for 30 min at 90 °C to induce protein denaturation. On cooling, glycerol [0.5% w/v (bioWORLD, Dublin, OH)] was added and the solution was homogenized for 4 min at 12,000 rpm using a homogenizer (Bio-Gen PRO200; PRO Scientific, Oxford, CT). ANTIOX solution was added to each EC solution at room temperature by stirring for 10 min. The concentrations of the different solutions were selected based on previous studies (Blanco-Díaz et al., 2014; Plotto et al., 2010). The pH of each solution was measured in duplicate (Table 1).

FRUIT SOURCE AND PROCESSING. ‘Tommy Atkins’ and ‘Kent’ mangoes from Mexico were purchased from the importer on arrival (Coast Tropical, Homestead, FL) and brought to the U.S. Horticultural Research Laboratory (Fort Pierce, FL). Fruit had been subjected to quarantine hot water treatments mandated by the U.S. Department of Agriculture (2016), and maintained at 12 °C during shipping. On reception, a subsample of mangoes was randomly selected and kept at room temperature to assess ripeness level by nondestructive compression firmness measurement using a texture analyzer (TA.XT *plus*; Stable Micro Systems, Godalming, UK) equipped with a 50-kg load cell and with a 5-cm-diameter flat plate (TA-25, Stable Micro Systems), and calibrated with a 5-kg weight. The tests

were performed at a crosshead speed of 0.8 mm·s⁻¹ and force was recorded at 2.5 mm deformation (Dea et al., 2013). Depending on subsample initial firmness, fruit were stored either at 13 °C (if firmness was 30 to 40 N for ‘Kent’) or 20 °C (if firmness was > 40 N for ‘Tommy Atkins’). Whole fruit compression firmness was monitored and when at least 250 mangoes ranged between 30 and 50 N (average 43.64 ± 0.40 N for ‘Tommy Atkins’, and 38.25 ± 0.58 N for ‘Kent’), processing was carried out. An average firmness of 35 N before processing was previously determined by Dea et al. (2013), and then confirmed in preliminary studies (unpublished data) as an appropriate ripeness stage for fresh-cut mango in terms of handling, visual quality, and quality maintenance during storage. In addition, simulating industry practice, whole fruit firmness was also measured after removal of the peel by penetration using an 11-mm probe. Any fruit softer than 5.5 N for ‘Tommy Atkins’ and 7 N for ‘Kent’, and firmer than 30 N (both cultivars) were discarded. Average penetration firmness was 14.12 ± 0.38 N for ‘Tommy Atkins’, and 14.96 ± 0.47 N for ‘Kent’. Mangoes were pre-washed with a fruit cleaner (JBT 395; JBT FoodTech, Lakeland, FL), then sanitized with 100 µL·L⁻¹ peroxyacetic acid [PAA (Jet-Oxide; Jet Harvest Solutions, Longwood, FL)] in warm water (30 ± 3 °C) for 3 min and air dried. Fruit were stored at 5 °C overnight. Processing was carried out at 5 °C in a cold room and all surfaces and tools were sanitized with 300 mg·L⁻¹ sodium hypochlorite (NaOCl) acidified with 2 M citric acid solution (pH 6.5), changing the solution every 10 fruit. Mangoes were manually peeled to a depth of ≈2 mm to ensure complete removal of the subepidermal

Table 1. Composition and pH of the different coating solutions applied to fresh-cut mango slices.

Solution ^a	Edible coating and concn (%)	Antibrowning agent and concn (%)	pH
CaAS	—	Calcium ascorbate, 2%	6.52
ANTIOX	—	Calcium ascorbate, 2%	3.56
		Citric acid, 0.8%	
		<i>N</i> -acetyl-L-cysteine, 0.4%	
CMC	Carboxymethylcellulose, 1% + maltodextrin, 0.5%	ANTIOX	3.75
ALOE	Aloe powder, 2%	ANTIOX	3.59
WPI	Whey protein isolate, 2% + glycerol, 0.5%	ANTIOX	3.71

^aCaAS = calcium ascorbate; ANTIOX = calcium ascorbate + citric acid + *N*-acetyl-L-cysteine; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX.

