1 **Microbial Safety and Overall Quality of Cantaloupe Fresh-cut Pieces Prepared from**
2 **Whole Fruit after Wet Steam Treatment[†]**

3 Dike O. Ukuku¹, David J. Geveke, Lee Chau and Brendan A. Niemira

4 *Food Safety and Intervention Technologies Research Unit, U.S. Department of Agriculture,*
5 *Agriculture Research Service, Eastern Regional Research Center, 600 East Mermaid Lane,*
6 *Wyndmoor, PA 19038*

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11 ¹ Author for correspondence. Tel: 215-233-6427; Fax: 215-233-6406

12 E-mail: address: dike.ukuku@ars.usda.gov.

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ABSTRACT

Fresh-cut cantaloupes have been associated with outbreaks of Salmonellosis. Minimally processed fresh-cut fruits have a limited shelf life because of deterioration caused by spoilage microflora and physiological processes. The objectives of this study were to use a wet steam process to 1) reduce indigenous spoilage microflora and inoculated populations of *Salmonella*, *E. coli* O157:H7 and *Listeria monocytogenes* on the surface of cantaloupes, and 2) reduce the populations counts in cantaloupe fresh-cut pieces after rind removal and cutting. The average inocula of *Salmonella*, *E. coli* O157:H7 and *Listeria monocytogenes* was 10^7 CFU/ml and the populations recovered on the cantaloupe rind surfaces after inoculation averaged 4.5, 4.8 and 4.1 log CFU/cm², respectively. Whole cantaloupes were treated with a wet steam processing unit for 180 s, and the treated melons were stored at 5°C for 29 days. Bacterial populations in fresh-cut pieces prepared from treated and control samples stored at 5 and 10°C for up to 12 days were determined and changes in color (CIE L*, a*, and b*) due to treatments were measured during storage. Presence and growth of aerobic mesophilic bacteria and *Salmonella*, *E. coli* O157:H7 and *L. monocytogenes* were determined in fresh-cut cantaloupe samples. There were no visual signs of physical damage on all treated cantaloupe surfaces immediately after treatments and during storage. All fresh-cut pieces from treated cantaloupes rind surfaces were negative for bacterial pathogens even after an enrichment process. Steam treatment significantly ($p < 0.05$) changed the color of the fresh-cut pieces. Minimal wet steam treatment of cantaloupes rind surfaces designated for fresh-cut preparation will enhance the microbial safety of fresh-cut pieces, by reducing total bacterial populations. This process holds the potential to significantly reduce the incidence of foodborne illness associated with fresh-cut fruits

1. Introduction

Fruits and vegetables are frequently in contact with soil, insects, animals, or humans during growing or harvesting and in the processing plant (Ukuku et al., 2012). Thus, their surfaces are exposed to natural contaminants, and by the time they reach the packinghouse, most fresh produce retain populations of 4 to 6 log microorganisms/g (Beuchat, 1995; Ukuku et al., 2001). Fresh fruit and vegetable produce are ranked the fourth food category responsible for foodborne illnesses in the United States, implicated in 1.2 million illness, 7,100 hospitalizations, 134 human deaths, and \$1.4 billion in associated illness costs each year (Batz et al., 2011). FDA survey of imported fresh produce reported an incidence of 5.3% positives for *Salmonella* and 2% for *Shigella* in 151 samples of cantaloupes, with all contaminated samples originating in Mexico, Costa Rica and Guatemala (FDA, 2001). Surface structures of watermelon, honeydew and cantaloupe rinds differ and thereby affect bacterial attachments and decontaminations. According to the FDA, *Salmonella*, *E. coli* O157:H7, *Shigella*, and *L. monocytogenes* have been isolated from a wide variety of produce including tomatoes, peppers (jalapeño and Serrano), cantaloupes, mangoes, green onions, parsley, cabbage, cucumbers, and radishes. Specific mechanisms of contamination of produce are unknown, although several explanations have been offered (Ukuku and Fett, 2002, 2004, 2006). The ability of pathogenic bacteria to adhere to surfaces of fruits and vegetables continues to be a potential food safety problem of great concern to the produce industry (Ukuku and Fett, 2006).

