Sanitary dips with calcium propionate, calcium chloride, or a calcium amino acid chelate maintain quality and shelf stability of fresh-cut honeydew chunks

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Abstract

Freshly cut honeydew chunks were dipped for 30 s in a solution containing 1.9 mM hypochlorous acid (ClO) without or with a 40 mM concentration of calcium (Ca) propionate, Ca amino acid chelate formulation (Ca chelate), calcium chloride (CaCl₂), or not treated. Respiration and ethylene production rates, firmness, translucency, microbiological and sensory characteristics, surface color, volatile abundance, and tissue calcium content were evaluated during 7 d at 10 °C. Nontreated samples developed the highest respiration and ethylene production rates during storage, followed by samples dipped in ClO, ClO+CaCl₂ or ClO+Ca chelate, and ClO+Ca propionate. Calcium salt and chelate treatments more than doubled tissue Ca content and inhibited changes in melon firmness, surface color, and the development of tissue translucency during storage. Treatment with ClO alone increased tissue translucency development, but inhibited surface microbial development. Microbial development was higher on nontreated melon samples than on ClO+Ca propionate-treated samples. Total quality-associated volatile abundance increased throughout storage and was higher in ClO+Ca propionate-treated samples than in other treated and nontreated samples. No sensorial preference was observed by consumer panels among ClO-, ClO+Ca propionate-, or ClO+Ca chelate-treated samples. The results indicate that a sanitary dip with Ca is a better alternative to a sanitary dip alone for quality maintenance and shelf-life stability of fresh-cut honeydew melon tissue.

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Keywords: Firmness; Fresh-cut; Melon; Microbiology; Postharvest physiology; Sensory analysis; Translucency; Volatiles

1. Introduction

Fresh-cut honeydew melons (*Cucumis melo* L. (Inodorus Group)) are a common component of fresh-cut fruit products and are available year-round throughout the United States. Quality maintenance and shelf-life extension of fresh-cut
products are important to the industry because of their economic impact. Honeydew melons are climacteric fruit with high respiration (Pratt et al., 1977) and ethylene production rates (Miccolis and Saltveit, 1991; Pratt et al., 1977), particularly among the widely grown hybrids (Kevin Crosby, personal communication), that make the fresh-cut products highly perishable, especially when temperature is not strictly controlled. Fresh-cut honeydew has a retail shelf-life of 2–5 d in air (Qi et al., 1999), less than half that desired in the distribution chain (Anonymous, 1996). In retail stores, the temperature fluctuates widely and often reaches 10 °C or higher (Lamikaura et al., 2000; Qi et al., 1999). Since the respiration rate of fresh-cut honeydew products at least doubles for every 5 °C increase above 5 °C (Watada et al., 1996), temperature management is essential for shelf-life extension.

In addition to good temperature management, fresh-cut melon shelf-life also may be extended by using modified atmospheres (Ayhan et al., 1998; Nguyen-the and Carlin, 1994; O’Conner-Shaw et al., 1996; Portela and Cantwell, 1998; Qi et al., 1999), strict sanitation to produce a sterile product (O’Conner-Shaw et al., 1996), or postprocessing with CaCl₂ (Luna-Guzmán et al., 1999) or Ca lactate (Luna-Guzmán and Barrett, 2000) dips. Calcium salts, particularly CaCl₂, have long been used as firming agents for canned fruits and vegetables (Camire et al., 1994). Calcium treatments also maintain firmness in a wide variety of whole, peeled, and fresh-cut fruits and vegetables including whole honeydew melons (Lester and Grusak, 1999) and fresh-cut muskmelons (Luna-Guzmán et al., 1999; Luna-Guzmán and Barrett, 2000). Calcium is reported to maintain firmness by crosslinking with cell wall and middle lamella pectins (Grant et al., 1973), stabilizing cell membranes (Picchioni et al., 1996), and/or affecting cell turgor potential (Mignani et al., 1995).

