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Effect of alginate coatings with cinnamon bark oil and soybean oil on quality and microbiological safety of cantaloupe

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ABSTRACT

The quality and microbiological safety of cantaloupes can potentially be improved using antimicrobial coatings that are able to maintain effectiveness throughout storage. The objective of this work was to study the effect of coating mixtures containing sodium alginate and cinnamon bark oil (CBO) on the quality of cantaloupes and the survival of inoculated bacterial pathogens and naturally occurring yeasts and molds during ambient storage at 21 °C. Cantaloupes were dipped in mixtures containing 1% sodium alginate with or without 2% CBO and 0 or 0.5% soybean oil (SBO). Weight loss and total soluble solids content of the flesh were not significantly different among coating treatments. However, changes in color and firmness of cantaloupes were delayed to different extents after coating, most significantly for the CBO + SBO treatment. Cocktails of *Salmonella enterica*, *Escherichia coli* O157:H7, or *Listeria monocytogenes* inoculated on cantaloupes were reduced to the detection limit (1.3 log CFU/cm^2) and completely inhibited during the 15-day storage by the CBO + SBO treatment, while *L. monocytogenes* and *S. enterica* reached populations of 2.9 log CFU/cm^2 and 2.4 log CFU/cm^2, respectively, on cantaloupes coated with CBO alone. Antimicrobial coatings, especially with SBO, also reduced yeast and mold counts on cantaloupes by 2.6 log CFU/cm^2. SBO improved the retention of CBO during storage suggesting it is related to the enhancement of quality and microbiological safety. Findings demonstrated the potential of the antimicrobial coating system studied to improve microbiological safety and quality of cantaloupes.

1. Introduction

Cantaloupes have been linked to several outbreaks of foodborne illness caused by contamination with *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella enterica* (Bowen et al., 2006; Prevention, 2011). Contamination can arise from various factors during pre- and post-harvest production (Ukuku et al., 2001), and many intervention strategies including hot water, hydrogen peroxide, and chlorine have been studied to eliminate or reduce pathogenic and spoilage microorganisms (Ukuku, 2006). However, cantaloupes after these treatments, especially hot water treatment, could become more susceptible to later recontamination by pathogens (Ukuku, 2006). The introduction of organic material during washing also neutralizes the antibacterial activity of chlorine, making it ineffective in reducing pathogens (Beuchat and Ryu, 1997; Fukuzaki, 2006). The irregular topographical surfaces of cantaloupes increase the risk of entrapping and protecting attached pathogens. The hydrophobicity and topological non-uniformity of the cantaloupe surface may also prevent aqueous sanitizers from reaching the cavities on rinds and hence reduce effectiveness of washing treatments even with increased concentrations of sanitizers (Rodgers et al., 2004).

Edible antimicrobial films and coatings have been studied as an intervention strategy to improve the microbiological safety of fresh produce (Chen et al., 2012; Eswaranandam et al., 2006; Park, 1999). Several studies have demonstrated the effectiveness of edible coatings including chitosan with and without antimicrobials on the microbiological safety of whole and fresh-cut cantaloupes (Chen et al., 2012; Krasaekoopt and Mabumrung, 2008). However, the cost of coating materials and some undesirable side-effects on quality including color and odor can limit their practical application. The survival of foodborne pathogens after coating and subsequent recovery during storage are other concerns that call for coating systems that can maintain antimicrobial effectiveness throughout the shelf-life of cantaloupes.

Many essential oils (EOs) have bactericidal activities against a wide range of foodborne pathogens and thus have received attention for their potential as "natural" antimicrobials because many are classified by U.S. Food and Drug Administration as generally-recognized-as-safe (GRAS) (Chen et al., 2014; Ma et al., 2013). Additionally, there has been growing interest in incorporating EOs in coatings to improve shelf-life and microbiological safety of whole and fresh-cut fruits (Campos et al., 2011). However, studies using EO coatings on whole cantaloupes are limited. One potential problem with EOs is the high

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volatility so they may be lost during storage, reducing the antibacterial efficacy (Sánchez-González et al., 2010).