The mechanism of attachment of bacterial cells to plant surfaces has been studied most extensively for plant pathogens and symbionts (Takeuchi and Frank, 2001, Takeuchi et al., 2000, Ukuku and Fett, 2002, Ukuku and Fett, 2006, Zogaj et al., 2001). The outer surface (rind) of a cantaloupe presents a variety of area to which a bacterium may bind (Ukuku et al., 2004). The

epidermal cell surface is ruptured with a meshwork of raised tissue (the net). This net consists of lenticels and phellum (cork) cells (Ukuku et al., 2005). Bacterial attachment to surfaces is influenced not only by cell surface charge (Fletcher, M., and G. I. Loeb. 1979) but also by the presence of particular surface appendages such as flagella and fimbriae as well as extracellular polysaccharides (Fletcher and Floodgate, 1973, Frank, 2000). The longer the attached bacteria stay on the produce surface, the more difficult it becomes to decontaminate due to possible formation of biofilm (Annous et al., 2005, Ukuku et al., 2005, Ethan et al., 2005). There is a need for a better approach for treating produce surfaces for mitigating the problems stated above.

Methods of applying sanitizers for effective reduction of bacteria on melon rind surfaces have been reported (Ukuku and Fett, 2004). Wash water containing up to 200 ppm chlorine is routinely applied to reduce microbial contamination in produce processing lines (Ukuku et al., 2013, Wei et al., 1995). However, the use of chlorine is of concern due to the potential formation of harmful by-products (Richardson et al., 1998) and can only achieve approximately 2 to 3 log reductions of native microflora and other pathogens depending on type and method of application and washing treatments (Ukuku et al., 2012). Efficacy of hydrogen peroxide in reducing attached bacteria on whole cantaloupe surfaces, preservation of fresh fruits and fresh-cut melons (Ukuku et al., 2005, Ukuku, 2004, Ukuku et al., 2004) have been reported. We have investigated hydrogen peroxide wash for reducing attached bacteria on whole cantaloupe surfaces (Ukuku et al., 2014). Hot water decontamination of whole cantaloupe surfaces designated for fresh-cut industries could have major advantages over the use of chemicals, including near elimination of pathogenic vegetative bacteria, thus reducing the probability of potential transfer of pathogenic bacteria from the rind to the interior tissue during cutting (Ukuku

et al., 2004, Annous et al., 2005). In all the studies, the authors reported 2-3 log reduction depending on type and method of application and washing treatments.

Agricultural Research Service engineers developed and patented the vacuum-steam-vacuum (VSV) process for reducing bacteria on the surfaces of solid foods, especially raw food, without causing thermal damage to the food (Richardson, et al., 1998, Shewfelt, 1987, Ukuku et al, 2001, Ukuku and Sapers, 2001, Ukuku et al, 2004). The VSV surface intervention employs a short exposure to vacuum to remove any insulating fluids, followed by a quick burst of condensing steam that rapidly transfers energy directly to the contaminated sample. Although the surface debris is removed with the initial application of vacuum, the condensing steam itself continuously deposits an insulating water (condensate) layer during processing and microbial reduction on cantaloupe rind surface was approximately 2 log (Ukuku et al, 2004). In this study, we explored the efficacy of using flash wet steam treatments for inactivating native microbial and inoculated populations of *S. enterica*, *E. coli* O157:H7 and *L. monocytogenes* on cantaloupe rinds surfaces designated for fresh-cut preparation. The effect of wet steam treatments in reducing bacterial populations from the surface of treated cantaloupes and transfer to the interior flesh during fresh-cut preparation was investigated. Also, the distance of the wet steam nozzle to cantaloupe rind surfaces in relation to changes in rind surface temperatures was studied. Finally, changes in the physical and color characteristic of whole treated melons and fresh-cut pieces prepared after treatments were analyzed.

