Modified Atmosphere Packaging for Fresh-cut ‘Kent’ Mango under Common Retail Display Conditions

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A modified atmosphere package (MAP) was designed to optimize the quality and shelf-life of fresh-cut ‘Kent’ mango during exposure to common retail display conditions. The synergism between the MAP system and an antioxidant treatment (calcium ascorbate + citric acid) was also investigated. Mango slices in trays covered with polyvinylchloride (PVC) film and an initial atmosphere of 2 kPa O2 were stored at 5 or 15 °C for 10 or 5 days, respectively. Overall sensory quality, firmness, composition, and microbial load were evaluated daily. The MAP system maintained O2 concentrations of 5–6 and 4 kPa at 5 and 15 °C, respectively; however, the corresponding CO2 concentrations were 6–8 and 16–18 kPa. The high CO2 at 15 °C resulted in softer slices compared to samples stored in air. Fresh-cut ‘Kent’ mango slices treated with the antioxidant solution had better visual quality and the shelf-life was extended by 1 d at 15 °C and by 2 d at 5 °C compared to non-treated fruit. Storage at 5 °C resulted in loss of characteristic mango aroma and development of a plastic-like odor, most likely due to the interaction between the film and the aroma volatiles, suggesting that the type of film used was not suitable for use in a MAP system for fresh-cut mango. The development of a polymeric film with a higher CO2/O2 permeability ratio would most likely enhance the positive effect of MAP on fresh-cut mango when exposed to high temperatures during retail display.

Modified atmosphere package (MAP) systems in association with low temperature are widely used to extend shelf life of fresh-cut products by reducing respiration rate, cell wall degradation, water loss, phenolic oxidation, microbial growth, and ethylene biosynthesis and action (Beaudry, 2000; Gorny, 2003). The main challenge in designing a MAP for fresh produce is to find the appropriate polymer film or perforation configuration that can provide the desired concentrations of O2 and CO2. This selection is made by matching the package permeability with the respiration rate of the produce when held in the desired modified atmosphere (MA) at a given temperature.

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

Even though the optimal handling temperature of fresh-cut fruit is 5 °C (Beaulieu and Gorny, 2004), it has been documented that at the retail level, fresh-cut fruits can be exposed to temperatures ranging from −0.7 to 16.4 °C (Nunes et al., 2009). In a previous work (Dea, 2009), an atmosphere consisting of 2 to 5 kPa O2 plus 10 kPa CO2 was found to help maintain the quality and composition of fresh-cut ‘Kent’ mango slices at a temperature between 5 and 15 °C. Moreover, the chilling injury threshold for whole mango fruit is in the range of 12 to 15 °C, depending on cultivar and fruit maturity (Abou-Azziz et al., 1976; Chaplin et al., 1991; Thomas and Joshi, 1988); however, for fresh-cut mango the fruit tissue was shown to undergo chilling stress when held at 5 °C, but not at 15 °C (Dea et al., 2010b). Consequently, it was determined that at 15 °C an atmosphere of approximately 3 to 4 kPa O2 plus a maximum of 10 kPa CO2 should be targeted for the MAP design.

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

In the fresh-cut industry, antioxidant dipping solutions are widely used to preserve the original color of fresh-cut fruits by inhibiting oxidative browning reactions (Soliva-Fortuny and Martín-Belloso, 2003). In experiments conducted previously, discoloration such as browning of fresh-cut mango slices was an important factor limiting the shelf life (Dea et al., 2010a, 2010b; Rattanapanone and Watada, 2000; Souza et al., 2006). The objectives of this study was to evaluate the effects of a MAP designed to maintain an atmosphere of 3–4 kPa O₂ with less than 10 kPa CO₂ and of an antioxidant treatment on fresh-cut ‘Kent’ mango slices shelf-life, based on visual quality, composition, texture, color and microbial load, during common retail display conditions (i.e., 5 and 15 °C).