Cinnamomum cassia Blume, also named Chinese cinnamon, is a popular natural spice with excellent antioxidant and antimicrobial activities (Lin et al., 2003). The main constituent of essential oil extracted from the bark (CBO) is trans-cinnamaldehyde (Geng et al., 2011). Alginate, a GRAS polysaccharide extracted from brown seaweed, is a desirable coating material because of its low cost and biocompatibility (Mokarram et al., 2009). In a previous study (Zhang et al., 2015), alginate-cast films prepared with 2% CBO were found to be effective in inhibiting *E. coli* O157:H7, *L. monocytogenes*, and *S. enterica* in vitro. The film prepared with 2% CBO and 0.5% soybean oil (SBO) exhibited the reduced loss of CBO during storage of films because the incorporation of non-polar SBO decreased the polarity of alginate films to favor the retention of CBO (Zhang et al., 2015). Thus, this particular film may have potential as an antimicrobial coating to improve microbiological safety and quality of cantaloupes. Therefore, the objectives of this study were to 1) study the effects of alginate coatings with CBO on the survival of inoculated bacterial pathogens and the natural mycoflora on cantaloupe rinds, and 2) evaluate the effect of coatings on the quality of cantaloupes.

2. Materials and methods

2.1. Materials

Cantaloupes were purchased from a local grocery store on the same day as their arrival and stored at 4 °C for a maximum of 2 days before experiments. Same batch of cantaloupes from the same producer was used in comparable treatments. Sodium alginate was purchased from Sigma-Aldrich Corp. (St. Louis, MO). CBO extracted from *Cinnamomum cassia* Blume was a product from Plant Therapy Essential Oils (Twin Falls, ID). SBO containing 50–54% linoleic acid was procured from MP Biomedicals, LLC (Santa Ana, CA). Other chemicals were obtained from either Sigma-Aldrich or Fisher Scientific (Pittsburgh, PA).

2.2. Preparation of coating mixture

Sodium alginate solution was prepared by dissolving 20 g in 1 L of sterile distilled water at 70 °C. After 30 min stirring for complete dissolution, glycerol was added at 1.2 g/g alginate as a plasticizer, while $CaCl_2$ (0.05 g/g alginate) was added to strengthen the coating structure. For CBO coating mixtures, CBO was mixed with polysorbate 80 (Tween® 80) at a 4:1 mass ratio, followed by mixing with the alginate solution with and without SBO on a magnetic stir plate. Water was added to bring the total volume to 2 L. The final coating formulations contained 1% w/v alginate, 0.5% w/v Tween® 80, 0 or 2% w/v CBO, and 0 or 0.5% w/v SBO.

2.3. Bacteria cultures and inoculum preparation

Cultures were obtained from the collection of the Department of Food Science and Technology at the University of Tennessee (Knoxville, TN). A cocktail was prepared from 5 strains each of *E. coli* O157:H7 (H1730, F4546, K3995, K4492 and 932) and *L. monocytogenes* (ENV2011010804-1 (390-1), ENV2011010804-2 (390-2), 310, Scott A, and V7) or 5 serovars of *S. enterica* (Agona, Montevideo, Gaminara, Michigan, and Saint Paul). Each test strain or serovar stored in glycerol at −20 °C was transferred twice to tryptic soy broth (TSB; Fisher Scientific) at 37 °C (for *E. coli* O157:H7 and *S. enterica*) or 32 °C (for *L. monocytogenes*) and incubated for 24 h. The 5 test strains/serovars were combined to yield a mixed culture containing equal proportions of each test strain/serovar and diluted to ~10^8 CFU/mL as the working culture.

2.4. Weight loss, color, firmness, and total soluble solids content of whole cantaloupes

Unwashed whole cantaloupes were immersed in the 2 L coating mixture for 10 s, drained on a rack, and dried at ambient conditions (21 °C, 58–70% RH) for 24 h. Uncoated cantaloupes were used as controls. During ambient storage, various quality parameters were determined. The weight of seven whole cantaloupes was recorded for each coating treatment and the percentages of weight loss were calculated with respect to the weight of sample after drying for 24 h (day 0).

Cantaloupe surface color was measured using a MiniScan XE Plus Hunter colorimeter (Hunter Associates Laboratory, Inc., Reston, VA). Three determinations were performed at different locations on each cantaloupe. The *L* (lightness), *a* (redness to greenness), and *b* (yellowness to blueness) values of three cantaloupes were recorded for each treatment.