2. MATERIALS AND METHODS

2.1. Bacterial strains, growth conditions, and preparation.

Bacterial strains used in this study were *Escherichia coli*, O157:H7 strains SEA13B88 and Oklahoma apple juice cider-related outbreaks; *Salmonella* Stanley H0558 (alfalfa sprouts-related

outbreak), *S. Poona* RM2350, *S. saphra* 97A3312 (cantaloupe-related outbreaks); and *Listeria*
monocytogenes Scott A (clinical isolate), *L. monocytogenes* F8385 (carrot, Serotype 1/2b), and
G1091 (coleslaw, Serotype 4b) both were obtained from Dr. Larry Beuchat, Univ. of Georgia .
Except where designated, bacterial strains were obtained from the USDA-ARS-ERRC culture
collection. Bacteria were maintained on Brain Heart Infusion Agar (BHIA, Difco, Detroit, MI)
slants held at 4°C. Prior to use, the cultures were subjected to two successive transfers by loop
inocula to 5 ml Brain Heart Infusion Broth (BHIB, Difco) (*Salmonella* and *E. coli*) and 5 ml
Trypticase Soy Broth supplemented with 0.6% yeast extract (TSBYE, Difco) for *L.*
monocytogenes. A final transfer of 0.2 ml was made into 20 ml BHIB or TSBYE with incubation
at 36°C for 18 h under static conditions. The bacterial cells were harvested by centrifugation
(10,000 g, 10 min) at 4°C. The cell pellets were washed in salt-peptone [0.85% NaCl, 0.05 %
Bacto-peptone (Difco)]. The cell pellets were used to prepare three different types of inoculum
as stated below. The first inoculum type consisted of the individual bacterial strains at 10⁸
CFU/ml. The second inoculum type consisted of a mixture containing strains of individual
genera (3 to 4 strains/genus). The final inoculum consisted *Salmonella*, *E. coli*, and *L.*
monocytogenes at concentrations of 1.23 x10⁷ CFU/ml, 2.26 x 10⁷ CFU/ml and 2.35 x 10⁷
CFU/ml, respectively. All inocula were prepared in 3 L of 0.1 % (w/v) peptone-water.

2.2. Inoculation of whole melon.

Unwaxed whole “Western shippers” cantaloupes (1745 to 1778 g) purchased from a local
distributor were placed on a bench top for 18-20 h to allow the melons to come to room
temperature (~20°C) before being inoculated. All bacterial inoculation on cantaloupe rind
surface and decontaminations was performed inside a biosafety cabinet (Nuair, Class II, Type

A2, Plymouth, MN. USA). For inoculation, two cantaloupes at a time were submerged in 3 L of each bacterial inoculum stated above and agitated by stirring with a glove-covered hand for 5 min to ensure uniform inoculation. Twenty-four cantaloupes were inoculated with bacterium. After inoculation, the cantaloupes were placed inside a biosafety cabinet to dry for 1 h and then were stored at 5°C for up to 7 days before treatments and fresh-cut preparation.

2.3. *Wet steam treatments.*

The steam generator used in this study was a 915 Power Steamer (Wagner SprayTech Corp. MN). It is a pressurized system that supplies steam at the touch of a button. The chamber was filled with 1.5 L of tap water and the system took about 5-10 min to generate steam. A filled up tank generated steam for approximately 30 min. Changes in surface temperatures and the distance of the wet steam nozzle to the whole melon was measured and temperatures recorded immediately upon contact with the wet steam. The effect of wet steam nozzle placement in relation to changes on the surface temperature of treated whole melons were investigated at a distance of 0, 2.5, 5.1, 7.6, 10.2, 10.8 and 11.4 cm and the appropriate temperature values on melon rind surfaces were recorded using a digital thermometer (Fischer Scientific, USA). When the wet steam nozzle was adjusted to a shorter distances of 7.6 cm to the melon surface, a surface temperature of 68°C (0- 70 s) was achieved. Cantaloupes and other produces are heat sensitive and to minimize thermal effect on the rind surfaces, 7.6 cm was chosen as the appropriate distant for the nozzle for rest of the treatment study. For treatments, two types of treatment procedure with the steam nozzle placed at distance of 7.6 cm was investigated. For the first type of treatments, the melons were hosed down in a sweeping motion using the wet steam nozzle for 3 min. In another study to investigate the effect of non-sweeping motion, inoculated melons were

again placed at a distance of 7.6 cm below the nozzle and the steam treatments applied steadily for 3 min without moving the nozzle. Immediately after treatment, fresh-cut pieces were prepared from some of the treated and untreated melons and the rest stored at 5°C for 7 days before fresh-cut preparation. Populations of surviving colony forming units (CFU) of aerobic mesophilic bacteria and the inoculated *Salmonella*, *L. monocytogenes* and *E. coli* O157:H7 bacteria on all treated (steady and sweeping treatments) and untreated cantaloupe rind surfaces were determined on a range of media as described below including quality parameters of fresh-cut pieces from treated and untreated cantaloupes . The inoculation procedure and the wet steam treatments were randomized and replicated.

