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Microbial safety and overall quality of cantaloupe fresh-cut pieces prepared from whole fruit after wet steam treatment☆

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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*, *Escherichia 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/cm^2, 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.

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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, 7100 hospitalizations, 134 human deaths, and $1.4 billion in associated illness costs each year (Batz et al., 2004). 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*, *Escherichia coli* O157:H7, *Shigella*, and *Listeria 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, 2002a, 2004; Ukuku et al., 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, 2002a, 2002b; Ukuku et al., 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., 2005a, 2005b). Bacterial attachment to surfaces is influenced not only by cell surface charge (Fletcher

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and 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., 2005a, 2005b; 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 (Sapers and Simmons, 1998; Sapers et al., 1999; 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., 2005a, 2005b; 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 °*Chironomus 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 10^8 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 1.2×10^7 CFU/ml × 10 CFU/ml, 2.3×10^7 CFU/ml and 2.4×10^7 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 (Nuaire, 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.