For the firmness test, each cantaloupe was cut into four pieces. For each piece, the flesh in the center was converted into a 4.52 cm^2 × 1 cm cylinder that was tested using a TA.XTplus Texture Analyzer in the compression mode (Texture Technologies Corp., Scarsdale, NY) with a cylindrical probe (TA-57R, 7 mm-1″R) traveling at 50 mm/min.

Total soluble solids (TSS) content of the flesh was measured directly with a refractometer (model TS400, Reichert Analytical Instruments, Depew, NY). For each treatment, three cantaloupes with four measurements on each cantaloupe were taken to measure firmness and TSS changes.

2.5. Inhibition of pathogens on cantaloupes by antimicrobial coatings

Coating treatments on cantaloupes were done according to the method of Chen et al. (Chen et al., 2012). Cantaloupes were washed in tap water containing 0.5% Tween 80, followed by rinsing with tap water and drying overnight at ambient conditions (21 °C, 58–70% RH). A total of 100 μL culture containing ~10^8 CFU/mL bacteria was spot-inoculated (10 μL at 10 different locations) on each of two 2.5 cm × 2.5 cm marked squares on the surface of cantaloupes to facilitate drying. Thereafter, 0.8 mL of the coating mixture was evenly applied over the inoculation area with a small sterilized paint brush. Inoculated cantaloupes without treatment were used as controls. After incubation at ambient conditions for up to 15 days, the treated areas were excised using a sterile knife and were placed into a sterile blender bag containing 25 mL of sterile PBS (10 mM, pH 7.4) with 0.2% Tween® 80 and rubbed by hand for 1 min. The liquid obtained was serially diluted in 0.1% peptone water and surface plated on CT-SMAC (Thermo Scientific Remel, Lenexa, KS) agar plates for *E. coli* O157:H7, XLT4 agar (Thermo Scientific Remel) plates for *S. enterica*, or Modified Oxford medium (MOX) agar (Thermo Scientific Remel) for *L. monocytogenes*. After incubation at 37 °C (*E. coli* O157:H7 and *S. enterica*) or 32 °C (*L. monocytogenes*) for 48 h, colonies were enumerated. For each treatment, experiments were replicated 4 times (2 squares on each of 2 cantaloupes).

2.6. Detection of yeasts and molds on cantaloupes

The same cantaloupes treated in Section 2.4 were used in this set of experiments. After storage at ambient conditions for 5 days, the populations of yeasts and molds on the surface of three cantaloupes with and without coatings were determined for each treatment. Four circular disks of cantaloupe rinds were cut with a sterile stainless steel cork borer (area ~4.52 cm^2) from different locations of one cantaloupe. After removing the flesh, the four round disks were placed in sterile blender bags and treated using the same procedures described in Section 2.5. The populations of yeasts and molds were enumerated on dichloran rose Bengal chloramphenicol agar (DRBC; Thermo Scientific Remel) after incubation at 21 °C with 58–70% RH for 5 days. For

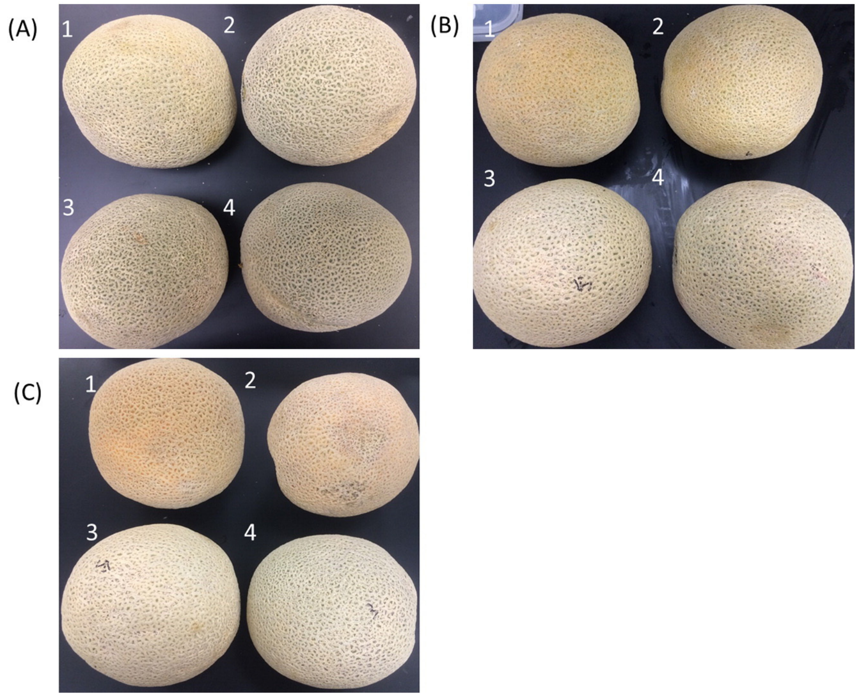

Fig. 1. Cantaloupes before (A) and after room temperature storage for 3 (B) and 15 days (C). The coating treatments were (1) no coating (control), (2) alginate only, (3) with 2% CBO, and (4) with 2% CBO and 0.5% SBO.