Materials and Methods

Plant Material. A total of 244 ‘Kent’ mangoes from Guatemala (12 boxes of each size 7, 8, and 9; i.e., 7, 8, or 9 fruit per 4.5-kg carton) were received directly from an importer in Pompano Beach, FL, in May 2009. The fruit were brought to the University of Florida within 5 h. Due to unexpected delays during transportation from Guatemala to Florida, the fruit were quite variable in firmness (average fruit firmness ± standard deviation was 53.8 ± 19.13 N for size 7, 41.0 ± 12.2 N for size 8, and 41.4 ± 13.7 N for size 9). Upon arrival, 70 fruits of similar firmness were selected, and the remaining fruit were stored at 15 °C and allowed to ripen slowly in order to be used a few days later in the second experiment (E2). The average firmness of the mangoes selected for processing was 34.8 ± 4.4 N for E1 and 38.4 ± 8.0 N for E2. Whole fruit firmness was measured using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a flat plate probe (5-cm diameter), and equipped with a 50-kg load cell. After establishing zero force contact between the probe and the equatorial region of the fruit, the probe was driven with a crosshead speed of 0.8 mm·s⁻¹. The force was recorded at 2.5 mm deformation.

Preparation of fresh-cut slices. The fruit were processed in a sanitized cold room with a temperature of 5 °C. Before being peeled, all mangoes were immersed for 3 min in a (1.3 mM) sodium hypochlorite solution (NaOCl, Clorox®, Oakland, CA) at 5 °C, adjusted to pH 7 with 2 N citric acid solution (Fisher Scientific Company LLC, Pittsburgh, PA). The peeled mangoes were submerged in a second sodium hypochlorite solution (1.3 mM) at 5 °C for 1 min, and left to drain until they were processed (5–15 min).

Each mango was halved and cut into eight longitudinal slices, and all mango slices from the same treatment were pooled together and randomized before being distributed into the containers for an approximate total of 300 g (about eight random slices per container). The weight of each individual sample container was recorded.

For the MAP + Aox treatment, the slices were dipped in a 0.13 mM NaOCl solution for 30 s at 5 °C, drained for 30 s and then dipped in a solution of 51 mM (2%) calcium L-ascorbate dehydride (Sigma-Aldrich Co., St. Louis, MO) and 52 mM (1%) citric acid for another 30 s at 5 °C (Plotto et al., 2006). The slices were then drained for 2 min before being distributed into storage containers as previously explained.

A total of four sample containers of fresh-cut slices per treatment were used for each sampling time for analysis.

MAP system design. In previous work with fresh-cut ‘Kent’ mango stored in CA, it was determined that the respiration rate (RR; CO₂ production) of fresh-cut slices in an atmosphere of 3–4 kPa O₂ plus 10 kPa CO₂ at 15 °C was about 30 mg·kg⁻¹·h⁻¹ (Dea, 2009). The O₂ permeability of the stretch PVC Omni film (PVC-RMF 61, Goodyear, OH) that was selected for this MAP system was 2.3 × 10⁻² mL-mil·cm⁻²·h⁻¹·atm⁻¹ and the CO₂/O₂ permeability ratio was 6.1:1 (Exama et al., 1993). The film transmission requirements were established to match the RR of fresh-cut mango slices at 15 °C and to achieve an atmosphere 3 to 4 kPa O₂ inside the package. The film O₂ permeability requirements were calculated with the following mass balance equations for O₂ and CO₂:

\[
\begin{align*}
\left[ \frac{[M_{O_2}PV]}{100RT} \right] \frac{d[O_2]}{dt} & = \left( \frac{SP_{O_2}}{L} \right) \left( [O_2]_i - [O_2]_i \right) - W_{O_2} \quad \text{(Eq. 1)} \\
\left[ \frac{[M_{CO_2}PV]}{100RT} \right] \frac{d[CO_2]}{dt} & = \left( \frac{SP_{CO_2}}{L} \right) \left( [CO_2]_i - [CO_2]_i \right) - W_{CO_2} \quad \text{(Eq. 2)}
\end{align*}
\]

where \( M_{O_2} \) and \( M_{CO_2} \) are the molecular weight of \( O_2 \) (0.032 kg·mole⁻¹) and \( CO_2 \) (0.044 kg·mole⁻¹); \( P \), the pressure in the package; \( V \), the free volume in package (mL); \( R \), the universal gas constant (8.3141·mol⁻¹·K⁻¹); \( T \), the absolute temperature (K); \( S \), the package surface area (m²); \( P_{O_2} \) and \( P_{CO_2} \), the permeability to \( O_2 \) or \( CO_2 \) (mL·mil·cm⁻²·h⁻¹·atm⁻¹); \( L \), the thickness of the film (mm); \( [O_2] \) and \( [CO_2] \), the percentage of \( O_2 \) or \( CO_2 \) concentrations; \( W \), the weight of one atmosphere; \( W \), the product weight (kg) and \( R_{O_2} \) or \( R_{CO_2} \), the rate of \( O_2 \) consumption or \( CO_2 \) evolution (mg·h⁻¹) per kilogram of fruit, and with the subscripts “i” and “o” that denote the inside and outside of the package (Yam and Lee, 1995). For 300 g of mango slices in a container with a volume of 591 mL and a surface area of approximately 169 cm², two layers of the PVC Omni film were required in order to achieve the desired O₂ concentration.