Fig. 1. Firmness of fresh-cut ‘Tommy Atkins’ and ‘Kent’ mango slices coated with different solutions stored at 5 °C (41.0 °F) for 14 d (CTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX + ANTIOX; WPI = whey protein isolate + ANTIOX). Values are means (with SE) of 10 measurements per four containers; NS = not significant between coating treatments and within a storage time; *, **, ***significant at $P < 0.05$, 0.01, or 0.001, respectively; 1 N = 0.2248 lbf.

tissue, which tends to discolor (brown) during storage. Each fruit was cut into halves on each side of the seed and then into uniform slices of 5/8-inch thickness using a commercial electric meat slicer (Della 8.7 inch; Della Products USA, City of Industry, CA), making sure most of the fruit internal fibers were parallel as much as possible. Slices were randomly distributed in sanitized colanders and dipped in the corresponding coating solutions for 30 s. They were drained and distributed in 16-fl oz polyethylene terephthalate, unvented trays with lids (model 9057; D6, Portland, OR), 13 to 15 slices per container (450 ± 50 g), leaving minimal headspace in the container. There were four containers for each coating solution and planned storage pull-out. The control (CTRL) consisted of

noncoated slices, packaged right after slicing without any water dip or rinse, as would be done in a manufacturing plant. Because of the amount of time required to process and coat the fresh-cut mangoes, physicochemical measurements and sensory evaluations were done either on the day of processing (day 0) or after overnight storage at 5 °C (day 1); subsequent measurements and evaluations were made on days 7, 11, and 14 of storage at 5 °C.

Physicochemical assessment of mango slices included firmness, color, titratable acidity (TA), soluble solids concentration (SSC), and container internal atmosphere. Measurements were taken on 10 slices per container. Firmness of fresh-cut slices was determined using a texture analyzer equipped with a 7/16-inch diameter Magness-Taylor type probe (TA-212,

Stable Micro Systems) at a speed of $0.8 \text{ mm} \cdot \text{s}^{-1}$ and recording the force at 2.5-mm deformation (Dea et al., 2013). Slices were laid on one of the two parallel flat sides, with the probe penetrating perpendicularly to the longitudinal fibers. Color was measured with a chroma meter (model CR-400; Konica Minolta, Tokyo, Japan) used as per manufacturer’s instructions. L^* , a^* , and b^* were recorded on the center of both flat sides of each of 10 slices per container. Hue angle was calculated from a^* and b^* values [$h^\circ = \arctan(b^*/a^*)$] (Plotto et al., 2010). For TA and SSC determination, samples were homogenized with distilled water (50:50, w/w) and homogenate blends were centrifuged at $15,000 g_n$ for 15 min (Avanti J-E centrifuge; Beckman-Coulter, Brea, CA). The supernatant (6.0 g) was titrated with $0.1 \text{ mol} \cdot \text{L}^{-1}$ sodium hydroxide (NaOH) to a pH 8.1 endpoint using a titrator equipped with a robotic autosampler (model 855; Metrohm, Herisau, Switzerland), a dosing interface (Dosino model 800, Metrohm) and controlling software (Tiamo v.2.5, Metrohm). SSC (percent) was determined with a digital refractometer in triplicate measurement (RX5000 α ; Atago, Tokyo, Japan). Headspace atmosphere in containers was determined with an oxygen and carbon dioxide (O_2/CO_2) analyzer (model 900141; Bridge Analyzers, Bedford Heights, OH) measured at storage temperature (5 °C).