2.4. Microbiological examination.

To determine bacterial populations on cantaloupe rind surfaces before and after wet steam treatments, plugs (n = 40) of cantaloupe rind (2.2 cm diameter) weighing approximately 25 g total were cut with a sterile stainless steel cork borer and blended (Waring commercial blender, speed level 5, 1 min) in 75 ml of 0.1% peptone-water. Aerobic mesophilic bacteria on cantaloupe rind surface were enumerated by plating on BHIA, incubated at 35°C for 24 h (Messer *et al.* 1984). *Salmonella* was enumerated on Xylose Lysine Sodium Tetradecylsulfate (XLT4, BBL/Difco, Sparks, MD) agar with incubation at 37°C for 24 h. For comparison, a pure culture of *Salmonella* was plated on XLT4 agar (BBL/Difco), incubated as above, and run parallel with the samples. Selected black or black-centered colonies from the agar plates were confirmed to be *Salmonella* according to the FDA Bacteriological Analytical Manual following conventional biochemical methods (Andrew *et al.*, 1995). For enumeration of *E. coli*, plating was done on Cefixime Tellurite Sorbitol MacConkey agar (CT-SMAC, BBL/Difco) with incubation at 37°C

for 24 h. Selected colonies were confirmed to be *E. coli* as described by Hitchins et al. (1995). To enumerate *L. monocytogenes*, plating was performed on Modified Oxford Agar (MOX agar, Difco) incubated at 37°C for 48 h (Heisick et al., 1995). In addition, pure cultures of *L. monocytogenes* were surface plated onto MOX agar to serve as references for identification. Representative presumptive colonies of *L. monocytogenes* were subjected to the API *Listeria* tests (bioMeriux Marcy l’Etoile, France).

2.5. *Transfer of pathogens from the rind to the flesh during cutting.*

All utensils used for fresh-cut preparations were sanitized with 200 ppm chlorine. Inoculated cantaloupes, with or without prior treatments, were cut into four sections using a sterile knife. Each section was further cut and the rinds carefully removed. The interior flesh was cut with a second sterile knife into ~3 cm cubes, and 100 g of the cubes were placed in a Stomacher® bag along with 200 ml Difco nutrient broth and pummeled for 30 s in a Stomacher 400 (Dynatech Laboratories, Alexandria, VA). Plate Count Agar (PCA) with incubation at 35°C for 24h was used for enumeration of mesophilic aerobic bacteria. For *Salmonella*, XLT4 agar with incubation at 37°C for 24 h was used to count the colony forming units (CFU) of the bacteria. For comparison, a pure culture of *Salmonella* plated on XLT4 agar (Difco), incubated as above, and run parallel with the samples was used. Selected colonies from the agar plates were confirmed to be *Salmonella* according to the FDA Bacteriological Analytical Manual following conventional biochemical methods stated above as well as serological assays using latex agglutination (Oxoid, Ogdensburg, New York). Bacterial count for *E. coli* O157:H7 was performed on CT-SMAC with incubation at 37°C for 24 h. Selected colonies were confirmed to be *E. coli* O157:H7 as stated above. For *L. monocytogenes*, *Listeria* identification agar (PALCAM, Sigma) containing *Listeria*

selective supplement (L-4660, Sigma) was used with incubation at 37°C for 48 h (Ukuku et al., 2012, 2014). In addition, pure cultures of *L. monocytogenes* were surface plated onto PALCAM agar to serve as references for identification. Representative presumptive colonies of *L. monocytogenes* were subjected to the API *Listeria* tests (bioMeriux Marcy l’Etoile, France).