Preparation of MAP. For air-control samples, approximately 300 g of fresh-cut slices were placed in 591-mL rigid Ziploc® containers with the lid loosely closed (i.e., not airtight). For the MAP and MAP + Aox samples, each container was covered with two layers of the stretch PVC Omni film and sealed by overlapping and pressing together the sides of the film at the base of the container.

Each container was carefully flushed with nitrogen (N₂) until an atmosphere of 2 kPa O₂ inside the container was determined to have been obtained by measuring with an O₂-CO₂ gas analyzer (Checkmate 9900; PBI Dansensor, Ringsted, Denmark). The samples were stored at 5 or 15 °C, for 10 or 5 d, respectively. The atmospheres inside all of the MAPs were measured daily with the O₂-CO₂ gas analyzer. Four sample containers were removed from storage at each sampling time.
**Subjective quality evaluation.** The visual quality fresh-cut mango slices was assessed subjectively using 9-point visual rating scales for overall color, edge tissue damage, spoilage, aroma, and desiccation, with higher numbers corresponding to better quality (Beaulieu and Lea, 2003). Quality evaluations were performed on four sample containers selected randomly on days 2, 3, 4, and 5 for the samples stored at 15 °C, and on days 3, 5, 8, and 10 for the samples stored at 5 °C. All visual evaluations were performed by the same trained person.

**Firmness evaluation.** Firmness of fresh-cut slices was measured using an Instron Universal Testing Instrument (Model 4411) fitted with a 1-cm-diameter convex probe, and equipped with a 50-kg load cell. After establishing zero force contact between the probe and the largest flat side of each slice, the probe was driven with a crosshead speed of 50 mm·min⁻¹. The force was recorded at 2.5-mm deformation. The measurements were made on the cut surface of four fresh-cut slices per sample container approximately 30 min after transfer to room temperature for the slices stored at 5 °C and within minutes after transferring the samples to room temperature for the slices stored at 15 °C.

**Flesh color measurements.** Superficial flesh color measurements (L*, a*, b*) were taken with a reflectance colorimeter (Minolta CR 200h, Minolta Corp., Ramsey, NJ) on the cut surface of mango slices. There were 10 measurements made per treatment on 10 slices from four sample containers. Numerical values of a* and b* were converted into hue angle (H° = tan⁻¹ b*/a*) (Francis, 1980).

**Compositional measurements.** Samples destined for compositional analysis were homogenized and kept frozen at −20 °C in airtight plastic freezer bags until used.

**pH, titratable acidity, and soluble solids content.** The content of each individual sample container was thawed, and a 50-g aliquot of the tissue slurry was centrifuged at 17,600 g for 25 min. The clear juice was decanted from the centrifuge tubes and the pH and TA were determined using a digital titrator (model 719 S’Titroino; Metromoh Ion Analysis Ltd., Herisau, Switzerland). Aliquots (6.00 g) of mango juice were diluted with 50 mL distilled water and the TA determined by titration with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2. The TA was expressed as percent citric acid. The SSC of the resulting clear juice samples was determined with an Abbe refractometer (Cambridge Instruments, Inc., Buffalo, NY) and expressed as percent juice fresh weight.

**Microbial evaluation.** To determine the microbial load on the fresh-cut mango slices, 5-g samples of mango tissue (one sample per package) were placed in sterile centrifuge vials with 45 mL phosphate buffered saline (PBS) adjusted to pH 7.4 with 0.1 M HCl and agitated with a reciprocal shaker (Eberbach Corporation, Ann Arbor, MI) at 60 oscillations/min for 5 min. Appropriate dilutions of the resulting liquid were spread onto 3M Petrifilm™ Aerobic Count Plates and incubated for 48 h at 30 °C to estimate total aerobic mesophilic microbial population. Yeast and mold populations were estimated on 3M Petrifilm™ Yeast and Mold Count Plates incubated for 120 h at 25 °C. Microbial analyses were performed on the day of preparation of the fresh-cut mango slices, immediately after cutting; after holding the fresh-cut mango for 3 d at 5 °C or 15 °C; and at the end of the shelf life for each treatment, as determined by the visual subjective evaluation.