SENSORY EVALUATION OF MANGO SLICES. Eight to 10 trained panelists performed descriptive sensory analysis of slices and rated the samples using a line scale with anchors at 0 (none) and 10 (high). Attributes were appearance (hue/color, cut-edge sharpness, flesh browning, moistness, and translucency), texture in mouth (firmness, juiciness, and melting), taste and mouthfeel (sweetness, sourness, bitterness, and astringency), and flavor (mango flavor, piney/terpene, green/unripe, fermented/fizzy, and off flavor). The panelists conducted the evaluations in individual booths at 22 °C under positive pressure and red lighting. Panelists were presented with three half slices (taken from each replicate container) on plates identified with three-digit codes. The order of presentation followed a Williams’ design

Fig. 2. Color (L^* , lightness) of fresh-cut ‘Tommy Atkins’ and ‘Kent’ mango slices coated with different solutions stored at 5 °C (41.0 °F) for 14 d (CTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX). Values are means (with SE) of 10 measurements per four containers; NS = not significant between coating treatments and within a storage time; *, **, ***significant at $P < 0.05$, 0.01, or 0.001, respectively.

(Plotto et al., 2017). A recording software (Compusense Cloud; Compusense, Guelph, ON, Canada) was used to record panelist scores.

MICROBIAL ASSESSMENT OF MANGO SLICES. At the end of the storage period (14 d), three to five random slices (average weight 80 g) were sampled from each container (experimental unit) before doing any other measurements to avoid external contamination. Slices were placed in sterile Whirl-Pak bags (Fisher Scientific, Pittsburgh, PA) containing 99 mL of sterile potassium phosphate buffer and agitated by an orbital shaker (Innova 2100; New Brunswick Scientific, New Brunswick, NJ) for 30 min to retrieve microorganisms from cut surfaces. Fifty microliters of buffer were plated on potato dextrose agar [PDA (Difco; BD, Sparks, MD)],

orange serum agar [OSA (Difco; BD)], plate count agar [PCA (Difco; BD)], and Levine Eosin Methylene Blue agar [EMBA (Remel, Lenaxa, KS)] using a spiral plater (Eddy Jet; NeuTec Group, Farmingdale, NY). The different media types were chosen to isolate a broad range of organisms. For yeast, viable bacterial, and fecal coliform cultures, plates were incubated at 31 °C for 48 h, and results were read on a colony counter (ProtoCOL; Microbiology International, Frederick, MD). For mold enumeration, plates were further incubated at 24 °C for 7 to 10 d, and visually assessed. Colony-forming units (cfu) per milliliter were determined and adjusted for sample weight. The final results were used for mean value calculations and statistical analyses.

STATISTICAL ANALYSIS. Instrumental data were analyzed by a two-way analysis of variance (ANOVA) with coating and storage as main effects using statistical software (SAS version 9.4; SAS Institute, Cary, NC). Duncan’s multiple range tests were performed to identify significant differences between samples, within storage across coating treatments, or within coating treatment across storage. Significance was defined as $P < 0.05$. Sensory data were analyzed using statistical software (SenPAQ v. 5.01; Qi Statistics, Reading, UK). A one-way ANOVA was performed for each sensory attribute within each storage date, and for each coating across storage, using a mixed model where “panelists” are random and the main effect is tested against the interaction (panelist $\times$ sample). Fisher’s least significant difference multiple comparison test was used for means separation. Microbial data (cfu/g) were analyzed by one-way ANOVA (EC treatment effect) using the statistical suite (NCSS, Kaysville, UT).

Results and discussion

FIRMNESS. Firmness loss has a considerable impact on fresh-cut fruit acceptability and is a natural process caused by enzymatic degradation of pectin and other cell wall macromolecules (Kader, 2002; Kumar et al., 2018). Although the whole fruit firmness before processing was in the same range in both experiments, ‘Tommy Atkins’ slices showed a greater initial firmness than ‘Kent’ (Fig. 1), probably because of their higher fiber content (Abourayya et al., 2011). Fruit firmness progressively declined during storage in ‘Tommy Atkins’ from an initial value of 10.5 N to a final average value of 7.09 N, with no differences among samples by day 11. The sharpest decrease was found between days 1 and 7, when ALOE-coated slices maintained the highest firmness and were significantly ($P = 0.031$) different from CTRL and CMC- and WPI-coated slices. Similarly, ‘Kent’ slices softened during storage, decreasing from 7.80 N to an average of 5.47 N. Significant differences ($P = 0.004$) between EC treatments were found on day 11 in storage, with WPI- and CMC-coated slices being firmer than all other coatings, but not different