each treatment, experiments were replicated 3 times from different cantaloupes.

2.7. Statistical analysis

All results were reported as means ± standard deviations. Statistical analyses were performed using the SPSS 16.0 statistical analysis system (SPSS Inc., Chicago, IL). The one-way analysis of variance (ANOVA) of means was separated at a significance level (*P*) of 0.05 using the least significant difference method.

3. Results and discussion

3.1. Effects of coatings on appearance of cantaloupes

As shown in Fig. 1, no obvious visual change was observed for cantaloupes immediately after coating treatments. After 15 day of storage, uncoated cantaloupes and those coated by alginate showed more intense yellowness than those with CBO coatings. The control and alginate-only treatments had visible mold growth and spoilage, while no spoilage or mold colonies were observed on CBO-coated cantaloupes (not visible in Fig. 1).

Impacts of coatings on cantaloupe color were further quantified for Hunter *L*, *a* and *b* values because color is a primary factor in quality judgment of fruits and strongly influences acceptability by consumers (Castell-Perez et al., 2004). The color of cantaloupes became significantly lighter after 1 day storage for all treatments, with *L* values increasing from 59.4 to ~64, and no significant difference in *L* values was observed after day 1 among all treatments (Table 1). The increased *L* values for samples with and without coating treatments can be attributed to a faster respiration rate after moving cantaloupes from 4 °C refrigerator to room temperature (21 °C) (Serrano et al., 2008). For the redness (positive *a*) and yellowness (positive *b*), no difference was observed among treatments on day 1, suggesting that coating treatments had

Table 1
Effects of alginate coatings on the *L*, *a*, and *b* values of cantaloupes stored at room temperature for up to 15 days.

Coating	Day 1	Day 3	Day 5	Day 7	Day 10	Day 15
L (before coating 59.40 ± 2.54^{d})						
None (control)	64.05 ± 2.58^{abcd}	66.91 ± 1.60^{abc}	66.65 ± 3.15^{abc}	68.42 ± 2.92^{a}	67.46 ± 2.53^{abc}	65.59 ± 1.63^{abc}
Alginate only	63.48 ± 2.84^{bcd}	68.14 ± 1.84^{ab}	63.10 ± 1.54^{cd}	66.34 ± 1.83^{abc}	66.02 ± 2.08^{abc}	63.81 ± 3.35^{abcd}
With CBO	63.90 ± 2.20^{abcd}	65.07 ± 1.55^{abc}	65.69 ± 2.37^{abc}	67.57 ± 2.44^{abc}	66.40 ± 2.34^{abc}	66.36 ± 1.94^{abc}
With CBO + SBO	63.51 ± 2.66^{bcd}	63.54 ± 3.39^{bcd}	64.90 ± 2.18^{abc}	65.63 ± 0.3^{abc}	65.93 ± 3.11^{abc}	66.48 ± 0.71^{abc}
a. (before coating 1.36 ± 0.41^{i})						
None (control)	2.07 ± 0.92^{hi}	4.68 ± 1.70^{cde}	5.07 ± 1.23^{cd}	6.43 ± 0.96^{ab}	7.35 ± 2.02^{a}	7.28 ± 1.65^{a}
Alginate only	2.54 ± 0.83^{fghi}	3.44 ± 1.62^{efgh}	3.72 ± 2.00^{defg}	4.14 ± 1.73^{cde}	5.22 ± 1.10^{ab}	3.96 ± 2.14^{cdef}
With CBO	1.24 ± 0.97^{i}	1.98 ± 1.24^{hi}	2.00 ± 0.56^{hi}	2.36 ± 0.52^{ghi}	2.37 ± 0.61^{ghi}	2.71 ± 0.41^{fghi}
With CBO + SBO	1.86 ± 0.97^{i}	2.43 ± 0.78^{ghi}	2.31 ± 1.13^{ghi}	2.13 ± 0.82^{hi}	2.62 ± 0.87^{fghi}	1.93 ± 0.51^{hi}
b. (before coating 20.74 ± 1.21^{cdef})						
None (control)	21.26 ± 1.49^{bcde}	25.32 ± 1.75^{a}	26.16 ± 1.64^{a}	26.29 ± 0.96^{a}	25.70 ± 1.89^{a}	25.42 ± 1.36^{a}
Alginate only	21.00 ± 1.99^{cde}	22.04 ± 2.44^{bc}	21.68 ± 2.49^{bcd}	22.46 ± 2.75^{bc}	23.23 ± 1.51^{b}	20.73 ± 2.72^{cdef}
With CBO	18.60 ± 1.51^{f}	20.24 ± 2.43^{cdef}	20.52 ± 1.48^{cdef}	19.52 ± 1.18^{def}	19.34 ± 1.00^{ef}	20.24 ± 1.38^{cdef}
With CBO + SBO	20.93 ± 2.62^{cde}	20.81 ± 1.80^{cdef}	20.30 ± 1.64^{cdef}	19.19 ± 0.87^{ef}	19.29 ± 2.06^{ef}	18.90 ± 1.05^{f}