**Statistical analysis.** Analysis of variance (ANOVA) was performed using the General Linear Model to identify significant main effects due to the experiment replicates, MAP treatments, and storage duration, using the PC-SAS software package (SAS Institute, version 9.1, Cary, NC). Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. For the microbial analysis, means ± standard deviations were used.

**Results**

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

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

**Subjective quality evaluation.** During storage at 5 °C and regardless of the treatment, more edge damage, spoilage, and desiccation, and less off-odor were noticed for slices from E1 than from E2 (Fig. 2). This difference may be attributed to the use of firmer fruit in E2 than in E1. At 5 °C, MAP + Aox treated slices had better color retention, and developed less edge damage, off-odor development, and desiccation than the slices in MAP without Aox treatment. Slices held in air (control) at 5 °C had the lowest scores for all quality attributes (Fig. 2). Moreover, less indications of microbial spoilage (i.e., development of slimy and gooey surface) were noticed for slices in the MAP and MAP + Aox treatments compared with the air controls.

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

At 15 °C, better overall color, along with less edge damage, spoilage, and desiccation were noted for slices from E1 compared with E2 (Fig. 3). Overall, as noted for 5 °C, the MAP + Aox slices retained better color and developed less edge damage, off-odor development, spoilage, and desiccation than the MAP slices without Aox, followed by the air control. The visual quality decreased rapidly at 15 °C and therefore the shelf life was limited to 4 d, for both the control and the MAP samples. Control samples showed evidential signs of spoilage (i.e., apparent microbial colonies) on day 4. In addition, the slices were agglomerated and a musty...
Fig. 1. Oxygen (O\textsubscript{2}) and carbon dioxide (CO\textsubscript{2}) concentrations measured in MAP containers of fresh-cut mango slices stored at 5 °C or 15 °C ± standard deviation (day 0, n = 28, days 1–10 (5 °C) or 1–5 (15 °C), n = 8) for two replicate experiments.

Fig. 2. Subjective visual evaluation during storage at 5 °C for fresh-cut ‘Kent’ mango slices from air (control) or from MAP with or without antioxidant (Aox) treatment for two replicate experiments. 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/ or loss; 1 = poor, inedible. A score of 5 represents the minimum subjective score (limit) for marketing.
odor was perceived. For the samples in MAP, the development of browning, edge bruising, and mushy tissue were the limiting shelf life attributes. The MAP + Aox treatment extended the shelf life to 5 d at 15 °C, and subsequently quality was compromised by desiccation, which caused the slices to stick together in the container, a sign of lack of freshness.

Firmness. The slice firmness at 5 °C in E1 was lower than in E2, reflecting the difference in the initial whole fruit firmness (Table 1; Fig. 4). Firmness was not significantly affected by the MAP (with or without Aox treatment) (Table 1). Similarly, at 15 °C the slice firmness was lower in E1 than E2, and the firmness decreased significantly by the end of the storage period (Table 2; Fig. 5). Overall, slices held in MAP were softer than slices from the MAP + Aox treatment or the air control (Fig. 5).

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

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

pH, TA, and SSC. Slices from E1 stored at 5 °C had higher pH than slices from E2 (Table 1; Fig. 6). MAP + Aox treated slices had lower pH than the MAP and air-control slices, which had similar pH levels (Fig. 6). The TA of the slices from E1 was higher than from E2, but TA was not significantly affected by MAP or MAP + Aox (Table 1). The SSC from slices stored at
5 °C was not significantly different between the fruit from E1 and E2 (Table 1). However, the SSC was lower in the MAP + Aox treated slices than in MAP and air-control slices, which had similar SSC (Fig. 6).