Calcium chloride can cause a bitter aftertaste in foods, including muskmelon pieces, while a similar Ca lactate treatment does not (Luna-Guzmán and Barrett, 2000). However, suprathereshold concentrations (1–100 mM) of Ca lactate solutions are slightly more sour than equimolar CaCl₂ solutions, and both salts have an unpleasant taste (Tordoff, 2001). What effect low concentrations of these salts have in foods is not known. Calcium lactate has been suggested as a potential alternative firming additive for use in fresh-cut fruits (Luna-Guzmán and Barrett, 2000). Calcium propionate and Ca amino acid chelate formulations represent additional Ca sources that have been used in the food and/or nutritional industries but whose potential for use in the fresh-cut industry has not been explored.

Calcium propionate and propionic acid, which forms when the pH is lowered from neutrality, are widely used antimicrobial food additives and are GRAS (generally regarded as safe) in the United States with an upper limit only in identified foods (Davidson and Juneja, 1990). In preliminary experiments, we found that Ca propionate solutions at concentrations between 30 and 50 mM (< 1% w/w) had no detectable flavor or lip feel and could be used with chlorinated water as a sanitary treatment for fresh-cut melon.

Calcium amino acid chelate formulations are patented as nutritionally functional chelates for plant, animal, and human use (Albion Laboratories, personal communication). A postharvest dip in a Ca amino acid chelate maintained firmness and more than doubled the shelf-life of intact honeydew fruit (Lester and Grusak, 1999). While more expensive than Ca salts, the Ca chelates are not corrosive to processing equipment and are more likely to penetrate deeply in plant tissues owing, at least in part, to their slow dissociation rate in water which would inhibit Ca binding to anionic cell wall sites within plant tissues. All of Albion’s Ca chelate formulations have FDA GRAS status and all included ingredients have been certified Kosher and Parve by KOF-K Kosher Supervision of Teaneck, NJ (Albion, 1998). In preliminary experiments, we found that a formulation of Ca amino acid chelate for human use described as being taste free had a very limited solubility in water. Other formulations intended for human use and having a high solubility in chlorinated water had a proteinaceous odor as the dry powder, but were without a detectable odor or taste in solutions containing 40 mM Ca (percent dry mass variable depending on Ca content of the formulations).
Our objective was to determine the effects of just cutting or treating freshly cut honeydew chunks with hypochlorous acid (ClO)-containing water without or with Ca propionate, a highly water soluble Ca chelate formulation for human use, or CaCl₂ on the quality of fresh-cut honeydew stored at 10°C. The 10°C temperature was used to simulate the abusive temperature that commonly occurs at retail stores and to accentuate any beneficial or negative effects of the postharvest treatments. Addition of ClO to the Ca solutions was evaluated to determine if chlorinated water with Ca supplements could be used to maintain quality and shelf stability of fresh-cut honeydew.