Presence of human bacterial pathogens in fresh-cut pieces was also determined by enrichment methods. For the enrichment methods, approximately, 100 g of the interior flesh of all treated and untreated fresh-cut pieces were placed in a Stomacher® bag along with 200 ml Modified tryptone soya broth (mTSB, Oxoid) for *E. coli* O157:H7, Rappaport broth (Oxoid) for *Salmonella* or UVM broth (BBL/Difco) for *L. monocytogenes*. All samples were pummeled for 30 s in a Stomacher at medium speed followed by incubation at 35°C for 24 h. Aliquots (0.1 ml) of each undiluted homogenate from the enriched samples were plated on selective media for each bacterium stated above. The experiments were conducted three times with duplicate determination of colony forming units (CFU).

2.6. Effect of treatment on melon quality and stability

To determine whether flash steam treatment would have any adverse effects on whole cantaloupes, uninoculated, inoculated and treated cantaloupes were stored for as long as 29 d at 5 °C and were observed for indications of abnormal ripening, decay, or other defects. Periodically, melons were cut open and the flesh examined for indications of softening, discoloration or off-odor formation. Also, melons were periodically weighed to determine whether treatments resulted in moisture loss due to alteration of rind structure and permeability resulting from treatments.

2.7. Color analysis.

Color (CIE L*, a*, b*) was measured with a CR-400 Chroma meter (Konica Minolta Sensing Americas, NJ) using a 8 mm measuring aperture every three days during storage. L*, a*, and b* indicate luminosity, chromaticity on a green (–) to red (+) axis, and chromaticity on a blue (–) to yellow (+) axis, respectively (Chen, et al., 2010). The colorimeter was calibrated using the standard light trap and a white tile (L* 59.51, a* 13.08 and b* 37.99). D65 were the illuminant/viewing geometry. Two readings were taken on randomly selected opposite cut surfaces of each piece. Again, 5 out of 8 pieces per plate were measured for each experiment. Hue and chroma values were calculated from the following equations: $\text{Hue} = \tan^{-1}(b^*/a^*)$ and $\text{chroma} = (a^{*2} + b^{*2})^{1/2}$.

2.8. Data Analysis.

Microbial data determined from cantaloupe surfaces and fresh-cut pieces were converted to $\log_{10}$ CFU/cm² and $\log_{10}$ CFU/g, respectively. These values were appropriately analyzed for differences in response to treatments using analysis of variance (ANOVA) and the Bonferroni LSD method (Miller, 1981) to determine significant differences ($p \leq 0.05$). All statistical analyses were performed with Statistical Analysis System SAS/ STAT software (SAS Institute, Cary, NC., U.S.A.).

3. Results and discussion

3.1. Effect of wet steam on native and inoculated bacterial populations on cantaloupe surface.

The surfaces of cantaloupes purchased from a whole sale distributor were tested for the presence of bacterial pathogens immediately after purchase and storage at 5°C and the result is shown in Table 1. All cantaloupes tested were negative for *L. monocytogenes*, *E. coli* O157:H7

and *Salmonella* before inoculation and testing. The average populations of *L. monocytogenes*, *E. coli* O157:H7 and *Salmonella* recovered on the rind was 4.1 ± 0.1 , 4.8 ± 0.1 and 4.5 ± 0.2 log CFU/cm², respectively. The surface temperature as function of treatment distance between the cantaloupe and the steam nozzle was determined (Figure 1). The results showed substantial changes in temperature of the cantaloupe rind surface. When cantaloupes were positioned at shorter distances (2.5-5.1 cm) from the source of the wet steam, surface temperature of the cantaloupe rind where the steam made contact was slightly higher ($p>0.05$) during treatment applications indicating that the shorter the distance the cantaloupe is placed to the nozzle, the higher the surface temperature will be. The steam temperature at a distance of 7.6 cm from the steam nozzle averaged 68°C on cantaloupe rind surface within 60 s of application and because cantaloupe is a heat sensitive produce and in an attempt to minimize heat treatment, a distance of 7.6 cm from the nozzle was chosen for the rest of the study.