The pH of the mango slices from E1 stored at 15 °C was higher than that of mango slices from E2 (Table 2; Fig. 7). Slices from MAP + Aox stored at 15 °C had lower pH than slices in MAP or air control slices, which had similar pH (Fig. 7). Also, pH tended to increase over time at 15 °C, regardless of treatment (Fig. 7), however, when the treatments were analyzed separately by regression analysis, it was found that pH increased during storage only for the MAP + Aox treated slices, while ANOVA showed no significant treatment effect. TA of mango slices stored at 15 °C declined slightly over time in both experiments, with no significant differences among the treatments (Table 2; Fig. 7). There was not a significant effect of experiment, treatment or treatment duration on the SSC of mango slices stored at 15 °C (Table 2). However, for both experiments there was a slight decline in the SSC content of the slices over time, regardless of the treatment (Fig. 7).
Fig. 5. Firmness and flesh color (L* value and hue angle) of fresh-cut ‘Kent’ mango slices stored at 15 °C, in air (control), or in MAP with or without antioxidant treatment (Aox) ± standard deviation (n = 16 for firmness, n = 10 for L* and hue angle) for two replicate experiments. (Note: data missing for initial firmness measurement for Experiment 2).

Table 2. ANOVA table for firmness, color, pH, titratable acidity (TA), and soluble solids content (SSC) of fresh-cut ‘Kent’ mango stored at 15 °C

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

Fresh-cut mango slices from E1 and E2 (E) were held in MAP, MAP + Aox or in air (T) at 15 °C for 5 d (D). Nonsignificant or significant at P < 0.05, 0.01, or 0.001, respectively.
MICROBIAL EVALUATION. Immediately after processing, the total aerobic mesophilic microbial population on the fresh-cut mango slices was 4.2 ± 0.3 log CFU/g in E1 and 4.5 ± 0.5 log CFU/g in E2 (Table 3). After 8 d at 5 °C, the aerobic microbe population increased to 7.1 ± 1.0 log CFU/g in E1 and to 7.4 ± 0.7 log CFU/g in E2 for the air control treatment and, increased to 6.6 ± 0.8 log CFU/g in E1 and to 8.3 ± 0.7 log CFU/g in E2 for the MAP treatment. After 10 d at 5 °C, the aerobic microbe population in the MAP + Aox treatment increased to 5.9 ± 1.0 log CFU/g in E1 and to 6.7 ± 0.1 log CFU/g in E2 (Table 3). However, the differences among the treatments were not statistically significant.

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

The yeast and mold populations on the fresh-cut mango slices stored at 5 °C were initially 3.0 ± 0.0 log CFU/g in E1 and 2.2
Fig. 7. pH, titratable acidity, and soluble solids content of fresh-cut ‘Kent’ mango slices stored at 15 °C, in air (control), or in MAP with or with antioxidant treatment (Aox) ± standard deviation (n = 4) for two replicate experiments.

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

<table>
<thead>
<tr>
<th>Storage duration (days)</th>
<th>Initial</th>
<th>Day 3</th>
<th>Day 8</th>
<th>Day 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control (air)</td>
<td>MAP</td>
<td>MAP+Aox</td>
<td>Control (air)</td>
</tr>
<tr>
<td>Total aerobic count (log CFU/g)</td>
<td>4.2 ± 0.3</td>
<td>5.3 ± 0.2</td>
<td>4.4 ± 2.0</td>
<td>7.1 ± 1.0</td>
</tr>
<tr>
<td>Yeast and mold (log CFU/g)</td>
<td>3.0 ± 0.0</td>
<td>3.4 ± 0.5</td>
<td>2.8 ± 0.3</td>
<td>6.0 ± 0.6</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Total aerobic count (log CFU/g)</th>
<th>Yeast and mold (log CFU/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experiment 1</td>
<td>Experiment 2</td>
</tr>
<tr>
<td>Initial</td>
<td>4.2 ± 0.3</td>
<td>4.5 ± 0.5</td>
</tr>
<tr>
<td>Day 3</td>
<td>8.7 ± 0.0</td>
<td>7.5 ± 0.7</td>
</tr>
<tr>
<td>MAP</td>
<td>7.0 ± 0.7</td>
<td>5.8 ± 0.5</td>
</tr>
<tr>
<td>MAP + Aox</td>
<td>6.5 ± 1.0</td>
<td>5.0 ± 0.6</td>
</tr>
<tr>
<td>Day 4</td>
<td>8.6 ± 0.2</td>
<td>---*</td>
</tr>
<tr>
<td>MAP</td>
<td>7.9 ± 0.2</td>
<td>7.4 ± 0.1</td>
</tr>
<tr>
<td>MAP + Aox</td>
<td>7.9 ± 0.1</td>
<td>8.0 ± 0.7</td>
</tr>
</tbody>
</table>

*Data missing.