Numbers are mean ± standard deviation (n = 9). Mean values with different superscript letters in the same parameter are significantly different ($P < 0.05$).

Table 2
Effects of alginate coatings on weight loss (% of mass at day 0 after coating) of cantaloupes during ambient storage for up to 15 days.

Coating	Day 1	Day 5	Day 12	Day 15
None (control)	1.93 ± 0.34^{E}	4.47 ± 0.44^{D}	11.29 ± 1.42^{C}	12.89 ± 1.58^{ABC}
Alginate only	1.94 ± 0.27^{E}	5.12 ± 0.26^{D}	11.54 ± 3.58^{C}	12.45 ± 0.82^{ABC}
With CBO	2.11 ± 0.33^{E}	4.50 ± 0.80^{D}	12.83 ± 1.24^{ABC}	13.99 ± 1.40^{A}
With CBO + SBO	1.72 ± 0.44^{E}	4.12 ± 0.56^{D}	11.71 ± 1.19^{BC}	13.39 ± 1.03^{AB}

Numbers are mean ± standard deviation (n = 7). Mean values with different superscript letters are significantly different ($P < 0.05$).

no obvious effects on the appearance of cantaloupes. During 15 days storage, the increase in *a* and *b* values for the control cantaloupes without coating were significantly higher than those of coated cantaloupes. Overall, no significant changes in *L*, *a*, and *b* values were observed between coating treatments with CBO or CBO + SBO (Table 1). The results suggest that alginate coatings especially those with CBO can help maintain the color of cantaloupes during postharvest storage.

3.2. Effects of coatings on weight loss, firmness and total soluble solids content of cantaloupes

The effects of coatings on the quality of cantaloupes were also determined by measurements of weight loss, firmness, and TSS content. Table 2 shows weight loss of cantaloupes with and without coatings during room temperature storage. Throughout the 15-day storage, all samples gradually lost weight due to the respiration and moisture evaporation through the rind (Hernandez-Munoz et al., 2008). The weight loss of cantaloupes reached ~13% at the end of the storage, and no significant difference was found between uncoated controls and the coating treatments. The alginate coatings under conditions studied did not reduce weight loss, possibly because of the high hygroscopic nature of alginate and the thin coating on surface (only 0.06 g alginate/count) (Olivas et al., 2007).

The flesh of all cantaloupes softened after the third day of storage (Table 3). No significant difference was observed between the uncoated control and the alginate only treatment during the 15 days storage. The flesh from CBO-coated cantaloupes was significantly firmer than the control and the coating without CBO up to the tenth day of storage, especially for those coated with CBO + SBO. After 15 days storage, there was no difference among all treatments. Fruit texture is affected by cell rigidity and the structure and composition of cell wall polysaccharides (Reeve, 1970) and is one of the most important determinants of shelf-life of fruits (Gil et al., 2006). Retention of cantaloupe firmness suggests that CBO may be effective in delaying the postharvest ripening of cantaloupes. The improved effectiveness of the coating treatment with CBO + SBO than that with CBO alone may be because of the better retention of CBO in the alginate matrix by SBO. As discussed previously, the volatility of CBO can be lowered once CBO is associated with long-chain fatty acids of SBO during film formation (Zhang et al., 2015) .