Efficacy of steady wet steam treatments at a particular spot on the surface of cantaloupe rind for 3 min resulted in approximately 3.6 log reduction of aerobic mesophilic bacteria and 4 log reductions of each bacterial pathogens. Treatments with a sweeping motion resulted in an approximate 2.4 log reduction of aerobic mesophilic bacteria and 3 log reduction of all pathogens tested. The results indicate that the method of treatment (sweeping or fixed) application is very important as fixed treatments resulted in an additional 1 log reduction. The extra 1 log inactivation of bacteria from fixed (spot) treatments for 3 min could be attributed to a combination of factors; direct steady wet steam treatment, constant impact of steam temperature and pressure at a spot than when the nozzle was moved in a sweeping motion.

3.2. Effect of steam treatments on whole cantaloupe quality and stability

Treated cantaloupes at 7.62 cm away from the steam nozzle showed no evidence of physiological disorders, decay or other effects after treatments and during storage for 29 d at 5 °C. In contrast, untreated controls showed mold growth in the stem scar area as early as 6 d into storage. Visual observations of wet steam treated whole cantaloupes indicated that treatments enhanced the color of the melon (Figure 2) and this observation was noted even on treated cantaloupes stored at 5°C for 7 days. The L*, a* and b* and the calculated Hue and chroma values were significantly ($p<0.05$) higher than those of the controls. Weight losses were significantly ($p>0.05$) different and averaged about 0.8% in untreated controls and 4% in treated melons. Physical appearance of the fresh-cut pieces prepared immediately from the wet steam-treated cantaloupe was not different from those prepared from the control. Cut, treated cantaloupes showed no softening, discoloration or off-odor formation, initially or after storage for as long as 15 d. Visual inspection of fresh-cut pieces stored at abusive temperature of 10 or 22°C revealed a slimy appearance on some of the samples (Data not shown). Sliminess was observed by day 6 of storage at 10°C compared to day 9 at 5°C. Yeast and mold spots were observed on fresh-cut pieces stored at 22°C by day 2 for control and day 5 for fresh-cut pieces stored at 10°C.

3.3. Effect of wet steam treatments on quality changes of fresh-cut cantaloupes.

Cut, treated cantaloupes showed no softening, discoloration or off-odor formation, initially or after storage for as long as 7 d. The L* values of fresh-cut pieces prepared from melons treated for 180 s and stored at 5°C for 7 days was slightly higher while the a* and b* values including the calculated Hue and chroma values were significantly ($p>0.05$) lower than the control. Treatments for 3 min increased the calculated Hue values while a* and b* and the calculated

chroma values were significantly lower than the control ($p>0.05$) (Table 2). Visual observation of treated whole melons stored at 5°C for 7 day before fresh-cut pieces preparation were similar to fresh-cut pieces prepared immediately after treatments. There were no significant changes in fresh-cut pieces prepared from cantaloupes immediately after treatment and those prepared after treatment and storage for 7 days at 5°C (Table 3). The L^* , a^* and b^* values for fresh-cut pieces prepared from melons treated for 60 and 120 s were not significantly ($p<0.05$) different but were different ($p<0.05$) than fresh-cut pieces prepared from control. During storage of fresh-cut pieces at 10°C, the a^* values, that is the chromatic spectrum of green to red of all samples decreased by day 6, indicating that these samples had a shorter shelf life than those stored at 5°C. The b^* values of the chromatic spectrum of blue to yellow of fresh-cut pieces prepared from treated cantaloupes were significantly ($p<0.05$) higher than those of the controls. The reason for the higher b^* values in wet steam-treated samples is probably due to the absence of yeast and mold spots. Hue values of samples treated with steam were generally lower than the controls during the entire storage period at both temperatures. Similarly, observation in chroma values between steam-treated samples and the controls on day 8 at 10°C was significantly ($p<0.05$) different, indicating that steam treatment preserved the saturation of cantaloupe color (Data not shown). Wet steam treatment had no consistent effect on texture of cut cantaloupe in terms of either maximum force or area (Table 3). A day-to-day variability in textural parameters observed could have been due to variation in ripeness among melons. It is unlikely that consumers could distinguish the color difference among samples from the three experimental groups except for samples stored for 9 days at 10°C.