2. Materials and methods

2.1. Fruit

Honeydew melons of unknown cultivar were obtained from the Maryland Wholesale Distribution Center in Jessup, Maryland. Only fruit containing at least 9% soluble solids content (SSC) were selected for these studies, with a range of <2% SSC within an experiment. The average weight of each melon was ~2300 g. After overnight storage at 10°C, 18 melons, free of defects, were selected visually for similarity of maturity and size, washed with 19 mM hypochlorous acid (1000 μl l⁻¹ ClO supplied as sodium hypochlorite at pH 6) solution for 5 min, blotted with a paper towel, and processed at 10°C using equipment cleaned with 70% (v/v) ethanol. The melons were separated into three groups of six fruit (three replicates) and each fruit was uniformly peeled on a Muro CP-44 Melon Peeler (Tokyo, Japan). The blossom and stem-ends were discarded, each fruit was sliced once longitudinally with a sharp knife, seeds and placental tissue were removed, and ~2.5 cm equatorial slices were prepared using a 0.20 mm-thick stainless steel strap (Ace Co., Boise, Idaho) held taut in a hacksaw. Preliminary experiments indicated that strap slicing caused less compression injury to melon tissue during cutting than sharp knives, and produced a fresh-cut product essentially identical to that from commercial melon-cutting equipment. The strap slicer was also used to prepare 2–3 cm wide chunks in trapezoidal-shaped wedges from the melon slices. Chunks from each six-fruit replicate were randomized, subdivided into five colanders, and immediately dipped for 30 s in 1.9 mM (100 μl l⁻¹) ClO solution without or with a 40 mM concentration of Ca as CaCl₂·2H₂O (0.6%; Sigma, St. Louis, MO), Ca propionate (0.7%; Aldrich, St. Louis, MO), or Ca amino acid chelate formulation #3515, (1.5%; Albion Laboratories, Clearfield, Utah) or left nontreated. All solutions were adjusted to pH 6.0 using a minimal amount of HCl. The solutions were freshly prepared immediately before use on each replicate. After treatment of each replicate from each treatment, melon chunks were drained for about 1 min, four 300-g subsamples were placed into 18-oz clam shell containers (Rock-Tenn Co., Franklin Park, IL) and three 150-g subsamples were placed in 1-l sealed glass jars each containing a mesh liner elevated above 50 ml distilled water to maintain relative humidity >90%. The melon samples in clam shell containers were stored at 10°C for 0, 2, 4 or 5, and 7 d. Preliminary experiments indicated that O₂ and CO₂ levels that would favor aerobic respiration were present within the containers throughout storage. For each treatment, the three replicated samples in glass jars were stored at 10°C for 7 d under a continuous stream (15 ml min⁻¹) of 0.2 μm-filtered air to keep the CO₂ concentration <0.5 kPa.

2.2. Respiration and ethylene production rates

Carbon dioxide and ethylene contents of the outlet streams from samples in sealed glass jars were monitored every 6 h using a CO₂ analyzer (Model CD-3A; Ametek, Pittsburgh, PA) and a gas chromatograph (Model 5890a Series II; Agilent Technologies, Rockville, MD) equipped with a flame ionization detector (FID).

2.3. Quality analyses

Fruit tissue for Ca content analyses was prepared as described previously (Saftner et al., 1997). Freshly cut 300-g subsamples of replicates of each treatment were freeze-dried. Dried tissue samples
were then dry-ashed, dissolved 1:25 in 1 M HCl and analyzed for Ca concentration by inductively coupled plasma emission spectrometry (Model 61E; Thermo Jarrell Ash, Franklin, MA). Calcium concentration is reported on a dry weight basis (mg kg⁻¹).

The surface color of five chunks from each replicate of each treatment was measured with a chroma meter (Model CR-300; Minolta, Tokyo, Japan). L*, a*, and b* readings were recorded at two opposite sides of each chunk and results were expressed as lightness (L*) and chroma (C⁺ = [(a*)² + (b*)²]⁰.⁵). Translucency was expressed as the percentage of chunks in a sample showing signs of visible water soaking.

Texture was determined with a shear-compression cell (Model CS-1) attached to a Texture Test System (Model TMS-90; Food Technology Corporation, Rockville, MD) using a stroke speed of 1 cm s⁻¹. Chunks in 100-g subsamples from each replicate were placed in the cell randomly.

Analysis of volatile abundance using a solid-phase microextraction (SPME, Supelco Co., Bellefonte, Pa.) technique and gas chromatography was performed as described previously (Saftner et al., 1999). Briefly, juice from melon chunks of individual fruit was hand extracted using a crimping tool, 1 ml of each extract was transferred to a 4-ml vial, capped with a teflon liner, and frozen at −20 °C. For volatile sampling, frozen samples were thawed and equilibrated for 5 min at 20 °C. A SPME fiber coated with polydimethylsiloxane (1 cm long, 100 μm coating thickness) was used to collect and concentrate, by virtue of its sorption characteristics, the volatiles within each 4-ml vial for 16 min. The sorbed volatiles were desorbed for 2 min at 250 °C into a glass-lined, splitless injection port of a gas chromatograph (model 5890a Series II, Hewlett Packard Co., Rockville, MD) equipped with electronic pressure control and a FID. Volatiles were separated using a capillary column (HP-5, 11 m × 0.1 mm i.d., 0.34 μm coating thickness). The carrier gas was ultra purified hydrogen (6.0 research) at a flow velocity of 52 cm s⁻¹. The temperature program was isothermal for 2 min at 40 °C and then raised at 30 °C min⁻¹ to 250 °C and held for 3 min. Injector and detector temperatures were both 250 °C.