TSS content is an important sensory attribute of cantaloupes that can be measured using a refractometer (Guis et al., 1997). As shown in Fig. 2, the TSS content of flesh increased after the third day of storage due to ripening and loss of water, but decreased slightly during the following 12 days due to respiration (Hernandez-Munoz et al., 2008). The coated cantaloupes had slightly lower TSS content than the control up to the

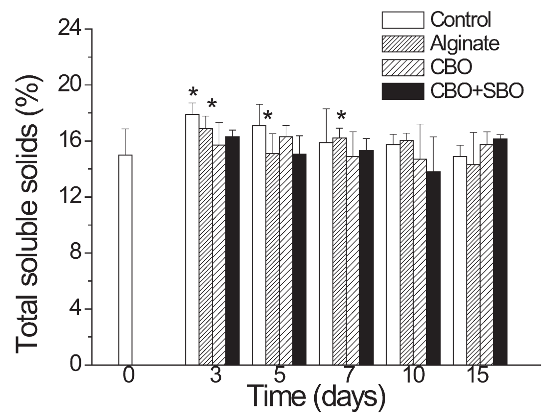

Fig. 2. Effects of alginate coatings on the total soluble solids content (%) of cantaloupe flesh after storage at room temperature for up to 15 days. Error bars are standard deviations (n = 12).

fifth day of storage and showed no significant difference in TSS content at day 0 attributed to the delay of ripening. No significant difference was observed between different coating formulations. Previous studies also demonstrated the effectiveness of EOs such as CBO on reducing the ripening rate and deterioration of fruits (Ranasinghe et al., 2005; Serrano et al., 2008). Significant reductions in the rates of O_2 depletion and CO_2 production were observed in apples treated by EOs such as oregano oil, showing the effectiveness of EOs inhibiting respiration and ethylene production (Rojas-Graü et al., 2007). The major component of CBO, cinnamaldehyde, is also a very potent fungicidal agent and therefore may also reduce negative effects caused by yeasts and molds (Antunes and Cavaco, 2010). Some EOs, including cinnamaldehyde, have antioxidant capacities and can inhibit enzymatic activities in fruits which may be responsible for the physiological deterioration (Jin et al., 2012). Detailed mechanisms need to be investigated.

Overall, the results suggest that CBO incorporated alginate coatings can further enhance the quality of cantaloupes by delaying the ripening process during postharvest storage.

3.3. Inactivation of bacteria on cantaloupes after antimicrobial coating treatments

Fig. 3 shows the populations of *S. enterica*, *E. coli* O157:H7, and *L. monocytogenes* on uncoated cantaloupes and cantaloupes coated with 1% alginate alone, alginate with 2% CBO alone, and alginate plus 2% CBO and 0.5% SBO during 15 days of storage. The populations of all three bacteria on cantaloupes without coating or treated with alginate only decreased gradually, especially for *E. coli* O157:H7 with only ca. 2.1 log CFU/cm^2 after 15 day storage (Fig. 1A). A decrease in survival over time may be attributed to the dry surface of cantaloupes without sufficient fluid retention to support bacterial survival (Behrsing et al., 2003; Knudsen et al., 2001). Without antimicrobials, *L. monocytogenes* survived better than the two Gram-negative bacteria during storage, with 3.5 log CFU/cm^2 after 15 days compared to 2.2 and 2.1 log CFU/cm^2 for *S. enterica* and *E. coli* O157:H7, respectively. This trend was also observed by others

Table 3
Effects of alginate coating on the firmness (N) of cantaloupe flesh after storage at room temperature for 15 days.

Coating	Day 0	Day 3	Day 5	Day 7	Day 10	Day 15
None (control)	12.61 ± 3.85^{a}	4.65 ± 1.37^{de}	3.66 ± 0.61^{ef}	2.73 ± 1.01^{fg}	3.16 ± 0.81^{fg}	2.09 ± 0.31^{g}
Alginate only	–	4.97 ± 1.64^{de}	3.66 ± 0.67^{ef}	3.00 ± 0.50^{fg}	2.53 ± 0.40^{fg}	2.64 ± 0.56^{fg}
With CBO	–	5.71 ± 1.07^{cd}	4.75 ± 1.47^{de}	5.35 ± 2.24^{cd}	4.75 ± 1.57^{de}	2.64 ± 0.49^{fg}
With CBO + SBO	–	8.45 ± 1.04^{b}	5.56 ± 0.32^{cd}	6.76 ± 1.61^{c}	4.68 ± 1.79^{de}	3.14 ± 0.56^{fg}

Numbers are mean ± standard deviation (n = 12). Mean values with different superscript letters are significantly different ($P < 0.05$).