Table 2. Titratable acidity of ‘Tommy Atkins’ (initial: 0.55% ± 0.03%) and ‘Kent’ (initial: 0.55% ± 0.04%) fresh-cut mango slices coated with the different solutions and stored at 5 °C (41.0 °F) for 14 d (N = 4).

Solution ^z	Storage (d)				<i>P</i> > <i>F</i> (storage)
	1	7	11	14	
	Titratable acidity [mean ± SE (%)] ^y				
Tommy Atkins					
CTRL	0.47 ± 0.03 b A ^x	0.44 ± 0.04 a A	0.49 ± 0.01 a A	0.43 ± 0.03 a A	0.400
CaAS	0.48 ± 0.04 b A	0.47 ± 0.02 a A	0.48 ± 0.03 a A	0.45 ± 0.02 a A	0.889
ANTIOX	0.55 ± 0.03 ab A	0.53 ± 0.04 a A	0.50 ± 0.03 a A	0.48 ± 0.04 a A	0.543
CMC	0.60 ± 0.02 a A	0.50 ± 0.04 a B	0.55 ± 0.02 a AB	0.46 ± 0.03 a B	0.022
ALOE	0.55 ± 0.01 ab A	0.53 ± 0.06 a A	0.50 ± 0.03 a A	0.44 ± 0.03 a A	0.168
WPI	0.62 ± 0.02 a A	0.48 ± 0.04 a B	0.50 ± 0.01 a B	0.48 ± 0.02 a B	0.007
<i>P</i> > <i>F</i> (solution)	0.005	0.573	0.352	0.800	
Kent					
CTRL	0.58 ± 0.03 a A	0.56 ± 0.02 ab AB	0.52 ± 0.02 a B	0.52 ± 0.01 aAB	0.091
CaAS	0.51 ± 0.05 a A	0.50 ± 0.03 b A	0.51 ± 0.03 a A	0.52 ± 0.04 a A	0.980
ANTIOX	0.51 ± 0.04 a A	0.59 ± 0.02 a A	0.54 ± 0.03 a A	0.52 ± 0.02 a A	0.205
CMC	0.52 ± 0.02 a A	0.57 ± 0.01 a A	0.46 ± 0.02 a B	0.55 ± 0.01 a A	0.001
ALOE	0.55 ± 0.03 a A	0.54 ± 0.03 ab A	0.49 ± 0.00 a A	0.52 ± 0.01 a A	0.225
WPI	0.49 ± 0.02 a A	0.50 ± 0.02 b A	0.48 ± 0.02 a A	0.55 ± 0.02 a A	0.426
<i>P</i> > <i>F</i> (solution)	0.383	0.033	0.120	0.185	

^zCTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX.

^y1% = 1 g/100 mL.

^xWithin the same cultivar, values with the same lower/upper case letters within the same column/row indicate no significant differences using Duncan’s multiple range test (*P* > 0.05), respectively.

from CTRL slices. Overall, statistical analysis revealed minimal differences among treatments for both varieties, and no clear pattern was found. ECs are known to prevent tissue softening by reducing water loss, whereas calcium, incorporated as calcium ascorbate or other salts, attaches to pectin, imparting strength to cell walls. This has been pointed out in a number of studies of fresh-cut mango (Plotto et al., 2010; Salinas-Roca et al., 2016) and other fruit, such as apple and cantaloupe (Koh et al., 2017; Kumar et al., 2018; Saba and Sogvar, 2016). However, in our study, neither coatings nor calcium ascorbate were effective in significantly delaying softening compared with CTRL samples. This could be because the mangoes in these tests were cut and coated at a more advanced ripeness stage than in previous studies (i.e., at the eating-ripe stage), and no treatment could prevent further softening.