Constructing calibration curves for each volatile analyte in each honeydew sample is not feasible and thus total volatile abundance is generally reported in FID area response units of pA rather than absolute amounts of individual analytes. Samples for volatile analyses were collected from treated and nontreated melon chunks after 0, 2, 4 or 5, and 7 d at 10 °C following fresh-cut processing. For volatile identification, a gas chromatograph/mass spectral procedure was used as described previously (Saftner et al., 1999).

Propionic acid levels were measured in honeydew chunks that had been treated with ClO₂ without or with Ca propionate. The honeydew samples were extracted with a garlic press, and the extract passed through a 0.45 μm nylon filter. Twenty microliter aliquots of honeydew extracts and propionic acid standards were injected onto a Shodex (Tokyo, Japan) HPLC precolumn (Ionpak 6 × 50 mm) and column (Ionpak 8 × 300 mm) maintained at 70 °C. The mobile phase was 0.002 N H₂SO₄, and the flow rate was maintained at 1.5 ml min⁻¹ using a Beckman Instruments pump (model 110B; Columbia, MD). A differential refractometer (model 410; Waters Instruments, Milford, MA) was used for propionic acid measurements.

2.4. Microbial assays

Total mesophilic aerobic microorganism (mostly bacteria) count was determined by incubating the culture of tryptic soy agar (TSA, Difco Laboratories, Detroit, MI) at 30 °C for 24 h. Yeast and mold count was determined from culture incubated on potato dextrose agar (PDA, Difco Laboratories) with addition of chloramphenicol at 30 °C for 36 h as described elsewhere (Babic et al., 1996).

2.5. Sensory analyses

Honeydew melons were purchased at a wholesale distribution center in Maryland about four days before Public Field Days at the Beltsville Agricultural Research Center in each of 2 years. Each melon was sanitized and a core of flesh removed with a 10-mm corkborer sterilized with
70% ethanol. Juice was squeezed from the flesh and SSC was measured with a digital refractometer (model PR-101, Atago, Tokyo, Japan). Melons were then ordered according to SSC and divided into three groups. Melons chunks from each group were prepared as previously described except that razor-like blades (Tissue-Tek Accu-Edge trimming blades, 260 mm long × 18.6 mm wide × 0.24 mm thick, Sakura Finetek USA, Torrance, CA) mounted in a laboratory-made holder were used instead of straps during slice preparation.

In year 1, subsamples from each group were treated with ClO solution without or with a 40 mM concentration of Ca as Ca propionate as described above. Melon chunks were held at 5°C for ~24–30 h before being presented to consumers. Each consumer received two chunks of each of the two treatments on a plate. Treatments were coded by neutral icons: pencil and light bulb, box and bell, or magnifying glass and scissor for the three replicates. Simple paper ballots with the two symbols were provided and the panelist was asked to circle the icon of the sample he liked best and then to answer, ‘Why is that melon better?’

In year 2, melons were again grouped by SSC, and subsamples from each group were treated with ClO solution without or with a 40 mM concentration of Ca as Ca propionate or Ca amino acid chelate as described. Melon chunks were held at 5°C for ~24–30 h before being presented to consumers. Each consumer received one chunk of each of the three treatments on a plate, additional chunks were provided if requested. Treatments were coded with three-digit numbers. Panelists were asked to provide gender and age information and asked, ‘Which sample do you like best?’ and ‘Which do you like least?’ They were then asked why they liked or disliked each.

In both years to ensure approximately equal numbers of consumers for each replicate and to minimize possible time-of-day effects, we served 25 of each replicate in cycles. Replicates were stored at 5°C when not being served and were embedded in crushed ice during the service period. A total of 205 usable ballots was obtained in year 1 and 395 in year 2. Panelists ranged in age from 5 to 80. Children under about 12 years old were closely supervised; only those who clearly understood the tasks and articulated their choices and reasons for those choices were included in the analyses.