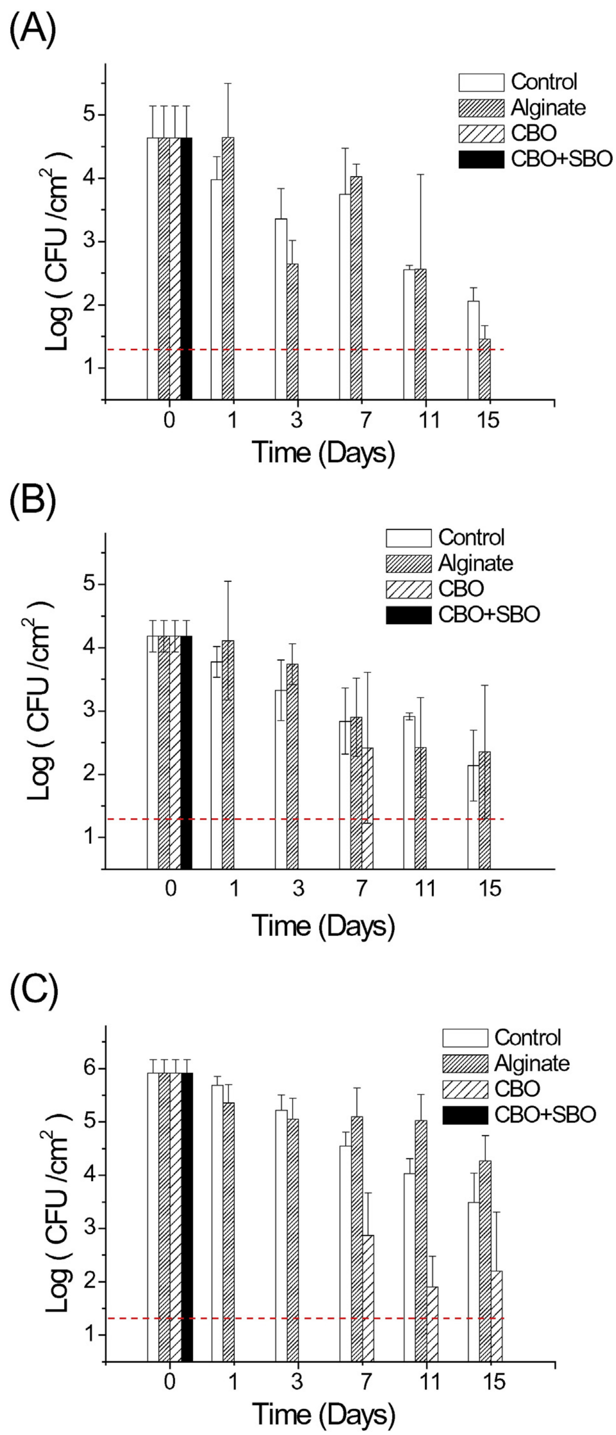

Fig. 3. Growth of *S. enterica* (A), *E. coli* O157:H7 (B) and *L. monocytogenes* (C) on cantaloupe surfaces at 21 °C after different coating treatments. Numbers at day 0 are the bacteria population before coating. Error bars are standard deviations (n = 4).

(Behrsing et al., 2003). Nonetheless, the ability of pathogens to survive during storage under ambient conditions presents a risk for foodborne illnesses (Sagoo et al., 2003).

For *E. coli* O157:H7, the CBO coating treatments with and without SBO reduced the pathogen to the detection limit after 1-day storage with no recovery during 15 day storage. For coating treatments with CBO, populations of 2.5 and 3.0 log CFU/cm^2 were detected at day 7 for *S. enterica* and *L. monocytogenes*, respectively. *S. enterica* became undetectable after 11 and 15 day storage, while *L. monocytogenes* maintained a relatively high level. In contrast, all three pathogens were absent during 15 days of storage when both CBO and SBO were used.