COLOR. Decrease in *L** values is frequently associated with mango flesh becoming darker, turning from yellow or light orange to dark orange, which appears overripe (Plotto et al., 2010). In ‘Tommy Atkins’, a sharp decrease in *L** after 1 d of storage was observed, but from then on changes were negligible in most of the samples (Fig. 2). No significant differences

among uncoated and coated slices were found, with the exception of WPI-coated slices, which showed significantly (*P* = 0.025) lower *L** on day 7. These differences were not visually detected, neither by the researchers performing the analyses nor by sensory panelists (see sensory analysis section). In ‘Kent’, CTRL slices showed higher *L** values than coated samples (*P* < 0.0001) on day 1, but as storage progressed, the differences became less marked and values by the end of storage were similar to initial values. There were significant differences (*P* = 0.001) in *L** among coatings on day 11, with WPI being lighter than CaAS, ANTIOX, and ALOE-coated slices. This was an opposite result from ‘Tommy Atkins’, likely attributable to mango slice differences rather than to WPI coating.

Hue angle changes, which are indicative of color turning from light yellow to orange/red in mango fruit (Plotto et al., 2010), were calculated. ‘Tommy Atkins’ had lower hue angle values than ‘Kent’ (85.1–89.4 vs. 90.0–91.8 for ‘Tommy Atkins’ and ‘Kent’, respectively) because of its more orange flesh, but the trends observed during the course of storage were similar for both varieties. Little changes in hue angle were reported by Plotto et al. (2010) in fresh-cut

mango slices coated with similar formulations; however, those authors did observe a significant effect of antioxidants in preventing *L** from decreasing in comparison with control. Similarly, Robles-Sánchez et al. (2013) pointed out the effectiveness of alginate coatings combined with ascorbic and citric acids in maintaining higher *L** and delaying fresh-browning. In our study, instrumental color measurements did not reveal a clear effect of the antioxidants incorporated in ECs in preventing browning. Sensory visual evaluation proved to be a more effective tool in determining differences among samples, described as follows.

SSC AND TA. SSC did not show any changes between treatments nor over storage time in ‘Tommy Atkins’ slices, and ranged from 14.5% to 15.8%. There were some significant differences between treatments for SSC in ‘Kent’, with CTRL slices being higher than CaAS and ANTIOX on day 1 (16.5% vs. 15.5%) and higher than all other coated treatments on day 11 (16.0% vs. 14.9% to 15.3%). A slight decrease in SSC-coated slices (CMC, ALOE, and WPI) was observed during storage (data not shown). All treatments containing citric acid had higher TA in ‘Tommy Atkins’ slices compared with CTRL and CaAS on day 1 (Table

Fig. 3. Carbon dioxide (CO₂) concentration in containers with fresh-cut 'Tommy Atkins' and 'Kent' mango slices coated with different solutions stored at 5 °C (41.0 °F) for 14 d (CTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX). Values are means (with SE) of four measurements, one per container; NS = not significant between coating treatments and within a storage time.

2); however, this trend did not continue during storage, nor was it observed in 'Kent' slices. Only 'Tommy Atkins' slices coated with CMC or WPI exhibited a decrease in TA from its initial value (Table 2), and in 'Kent', CMC slices had lower TA on day 11 but not day 14, indicating little variation over time. Overall, SSC and TA levels demonstrated an eating-ripe ripeness stage of mango slices, in contrast to the previous retail store survey in which some recorded SSC values were as low as 10% and TA as high as 1.5% (Brecht et al., 2017).