2.6. Statistical analyses

The experimental design was a randomized complete block with three replications. Most experiments were repeated at least twice and, except for sensory and gas analyses, were arranged in a 5 × 4 factorial: (nontreated, ClO, ClO + Ca propionate, ClO + CaCl₂, or ClO + Ca chelate treatment) × (0, 2, 4 or 5, and 7 d storage at 10°C). Sensory analyses compared nontreated, Ca propionate and/or Ca chelate treatments only and were repeated once. For gas analyses, the average of four measurements per day over the 7-d duration of the experiment were used for statistical analysis.

Data were analyzed by analysis of variance (ANOVA) within storage times to test for treatment effects. For sensory analyses, replicate means were used in ANOVAs. Treatments were compared to one another by Tukey’s HSD. Unless stated otherwise, only results significant at α = 0.05 are discussed.

3. Results and discussion

3.1. Calcium levels

All of the Ca treatments similarly increased the Ca level in the samples by more than twofold (Table 1), the exact increase being dependent upon the Ca level in the tissue before treatment (data not shown). The Ca level at chunk surfaces was not measured, but was probably much higher in CAtreated tissue than that for the tissue as a whole. While there was no significant difference in Ca levels between nontreated and ClO-treated tissue, the ClO-treated tissue consistently had a slightly lower Ca level than that of nontreated tissue (α = 0.108).
3.2. Respiration and ethylene production

The respiration rate of fresh-cut honeydew decreased during the first day after processing (Fig. 1A) and was probably due to recovery from tissue wounding. A similar wound response has been reported for freshly cut muskmelon (Luna-Guzmán et al., 1999). Following wound recovery, the respiration rate was relatively stable for ~1 d in all treated and nontreated melon chunks and was in the same range previously observed for honeydew chunks stored in air at 10 °C (Watada et al., 1996). After day 2, CO₂ production increased continually to a substantial level by day 5 (Fig. 1A; Qi et al., 1999). At least part of the increase was suspected to be due to climacteric CO₂ production since a similar pattern of increase was also noted for ethylene (Fig. 1B) and since intact honeydew melons go through a characteristic CO₂ and ethylene climactic after harvest (Pratt et al., 1977). However, the rates of ethylene and CO₂ production by day 5 were substantially higher than the rates reported by Pratt et al. (1977) and Watada et al. (1996) for ripening intact honeydew. Thus, part of the increase probably was due to microbial growth and/or to the altered physiology of the fresh-cut product. Preliminary experiments indicated that the degree of surface microbial contamination of honeydew chunks is correlated to the increase in respiration rate noted by day 5, although sterile chunks still show an increase in CO₂ production during storage. By day 5, non-treated (non-sanitized) chunks had the highest CO₂ and ethylene production rates (Fig. 1) and the most microbial contamination (Fig. 2) while treatment with Ca propionate, an antimicrobial food additive, had the lowest rates and, although not always significant, the least microbial growth. Interestingly, CO₂ and ethylene production rates in honeydew chunks stored at 5 °C (Madrid, 1993) were lower than for ours stored at 10 °C, as

Table 1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tissue Ca content (mg kg⁻¹ DW ± SE)</th>
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</thead>
<tbody>
<tr>
<td>Nontreated</td>
<td>400 ± 80 a¹</td>
</tr>
<tr>
<td>ClO</td>
<td>380 ± 60 a</td>
</tr>
<tr>
<td>ClO + Ca propionate</td>
<td>940 ± 150 b</td>
</tr>
<tr>
<td>ClO + CaCl₂</td>
<td>930 ± 90 b</td>
</tr>
<tr>
<td>ClO + Ca amino acid chelate</td>
<td>960 ± 130 b</td>
</tr>
</tbody>
</table>

¹ Means followed by the same letter are not significantly different by Tukey's HSD (z = 0.05).
expected, but they also remained relatively stable throughout storage periods up to 14 d suggesting that climacteric ripening was prevented at the generally preferred temperatures for fresh-cut melon storage. Honeydew chunks treated with ClO + CaCl₂ or Ca chelate also had lower CO₂ (Fig. 1A) but similar ethylene (Fig. 1B) production rates than chunks treated with ClO alone. While not fully understood, divergent patterns in respiration and ethylene production rates also have been reported in fresh-cut muskmelon and various intact climacteric fruit (Luna-Guzmán et al., 1999).