++ 0.3 log CFU/g in E2 (Table 3). After 8 d at 5 °C, the count increased to 6.0 ± 0.6 log CFU/g in E1 and 6.4 ± 1.1 log CFU/g in E2 for the air control, and to 6.3 ± 0.5 log CFU/g in E1 and 5.7 ± 0.3 log CFU/g in E2 for the MAP treatment. After 10 d at 5 °C, the yeasts and mold populations for the MAP + Aox treatment increased to 5.8 ± 0.6 log CFU/g in E1 and 5.1 ± 0.2 log CFU/g in E2. There were no significant differences in yeasts and mold populations among the treatments for E1, but in E2, lower yeasts and mold counts were observed in the MAP + Aox treatment than in the air-control and MAP treatments.

After 4 d at 15 °C, the yeasts and mold population in MAP increased to 6.4 ± 0.7 log CFU/g in E1 and 6.5 ± 0.2 log CFU/g in E2 (Table 4). For MAP + Aox treated slices, the yeasts and mold increased to 6.6 ± 0.3 log CFU/g in E1 and 6.4 ± 0.8 log CFU/g in E2. Due to an error in sample dilution, there were no results for yeasts and mold populations in the air control treatment at 15 °C.

Discussion

Oxygen and Carbon Dioxide Concentrations in MAP. When exposed to 15 °C, the MAP system containing fresh-cut mango slices maintained the desired O₂ level of 4 kPa. However, higher than desired CO₂ levels built up inside the packages, reaching approximately 17 kPa. These levels of O₂ and CO₂ suggest that fermentative metabolism was partially engaged in the fresh-cut mango slices at 15 °C; however, there was no indication of fermentative metabolism in the CA experiments that preceded this work (Dea, 2009). In contrast, at 5 °C, the CO₂ concentration increased to 8 kPa, but, by the end of storage, it had decreased to 5 to 6 kPa. Since the MAP was designed based on the previously measured RR of mango slices exposed to 15 °C, exposure to the lower temperature (5 °C) resulted in lower RR that led to maintenance of higher O₂ concentration in the package. Thus, O₂ partial pressure inside the MAP at 5 °C ranged from 5 to 6 kPa. Since, in general, the effect of low temperature is greater than the effect of a MA (Rattanaparone et al., 2001), in this study the effect of low temperature most likely mitigated the effects of reduced O₂ concentration and elevated CO₂.

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

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

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

Loss of firmness in MAP at 15 °C, as indicated by lower firmness measurements and development of mushy tissue, may be attributed to the supraoptimal CO₂ concentration measured (16–18 kPa CO₂). The effect of elevated CO₂ on firmness varies among fresh-cut products. For example, a 5 to 40 kPa CO₂ atmosphere promoted gradual tissue softening of 'Kensington' mango slices, stored at 3 °C (de Souza et al., 2006). On the other hand, high CO₂ atmospheres of 3%, 5%, and 10% did not have deleterious effects on the texture, respiration rates, ethanol content, ascorbic acid content, and bacterial count of ‘Carabao’ and ‘Nam Dok Mai’ mango cubes stored at 5 and 13 °C (Poubol and Izumi, 2005). Exposure of kiwifruit slices to 10 kPa CO₂ resulted in maintenance of higher slice firmness than air-control slices (Agar et al., 1999). Furthermore, the texture of pear, peach, and persimmon slices was not affected by exposure to 20 kPa CO₂ during storage at 5 °C (Gorny et al., 2002; Wright and Kader, 1997a, 1997b).

The CO₂ concentration of 10 kPa was chosen for the development of the MAP system for fresh-cut mango slices, because it was previously determined that firmness was greater in 'Kent' mango slices stored in CA consisting of air or reduced O₂ plus 10 kPa CO₂, compared with slices stored in reduced O₂ plus 0 or 20 kPa CO₂ (Dea, 2009). It was therefore suggested that 20 kPa CO₂ was not suitable for 'Kent' fresh-cut mango slices. In addition, visual quality of slices exposed to 20 kPa CO₂ was poor and not different from the control samples stored in air (Dea, 2009).