3.4. Survival of transferred bacteria during storage of fresh-cut melons.

Presence of aerobic mesophilic bacteria including inoculated populations of *Salmonella* and *E. coli* O157:H7 were detected on fresh cut cantaloupes prepared immediately after wet steam treatments but not on fixed treated cantaloupes. The level of aerobic mesophilic bacteria including *Salmonella* and *E. coli* O157:H7 transferred and determined on the fresh-cut pieces prepared from wet steam treatments of whole cantaloupe using the sweeping motion methods were very low, and only *L. monocytogenes* was not detected until day 9 of storage at 10 °C and 4°C (Figure 3). Populations of aerobic mesophilic bacteria including the *Salmonella*, *E. coli* O157:H7 and *L. monocytogenes* on the fresh-cut pieces were significantly ($p<0.05$) lower in treated cantaloupes than untreated.

The visual symptoms of deterioration of fresh-cut produce include flaccidity due to loss of water, changes in color resulting from oxidative browning at the cut surfaces, and microbial contamination (Rahman, 2007, Ukuku et al., 2013). The results of the current study on microbiological and sensory quality changes in fresh-cut pieces prepared from treated cantaloupes is similar to what has been reported in unwrapped and wrapped sliced watermelon (Abbey et al., 1988). Annous et al. (2004) found that hot water surface pasteurization of cantaloupes with pilot-scale equipment enhanced microbiological safety and extended shelf life. Our previous study using VSV treatments did not result in significant log reductions of surface microflora of cantaloupe compared with the hot water treatment (Ukuku et al., 2006) and the reason could be that the exposure time for the hot water treatments were 2 min compared to the 1.25 s using the VSV process. In this current study using wet steam alone, the exposure time was 3 min and this could explain the higher bacterial inactivation compared to the VSV treatment. In our previous study, we found increases in populations of all groups of microorganisms, including *Pseudomonas* spp., in all fresh-cut cantaloupes as storage time increased, regardless of the

treatment (Ukuku et al., 2006). Boyette et al. (1993) reported that the microbial decay of minimally processed lettuce is largely due to the growth of microorganisms originating from pre-harvest environments. In this study, spoilage yeasts and molds on fresh-cut cantaloupe pieces were below the limit of detection; however, as days of refrigerated storage increased, aerobic mesophilic microbes increased.

3.5 Conclusion

Wet steam processing inactivated and reduced the populations of *Salmonella*, *E. coli* O157:H7 and *L. monocytogenes* bacteria on contaminated whole melons and those transferred to fresh-cut pieces during fresh-cut preparation. Populations of *Salmonella* and *E. coli* O157:H7 recovered in fresh-cut pieces from treated melons averaged <2 CFU/g and were below (<1 CFU/g) detection for *L. monocytogenes*. Cantaloupe rind is very thick and acts as an effective insulator, and if wet steam exposure is minimal, the internal flesh used for fresh-cut preparation will not be affected as indicated by the sensory data. The increase in higher L* values of treated melons indicate that steam treatments preserved the lightness of the cantaloupe samples during post-treatment storage (Figure 2). In our study, visual inspection of fresh-cut cantaloupe pieces from wet steam treated cantaloupes did not reveal any signs of spoilage during storage at 5°C for up to 7 days suggesting that wet steam treatment of cantaloupe rind surface before fresh-cut preparation is an effective way of slowing microbial growth and extending shelf life of fresh-cut cantaloupe pieces. Minimal weight losses noted on treated cantaloupes may have resulted from disruption of natural waxes in the cantaloupe rind surface during exposure to wet steam treatments, thereby increasing water permeability of the rind. The information presented in this study will be a welcome

367 alternative to washing with chlorine and will complement the FDA (2008) guide to minimize
368 microbial food safety hazards of fresh-cut fruits.

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FIGURE LEGENDS

Figure 1. Changes in surface temperatures of cantaloupes rind surface relative to the wet steam nozzle distance at 0, 2.5, 5.1, 7.6, 10.2, 10.8 and 11.4 cm during processing of whole cantaloupes for 180 s.