3.3. Microbiology

The microbial population increased during storage (Fig. 2). The increase, mostly bacteria, was greatest in nontreated (non-sanitized) chunks (Fig. 2). By day 7, all melon chunks had high microbial counts, generally log 7 CFU g⁻¹ or higher, but none showed visible signs of microbial decay. Chunks treated with ClO without or with CaCl₂ or Ca chelate had total microbial counts about 1 log (90%) lower than that in nontreated tissue while even lower levels, though not significant, were observed in ClO + Ca propionate-treated tissue. Yeasts and molds were less numerous than bacteria, but otherwise followed the same general pattern as that observed for bacteria (Fig. 2B). By day 7, the yeast and mold population in nontreated samples was up to log 2 CFU g⁻¹ higher than that in ClO-treated tissue samples. The yeast and mold population was always slightly lower in ClO + Ca propionate-treated tissue (z = 0.137). A 3.8 mM ClO solution had been previously shown to reduce microbial load on honeydew chunks (Ayhan et al., 1998). Microbial loads similar to that observed in this study have been observed in many fresh-cut honeydew samples purchased from local retailers in Maryland (James McEvoy, personal communication).

Another organic acid salt, Ca lactate, has been observed to inhibit microbial growth in fresh-cut muskmelon. The antimicrobial properties of Ca propionate and Ca lactate are dependent upon their ability to form their corresponding undissociated acids in solution and to uncouple microbial substrate transport and oxidative phosphorylation from the electron transport system (Davidson and Juneja, 1990; Freese et al., 1973). Since the undissociated form of the acids is primarily responsible for their antimicrobial activities, both the use pH and the pKₐ of the acids are important considerations. In this study, a Ca propionate solution at pH 6.0 was applied to the surface of freshly prepared honeydew chunks. Since the pKₐ of propionic acid is 4.87 (CRC Handbook of Chemistry and Physics, 1980), there was essentially no undissociated antimicrobial propionic acid present in the Ca propionate solution as applied. However, during storage, preliminary results in-
dicated that the surface pH of honeydew chunks decreased from about 6.2 to <4.5 (Robert Saftner, unpublished data) during which time propionic acid levels remained elevated compared to nontreated tissue (see below). Thus, undissociated propionic acid probably was formed at or near the surface of honeydew chunks during storage and inhibited microbial growth. Still, the Ca propionate treatment used in this study cannot be recommended solely as an antimicrobial treatment due to its limited effectiveness. Had the Ca propionate treatment been buffered and applied at a pH <5, its usefulness as an antimicrobial agent may have been increased. Some short-chain organic acid-producing bacteria are tolerant to propionic and lactic acids, and are variably affected by these same acids (Davidson and Juneja, 1990). An alternative strategy combining a commercial detergent with an oxidizing agent as a preprocessing aid for reducing microbial growth by log 3 CFU g⁻¹ in fresh-cut muskmelon has recently been reported (Sapers et al., 1998). We are currently investigating the use of oxidizing substances as postprocessing antimicrobial treatments on melon chunks as well as identifying the most abundant microbes that occur on the surface of fresh-cut melons.

3.4. Firmness

Compression firmness measurements of individual muskmelon cylinders (Luna-Guzmán et al., 1999) and honeydew chunks are highly variable. To reduce such high inherent variability, an automated sampling system that measured shear force firmness of 100 g-subsamples (5–6 chunks) was used. The compression-shear firmness of nontreated and ClO-treated samples decreased more than 60% during 7 d storage (Fig. 3), which is not surprising considering the storage temperature of 10 °C used in this study. All Ca treatments had a slight, albeit generally not significant, firming effect initially. Maintenance of firmness was higher in Ca-treated tissue than in nontreated chunks or chunks treated with ClO alone. A firming response of Ca has also been observed in numerous fresh, fresh-cut, and processed produce including 2.5% CaCl₂ and Ca lactate treatments of fresh-cut muskmelon stored at 5 °C (Luna-Guzmán et al., 1999; Luna-Guzmán and Barrett, 2000). The firming effect is generally attributed to rigidification of cell wall and middle lamella pectins (Grant et al., 1973), stabilization of cell membranes (Picchioni et al., 1996), and maintenance of cell turgor potentials (Mignani et al., 1995).