CONTAINER INTERNAL ATMOSPHERE. Another function of coatings on fresh-cut fruit is reduction of respiration rate by the creation of a modified atmosphere around the product (Baldwin, 2007); however, in this study, O₂ and CO₂ in headspace of

containers were highly variable (CO₂ shown in Fig. 3) and there were no differences among coatings at any of the storage times. Nevertheless, CO₂ concentration showed an increasing trend in storage for all treatments except in CTRL slices, likely due to a combination of respiration by microorganisms and mango slices (see microbial assessment). Some extreme values, up to 73% CO₂ were measured in 'Kent' stored 11 d. Values above 30% CO₂ were usually associated with O₂ of ≈0.8% to 5.0%, and a slight off odor was detected on opening those containers, which dissipated quickly. In previous studies with store-bought fresh-cut mango packaged in the same container, similar extreme atmospheres (O₂ below 1% and CO₂ over 20%) were found; the extreme atmospheres is attributed to the lack

of gas exchange through the container's material (Brecht et al., 2017).

SENSORY ANALYSIS. Sensory assessment plays a key role in the study of fresh-cut products because consumer buying decisions are greatly influenced by their appearance and freshness at the time of purchase (Dea et al., 2013). Objective sensory evaluations were performed after 1, 7, and 11 d of storage by a trained panel using 17 sensory attributes. With a few exceptions, significant attributes within and across storage were mostly visual: browning, cut-edge sharpness, and translucency, as well as moistness for 'Kent'.

The most obvious changes across storage were browning of slices. At the beginning of storage, little flesh browning was noted (ratings <2.0). By day 7, browning rates increased in CTRL slices, and were significantly higher than in the coated slices on day 11 for both 'Tommy Atkins' (4.3 ± 0.8) and 'Kent' (3.8 ± 0.8) (Table 3). Ratings above 5.0 would not be acceptable. Generally, browning ratings were higher for 'Tommy Atkins' than 'Kent' slices (Table 3, Figs. 4 and 5). In 'Tommy Atkins', aqueous treatments (CTRL, CaAS, and ANTIOX) showed increased browning over storage, whereas coating treatments with film formers (CMC, ALOE, and WPI) exhibited no such difference (Table 3). Moreover, 'Tommy Atkins' CaAS-treated slices, which did not include citric acid or *N*-acetyl-L-cysteine, had scores close to 5.0 after 7 d of storage. Browning remained low (less than 2.0) for 'Kent' coated slices, even after 11 d, except for CTRL (Table 3). Hence, although instrumental measurements did not show differences in L*, panelists could perceive the darker slices under white light. The mixture of antioxidants was generally effective in preventing flesh browning, both alone and in combination with ECs. Solutions of the individual antibrowning ingredients were applied to slices under the same conditions in a preliminary study and flesh browning was visually evaluated (data not shown). Citric acid was the ingredient showing the best performance in maintaining lighter color, probably through inactivation of polyphenol oxidase by both lowering pH and chelating copper at the active site of the enzyme (He and Luo, 2007). It should be noted that browning of

Table 3. Visual browning of ‘Tommy Atkins’ and ‘Kent’ fresh-cut mango slices coated with different solutions and stored 1, 7, and 11 d at 5 °C (41.0 °F) (n = 8).

Solution ^z	Storage (d)			<i>P</i> > <i>F</i> (storage)
	1	7	11	
	Visual browning [mean ± SE (0–10 scale)] ^y			
Tommy Atkins				
CTRL	1.6 ± 1.0 a B ^x	4.1 ± 1.0 a AB	4.3 ± 0.8 a A	0.074
CaAS	0.4 ± 0.3 a B	4.8 ± 0.9 a A	4.3 ± 1.2 a A	0.011
ANTIOX	0.1 ± 0.1 a B	1.2 ± 0.6 b AB	1.3 ± 0.6 b A	0.076
CMC	0.6 ± 0.3 a A	1.1 ± 0.7 b A	1.1 ± 0.7 b A	0.548
ALOE	1.1 ± 0.7 a A	1.4 ± 0.6 b A	1.6 ± 0.7 b A	0.566
WPI	1.6 ± 0.7 a A	1.2 ± 0.6 b A	0.6 ± 0.3 b A	0.467
<i>P</i> > <i>F</i> (solution)	0.097	<0.0001	<0.0001	
Kent				
CTRL	0.9 ± 0.5 a B	2.2 ± 1.0 a B	3.8 ± 0.8 a A	0.004
CaAS	1.1 ± 0.7 a A	1.0 ± 0.5 b A	2.0 ± 0.7 b A	0.171
ANTIOX	0.9 ± 0.6 a A	0.7 ± 0.4 b A	1.1 ± 0.6 b A	0.371
CMC	0.5 ± 0.4 a B	1.0 ± 0.6 b B	1.3 ± 0.6 b A	0.011
ALOE	0.9 ± 0.6 a A	0.8 ± 0.4 b A	1.2 ± 0.5 b A	0.479
WPI	0.5 ± 0.5 a A	0.9 ± 0.5 b A	1.4 ± 0.6 b A	0.097
<i>P</i> > <i>F</i> (solution)	0.226	0.028	0.000	

^zCTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX.

^xValues above 5.0 are not acceptable.

^yWithin the same cultivar, values with the same lower/upper case letters within the same column/row indicate no significant differences using least significant difference test (*P* > 0.05), respectively.

slices remain sharp or if tissue disintegration has occurred. Cut-edge sharpness of CTRL slices was significantly lower (*P* < 0.05) than that of the coated samples, right after cutting in ‘Tommy Atkins’ (5.1 vs. 7.1–7.9) and after 11 d in storage in ‘Kent’ (4.3 vs. 6.1–7.2). ‘Kent’ slices dipped in CaAS had the highest cut-edge sharpness after 11 d (7.2 ± 0.7), suggesting CaAS maintained tissue cohesiveness in that cultivar.

Translucency is a physiological disorder caused by loss of cellular membrane integrity that results in leakage of liquid cell contents and accumulation of liquid in intercellular spaces (Tijssens et al., 2018). The effect of coating treatments on translucency was only perceived in ‘Tommy Atkins’ after 7 d in storage, with ANTIOX, CMC, and ALOE having significantly fewer translucent slices (1.6 ± 0.6 to 2.0 ± 0.7) than CTRL and CaAS (3.4 ± 1.0). Overall, translucency scores did not exceed 3.5 in both cultivars, being in an acceptable range.

Other appearance attributes such as overall hue and slice moistness were also rated. For hue assessment, 0 was considered to be pale yellow and 10 to be orange. In line with the instrumental results, ‘Tommy Atkins’ samples were rated as more orange (5.9 to 7.3) than ‘Kent’ (4.6 to 6.6), and hue values remained considerably stable over the storage period with no significant differences between coating treatments (data not shown). Uncoated fresh-cut slices were expected to show signs of dehydration at the end of the storage period; moistness ratings were between 5.1 and 7.8, and between 4.0 and 6.8 for ‘Tommy Atkins’ and ‘Kent’, respectively, without significant differences between treatments. ‘Kent’ CMC-coated slices were the only ones exhibiting a decrease in moistness rating during storage, from 7.2 initially to 4.3 after 11 d of storage (*P* = 0.003).

TEXTURE ATTRIBUTES. Firmness, juiciness, and melting were not significantly different between coatings or across storage durations for either ‘Tommy Atkins’ or ‘Kent’ (*P* > 0.05) (data not shown). Therefore, coating solutions did not affect texture in terms of mouthfeel attributes, confirming the lack of trend obtained with instrumental firmness measurements.

Fig. 4. Fresh-cut ‘Tommy Atkins’ mango slices coated with different solutions and stored at 5 °C (41.0 °F) up to 14 d (CTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX).

mango slices occurred primarily in locations where tissues had been bruised or crushed during processing as opposed to areas that had been smoothly peeled or sliced. Instrumental color measurements were taken at the center

of the cut surface of a slice and this may explain why sensory panelists were able to perceive browning that was not detected by measured *L** values.