Figure 2. Visual observation of physical appearance between wet steam treated and untreated whole cantaloupe surface after wet steam processing at a distance of 7.6 cm.

Figure 3. Populations of aerobic mesophilic bacteria, *Salmonella*, *Listeria monocytogenes* and *E. coli* O157:H7 recovered in fresh-cut cantaloupe pieces after treatment and storage at 5°C and 10°C for 12 days. (* = No *L. monocytogenes* was determined)

Table 1–Surviving populations of mesophilic bacteria and inoculated *E. coli* O157:H7, *L. monocytogenes* and *Salmonella* on cantaloupe surfaces before and after treatments^a.

Treatment	Log ₁₀ CFU/cm ²			
	Mesophilic bacteria	<i>E. coli</i> O157:H7	<i>Salmonella</i>	<i>L. monocytogenes</i>
Control	4.8 ± 0.2 (2.3)	4.8 ± 0.1 (2.4)	4.5 ± 0.2 (2.4)	4.1 ± 0.1 (2.0)
Steady ^b	1.2 ± 0.2 (0.9)	0.4 ± 0.2 (ND)	0.4 ± 0.1 (ND)	0.3 ± 0.1 (ND)
Sweeping motion ^c	2.4 ± 0.2 (1.4)	1.4 ± 0.1 (0.3)	1.5 ± 0.1 (0.3)	0.8 ± 0.1 (ND)

^aBacterial determination was performed 24 h post inoculation and storage at 5 °C and then treated.

^bFixed = Treatment was at a targeted spot for 3 min.

^cSweeping motion=Steam treatment was by sweeping motion in a parallel form for entire surface for 3 min.

Values in parenthesis represent Log CFU/g populations determined in fresh-cut pieces after treatments and fresh-cut preparation.

ND = none determined

Table 2. Average changes in color of whole cantaloupes rind surface before and after wet Steam treatments ^b

		Color				
Treatment	Time (s)	L*	a*	b*	Hue	Chroma
Control	0	63.1 ± 1.2b	-0.88 ± 0.3b	19.02 ± 0.7b	-87.4 ± 0.1b	18.9 ± 0.6b
Treated	180	68.6 ± 2.4a	0.05 ± 0.02a	22.38 ± 1.2a	89.9 ± 2.2a	22.4 ± 1.1a

^bValues are means ± standard deviation of three separate experiments with duplicate determinations. Mean in each column not followed by the same letter are significantly (p<0.05) different

Table 3. Changes in color and texture of fresh-cut cantaloupes pieces prepared from untreated and immediately after treatments of whole melons and those stored at 5°C for 7 days^Z

		Color					Texture	
Storage (days)	Treatment time (s)	L*	a*	b*	Hue	Chroma	Force (g)	Area
0	0	58.1±0.2ab	16.8±0.1a	41.2±0.4a	67.8±0.1bc	44.6±0.2a	1566±21a	5892±22a
	60	57.8±0.1b	16.6±0.2ab	40.7±0.2ab	67.7±0.1bc	43.9±0.2ab	1681±31a	6195±23a
	120	58.0±0.2ab	15.8±0.2b	40.0±0.1ab	67.8±0.2b	43.0±0.1b	1872±34a	6234±24a
	180	58.6 ±0.3a	15.6±0.2b	39.8±0.1b	68.6±0.4a	42.7±0.1c	1899±32a	6455±22a
7	0	58.0± 0.2a	16.9±0.1a	41.4±0.2a	67.8±0.1b	44.7±0.2a	1368±22a	5596±21a
	60	57.6± 0.1b	15.9±0.2b	40.7±0.1b	68.7±0.2a	43.7±0.1b	1384±18a	6264±22a
	120	57.7± 0.1b	15.6±0.2bc	40.0±0.1bc	68.7±0.2a	42.9±0.1c	1402±22a	6276±22a
	180	58.3± 0.2a	15.8±0.2bc	38.9±0.1c	67.9±0.1b	41.9±0.1d	1539±26a	6483±24a

^ZValues are means ± standard deviation of three separate experiments with duplicate determinations. Mean in each column not followed by the same letter are significantly (p<0.05) different.

Figure 1

Figure 2

Figure 3