3.5. Translucency

The translucency of treated and nontreated melon chunks increased slowly at first, then more rapidly during the last 2 d of storage (Fig. 4). Chunks treated with ClO alone developed the most translucency followed by nontreated chunks, then the ClO + Ca-treated chunks. Chunks treated with Ca propionate consistently had the least amount of translucency development during storage (x = 0.087). Due to translucency development, melon chunks treated with ClO alone and nontreated chunks had a shelf-life of no more than 5 and 7 d, respectively. Tissue translucency did not
exceed 10% in ClO + Ca-treated chunks during 7 d storage at 10 °C, and appeared to still be in salable condition.

The increased translucency with ClO treatment alone is not unexpected since melon tissue immersed in water rapidly leaks solutes (Simon, 1977) and thus becomes translucent. Increasing the osmotic concentration of the ambient solution reduces leakage from cell membranes (Epstein, 1972) probably by better maintaining tissue water relations. In this study, the Ca-containing solutions were hypotonic compared to the melon tissue but had significantly higher osmotic potentials than chlorinated water alone. The increased osmotic potential along with the membrane stabilizing effects of Ca likely accounted for all or most of the observed inhibition of translucency development in Ca-treated tissue. Unfortunately both chlorination, a common food safety treatment of fresh-cut salads, and GRAS treatments, such as the Ca treatments used in this and other studies, have seldom been applied to fresh-cut fruit that have little or no browning (Beaulieu and Baldwin, 2002).

3.6. Surface color

A high lightness, L* (Fig. 5A) and a pale green color were observed on good, high quality chunk surfaces. The initial L* value was ~ 68. The value in Ca-treated melon chunks remained essentially unchanged during storage, while L* decreased in nontreated chunks and chunks treated with ClO alone. By day 7, the L* value was lower in
nontreated chunks than in chunks treated with ClO alone. The chroma, C*, brightness of the chunk surface color, was initially 24 (Fig. 5B). Due to translucency development, C* showed a similar pattern of change as for L* in all samples: a generally nonsignificant change in C* value was observed in ClO + Ca-treated melon chunks, while the C* value in chunks treated with ClO alone or left nontreated had decreased by day 7.

3.7. Total volatile abundance

Total volatile abundance of treated and nontreated melon chunks increased during storage at 10 °C (Fig. 6A). By day 5, volatile abundance was higher in Ca propionate-treated samples than in other treated and nontreated chunks. The increased volatile abundance in Ca propionate-treated chunks was due primarily to an increase in propyl acetate abundance during storage (Fig. 6B), but other propyl esters were also detected by day 7 (data not shown). As propyl acetate abundance increased, the propionic acid level, which was ~3 μmol kg⁻¹ fresh mass immediately after Ca propionate treatment, decreased during storage (Fig. 6C). By day 7, the propionic acid level in Ca propionate-treated chunks was essentially the same as that in nontreated chunks. Part of the increase in total volatile abundance during storage in treated and nontreated melon chunks was due to an increase in volatile analytes having a melon aroma (data not shown). Characteristic aroma volatile analytes of melon detected in this study included cis-6-nonenal, trans-2, cis-6-nonadienal, trans-2, cis-6-nonadien-1-ol, cis-2-nonen-1-ol, cis-6-nonen-1-ol, trans-2-nonen-1-ol, and 2-nonenol. Most of these volatile analytes have been identified as flavor-related in honeydew (Buttery et al., 1982). The abundance of these melon-associated volatile analytes in all treated and nontreated samples either remained stable or increased during storage (data not shown). Honeydew aroma also increased during storage at 15 °C (Madrid, 1993), but decreased during storage at 5 °C (Madrid, 1993; Portela and Cantwell, 1998) suggesting that aroma quality was being compromised by storage at temperatures which more effectively control microbial growth. Aroma of fresh-cut muskmelon stored at 5 °C in air or controlled atmosphere also decreased during storage (Portela et al., 1997).