Cut-edge sharpness ratings indicate the extent to which the corners of

Fig. 5. Fresh-cut ‘Kent’ mango slices coated with different solutions and stored at 5 °C (41.0 °F) up to 14 d (CTRL = control; CaAS = calcium ascorbate; ANTIOX = antibrowning mix; CMC = carboxymethylcellulose + ANTIOX; ALOE = aloe + ANTIOX; WPI = whey protein isolate + ANTIOX).

When applying coating solutions to fresh-cut produce, one should consider not only the absence of foreign odors/taste from the ingredients, but also the formulation should not modify the product typical taste and flavor. This study showed no effect of the applied coatings on taste or flavor of fresh-cut mango slices. However, a slight decrease in sourness [3.8 to 2.3 ($P = 0.039$)] was detected in ‘Kent’ after 11 d for CMC-coated slices.

‘Tommy Atkins’ slices stored for 1 d had higher piney/terpene flavor (3.5 to 5.0) than ‘Kent’ slices (1.9 to 3.1). Piney flavor decreased in stored ANTIOX-treated slices for ‘Kent’ ($P = 0.031$), with ratings as low as 1.0 after 11 d. Scores for green/unripe and off flavor were low, suggesting that the initial firmness was appropriate for processing the fruit and that the solutions and coatings did not confer any abnormal flavor. Overripe fresh-cut mango has been reported to have an off odor (Dea et al., 2013). Ratings for fermented flavor were low too (data not shown), indicating that no fermentative metabolism took place, in spite of extreme atmospheres in a few containers.

MICROBIAL ASSESSMENT. No statistical differences were found between EC treatments in either ‘Tommy Atkins’ or ‘Kent’ slices at the end of the 14-d storage period, indicating that neither the antioxidant solutions nor coatings significantly promoted or inhibited microbial growth relative to CTRL. In general, microbial contamination was low in all samples, because in no case were counts higher than 7.7×10^4 cfu/g. Counts were slightly higher in ‘Kent’ with values ranging from 6.9×10^3 to 5.2×10^4 cfu/g of total viable bacteria and from 8.4×10^3 to 7.7×10^4 cfu/g of aciduric and putrefactive microorganisms. Microbial loads in ‘Tommy Atkins’ ranged between 7.1×10^2 and 1.1×10^4 cfu/g for total viable bacteria and between 5.7×10^2 and 3.7×10^3 cfu/g for aciduric and putrefactive microorganisms. These results suggest that any perceived differences in flavor between treatments were not due to the presence or activity of microorganisms; however, these levels of microbial growth could account for the increased in CO_2 production after 11 and 14 d of storage (Fig. 3).

In this study, our efforts to process mangoes at an eating-ripe stage (35 N by compression firmness) were

difficult to achieve because of the large variation in fruit ripeness on arrival. Mangoes were obtained directly from the importer, as would a fresh-cut processor. Nevertheless, by adjusting ripening temperature to fruit firmness on arrival, the range of whole fruit firmness before cutting was narrowed down to 30 to 50 N, with average of 43 N for ‘Tommy Atkins’, and 38 N for ‘Kent’. Furthermore, mangoes ripen progressively from the innermost mesocarp toward the outermost tissue and often exhibit significant firmness difference between the two sides of the fruit. Thus, there was substantial slice-to-slice variability in our samples, explaining the lack of significant differences between treatments for many parameters.

‘Tommy Atkins’ responded to antioxidant solutions much more readily than ‘Kent’ by showing a reduction in slice browning. ‘Tommy Atkins’ slices treated with the antioxidant solution had a shelf life of 10 d in comparison with uncoated slices (less than 7 d), whereas ‘Kent’ slices were extended to 11 d. ECs did not add much improvement to the antioxidant solution, but they did not substantially modify fruit taste and flavor and their influence on the rest of the examined parameters was minimal.

In conclusion, antioxidants, specifically citric acid, were beneficial at maintaining the visual appearance of fresh-cut mango slices for up to 11 d, and could be recommended to processors as a simple strategy to allow marketing of ripe fresh-cut mango.

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