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

At the end of shelf life, the fresh-cut mango slices stored in MAP at 5 °C had no fruity notes compared to the slices stored in air, which maintained the characteristic aroma of mango fruit. The altered atmosphere could have inhibited the ripening processes and thus inhibited aroma volatile biosynthesis during storage at 5 °C. It is possible also that the lack of mango aroma was related to sorption or permeation of the volatiles. It is known that MAP...
may directly impact the aroma of the contained product due to interactions between aroma compounds and packaging materials (Mattheis and Fellman, 2000). In fact, volatile loss can occur through sorption (i.e., scalping) of the volatile compounds on the film or permeation through the film (Brody, 2002), thus reducing or enhancing the loss of flavor volatiles depending on their chemical properties (Forney, 2007). Moreover, polymer films differ in their rates of transmission for volatiles compounds, just like for O$_2$ and CO$_2$ (Mount and Wagner, 2001). Also, under a low temperature and high humidity environment, like the one found in MAP, the loss of flavor can be enhanced due to the rate of sorption of gaseous flavor volatiles, which unlike liquids, increases with low temperature (Paik and Wagner, 2001).

Moreover, during storage at 5 °C, an unexpected plastic-like odor was perceived in mango samples when the MAP containers were opened. This off-odor was detectable for 1 to 2 h after opening. The appearance of a plastic odor could be due either to the migration of odorous substance from the PVC package material to the fruit to package headspace, or due to the reaction of substances in the film with each other or with the fresh-cut product (Baner et al., 2008). Moreover, retention of this plastic smell was probably greater at 5 °C than 15 °C due to slower permeation and off-gassing at the lower temperature. The interaction between fruit aroma volatiles and the packaging material used in this study needs further investigation.

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

MAP + Aox treated samples had lower pH than MAP and air-control samples, which were similar. This difference in pH can be attributed to the use of citric acid in the anti-browning dip solution, which has been widely accepted as effective in reducing superficial pH of cut fruits (Soliva-Fortuny and Martín-Belloso, 2003).

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

Bai et al. (2001) reported that active MAP (4 kPa O$_2$ plus 10 kPa CO$_2$), combined with low temperature storage (5 °C) slightly reduced bacterial and yeast and mold counts in fresh-cut cantaloupe. Under the same conditions, Rattanapanone et al. (2001) showed that compared with samples stored in air, the marketable period of mango cubes could be extended by 1 to 2 d in MAP, due to a significant decrease of both mesophilic aerobic and yeast and molds counts.

During this study, large variations among the samples (large standard deviations) were measured, leading to an uncertain conclusion regarding the effect of the MAP on the microbial load of fresh-cut mango slices. Nevertheless, a beneficial effect of MAP on the total aerobic counts was observed during storage at 15 °C, in which lower counts were present in the MAP and MAP + Aox treated samples than in the air-controls vs. no differences among the treatments during storage at 5 °C. In E1, the yeast and mold count was not affected by any treatment, but in E2 the count was lower in MAP + Aox treated samples stored at 5 °C. No significant differences among the treatments were observed for fresh-cut mango slices stored at 15 °C for the yeast and mold count.

**Conclusion**

This study evaluated the effect of a MAP system with or without an antioxidant dip treatment on the quality of fresh-cut ‘Kent’ mango slices stored at 5 or 15 °C. The MAP system used was efficient in maintaining the targeted 3 to 4 kPa O$_2$ concentration during storage at 15 °C. However, 17 to 18 kPa CO$_2$ developed inside the packages, resulting in mango slices that were softer than samples stored in air. The development of a new type of polymeric film tailored to the required CO$_2$/O$_2$ selectivity of 8 would be necessary in order to enhance the positive effect of MAP on fresh-cut mango when exposed to non-chilling temperatures. Further research is also required to better define the anaerobic compensation point for fresh-cut mangoes in a reduced O$_2$ plus elevated CO$_2$ environment.

An antioxidant dip applied to ‘Kent’ fresh-cut mango slices in combination with MAP resulted in better firmness and visual quality and extended the shelf life of the product by 1 d at 15 °C and by 2 d at 5 °C. The loss of characteristic mango aroma during storage at 5 °C was most likely due to interaction between the film and the aroma volatiles, while the plastic-like odor that developed apparently came from the PVC film.

Consequently, it can be concluded that the PVC film applied in this study is not suitable for use in a MAP system for mango fruit. It is also apparent that proper handling at low temperature (5 °C) remains the most critical practice for maintaining fresh-cut mango quality.

**Literature Cited**


Dea, S. 2009. Establishment of favorable physical and environmental
conditions for the optimization of the total product quality of fresh-cut ‘Kent’ mango. PhD Diss., Univ. of Fla., Gainesville.