The observation that CBO in coatings was slightly more effective against *E. coli* O157:H7 than *S. enterica* agreed with a previous study (Smith-Palmer et al., 1998). *L. monocytogenes* populations were ca. 0.5 and 1.4 log CFU/cm^2 higher on day 7 compared to *S. enterica* and *E. coli* O157:H7 that may be due to a more rapid adaptation to the antimicrobial by *L. monocytogenes* (Lundén et al., 2003).

While it is difficult to quantify the amount of CBO remaining on cantaloupes, residual CBO in cast alginate films prepared from the same coating mixtures was measured in a separate study (Zhang et al., 2015). The CBO in alginate films with 2% CBO without SBO decreased ~70% after 3 d storage compared to ~44% decrease in films prepared with 2% CBO and 0.5% SBO. Therefore, the volatility of CBO may be responsible for the reduced antibacterial activity of antimicrobial coatings on cantaloupes during extended storage. Better inhibition of *S. enterica* and *L. monocytogenes* by CBO with SBO than CBO alone may be attributed to better retention in the presence of SBO. The coating with alginate only showed better survival of *L. monocytogenes* than the control. This might be attributed to the water-binding ability of alginate coating to provide a relatively moist environment to benefit the survival of bacteria (Remunan-Lopez and Bodmeier, 1997). The results in Fig. 3 suggest that the coating with both CBO and SBO can provide a long-term effectiveness in controlling the contaminating foodborne pathogens.

It should however be noted that the protocol in the present study may result in observations different from treatments inoculating entire cantaloupes. Inhibition of pathogens on the stem scar can be different from circumference (as used in this study). The possibility of pathogen internalization was not studied. These important questions are to be answered in real production settings using surrogates to validate the effectiveness of coatings.

3.4. Growth of yeasts and molds on cantaloupes as affected by antimicrobial coatings

The effects of coating systems on the native mycoflora of cantaloupes during room temperature storage for 5 days are shown in Fig. 4. Coating treatments with CBO and CBO + SBO reduced the yeast and mold counts to significantly greater extent (ca. 1.8 and 2.6 log CFU/cm^2 lower, respectively) than with the control and alginate only treatments. The alginate coating actually had a slight increase in yeast and mold counts possibly due to the increased moisture content on the surface, as discussed above. The results suggest that coatings with CBO are effective against the native mycoflora on cantaloupes and hence can be used to preserve the quality of cantaloupes.

Approximately 6 g of mixtures was estimated to have coated on one cantaloupe, and the material costs of coating 100 cantaloupes were

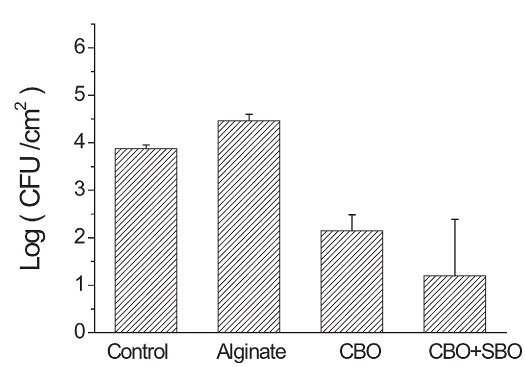

Fig. 4. Effects of coating treatments on the population of yeasts and molds on cantaloupe surfaces during storage at room temperature for 5 days. Error bars are standard deviations (n = 3).

estimated to be \$0.41. Considering operating costs, the total costs for each cantaloupe are expected to be less than 1 cent for the CBO + SBO formulation. The additional coating costs can be justified by the reduced number of recalls and the extended shelf-life of cantaloupes. Our findings can directly benefit melon producers to reduce the outbreak of foodborne illnesses and can be applied to other fruits and vegetables.

4. Conclusions

Findings from the present study demonstrate that alginate coatings with CBO can be used to preserve the microbiological safety and quality of whole cantaloupes. By incorporating 0.5% SBO in the coating treatment with 2.0% CBO, inactivation to the limit of detection of the foodborne pathogens *S. enterica*, *E. coli* O157:H7 and *L. monocytogenes* was achieved during ambient storage for 15 days. This coating formulation was also most effective in inhibiting the growth of native yeasts and molds on cantaloupes and delaying color change and softening of cantaloupes during storage.

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