Fig. 6. Effects of no treatment and hypochlorous acid treatment without or with Ca propionate, CaCl₂, or Ca chelate on the levels of total volatiles and propyl acetate in the headspace above of propionic acid in extracts of honeydew chunks stored in air at 10 °C for up to 7 days. Duplicate measurements from each of three replications (n = 6) were averaged to obtain a representative value at each storage time. Treatments are described in the caption to Fig. 1. Within the same sampling day, symbols labeled with the same letter are not significantly different at α = 0.05 using Tukey’s HSD.
3.8. Sensory analysis

In fresh-cut muskmelon, a 2.5% (~173 mM Ca) solution of CaCl₂ imparted an undesirable bitterness to the fruit product (Luna-Guzmán and Barrett, 2000). What effect, if any, the relatively low concentration CaCl₂ treatment used in this study would have had on melon taste is not known. Preliminary sensory evaluations by the authors indicated that the Ca propionate and Ca chelate solutions at the Ca concentration (40 mM) used in this study were taste free and did not impart a lip feel; the CaCl₂ solution had a slightly salty taste and lip feel. Consumer panels did not show a distinct preference among melon chunks treated with ClO without or with Ca propionate or Ca chelate (Table 2). Sweetness was the primary factor used in determining preference among treated samples. In Year 1, less than 5% of the panelists listed negative traits such as too sweet, too watery, and overripe taste, but these traits were not associated with any particular treatment. In Year 2, when more detailed comments were solicited, we tabulated about 630 comments. Of these, 41% related to sweetness or its lack, 24% to flavor, 16% to texture, 9% to juiciness and about 2.5% each to sourness and bitterness. Bitterness was mentioned three times for the ClO-treated, eight times for ClO + Ca chelate-treated, and four times for ClO + Ca propionate-treated chunks. Additionally, undescribed, ‘odd,’ or unpleasant aftertastes were mentioned seven times for the ClO-treated, twice for ClO + Ca chelate-treated, and 11 times for ClO + Ca propionate-treated chunks. Most of the consumers had comments that appeared unrelated to the treatments.

3.9. Concluding remarks

Sanitary (ClO) dips containing a low concentration of Ca as propionate or chloride salts or as an amino acid chelate maintained quality and extended shelf-life of fresh-cut honeydew as indicated by maintenance of firmness and surface color and the inhibition of respiration and ethylene production rates, microbial growth, and the development of tissue translucency. While not always significant, Ca propionate treatment was more effective at maintaining quality than either CaCl₂ or Ca chelate treatment. The Ca chelate

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Table 2
Consumer assessments of honeydew chunks that had been dipped for 30 s in 1.9 mM ClO solution without or with 40 mM Ca propionate or Ca amino acid chelate and stored for ~24–30 h at 5°C before analysis

<table>
<thead>
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<th>Year #1</th>
<th>N</th>
<th>Taste panel preference</th>
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<td>ClO</td>
</tr>
<tr>
<td>Replication number</td>
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<th>N&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Taste panel preference</th>
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<sup>a</sup> Total responses do not exactly add up because of 4 ties for most preferred, 7 for least preferred, and 2 indicating ‘all the same’.
treatment, however, would be much less corrosive to existing processing equipment than any Ca salt treatment, and thus is more likely to be accepted commercially despite the added manufacturing costs of the Ca chelate. Detailed evaluation of the detection thresholds and flavor consequences of these Ca treatments needs to be done by an expert flavor panel. Further studies also are required to investigate the possibility that sanitary dips containing a low concentration of Ca would maintain the microbial safety of the fresh-cut product while also maintaining quality during storage at temperatures above 5 °C. Nevertheless, the combination sanitary and GRAS Ca treatments maintain quality and control microbial growth better on fresh-cut honeydew than just cutting alone.

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