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# Combination effect of saturated or superheated steam and lactic acid on the inactivation of *Escherichia coli* O157:H7, *Salmonella* Typhimurium and *Listeria monocytogenes* on cantaloupe surfaces

Sun-Ah Kwon[a,b,1], Won-Jae Song[a,b,1], Dong-Hyun Kang[a,b,*]

[a] Department of Food and Animal Biotechnology, Department of Agricultural Biotechnology, Center for Food and Bioconvergence, and Research Institute for Agricultural and Life Sciences, Seoul National University, Seoul, 08826, Republic of Korea
[b] Institutes of Green Bio Science & Technology, Seoul National University, Pyeongchang-gun, Gangwon-do, 25354, Republic of Korea

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ABSTRACT

The purpose of this study was to evaluate the effectiveness of the combination treatment of lactic acid immersion and saturated or superheated steam (SHS) on inactivation of foodborne pathogens on cantaloupes. Saturated steam (SS) treatments were performed at 100 °C, while SHS treatments were delivered at either 150 or 200 °C. *Escherichia coli* O157:H7, *Salmonella* Typhimurium and *Listeria monocytogenes*-inoculated cantaloupes were exposed to 2% lactic acid or sterile distilled water for 1 min followed by a maximum of 20 s of SS or SHS. Populations of each of the three pathogens on cantaloupes were reduced to under the detection limit (1.0 log CFU/cm$^2$) after the combination treatment of 2% lactic acid and 200 °C steam for 20 s. To compare the effect of the lactic acid treatment method, we conducted spray application with 2% lactic acid combined with SS or SHS treatment; however, no significant log reduction differences were found between immersion and spraying techniques. After combination treatment of cantaloupes for 20 s, color and maximum load values (a characteristic of texture) were not significantly different from those of untreated controls. The results of this study suggest that the combination treatment of lactic acid and SHS can be used as an antimicrobial intervention for cantaloupes without inducing quality deterioration.

## 1. Introduction

Cantaloupes (*Cucumis melo* L. var. *reticulatus* NAUD) are a popular part of the human diet. However, since cantaloupes develop on the ground, their outer surfaces can easily become contaminated with foodborne pathogens during production and processing (Bowen et al., 2006). The outer rind of cantaloupe has an irregular surface including many cracks, crevices, and pores, which provide considerable protected sites for harboring microorganisms, including foodborne pathogens (Ukuku and Fett, 2006). Thus, pathogens can be easily attached to the netted rind of cantaloupes and resist removal by washing or inactivation by sanitizing agents. Pathogens on cantaloupe surfaces can be transferred to the edible tissues and juices during cutting (Ukuku and Fett, 2002). Cantaloupes have been implicated as the contaminated food vehicle in numerous outbreaks of foodborne illnesses. In the two decades prior to 2006, 23 cantaloupe-associated outbreaks were reported for a total of 1434 illnesses, 42 hospitalizations, and two deaths (Bowen et al., 2006). Also, in 2011, the largest listeriosis outbreak in the USA to date occurred, and was also associated with cantaloupes resulting in 147 illnesses and 33 deaths (McCollum et al., 2013). In 2012, a cantaloupe-related outbreak involving 261 persons infected with strains of *Salmonella* Typhimurium and *Salmonella* Newport occurred. These outbreaks emphasize the need for an effective pathogen inactivation intervention to ensure safety of fresh cantaloupes. Despite these events, consumers do not recognize the potential food safety hazards associated with cantaloupe melons. A study conducted in the Republic of Korea in 2010, indicated that 73.9% of consumers washed fruits or vegetables with running water. Washing fruit and vegetables with running water is not enough to ensure the safety of fresh produce. The Ministry of Food and Drug Safety of Korea recommends soaking fresh produce in water for 1–5 min and washing them twice with fresh water for 30 s with agitation (Kang et al., 2015).

Various sanitizing methods have been used to reduce microbial contamination on cantaloupes. Washing with chlorinated water

* Corresponding author. Department of Agricultural Biotechnology, Seoul National University, Seoul, 08826, Republic of Korea.
*E-mail address:* kang7820@snu.ac.kr (D.-H. Kang).
[1] These authors contributed equally to this work.

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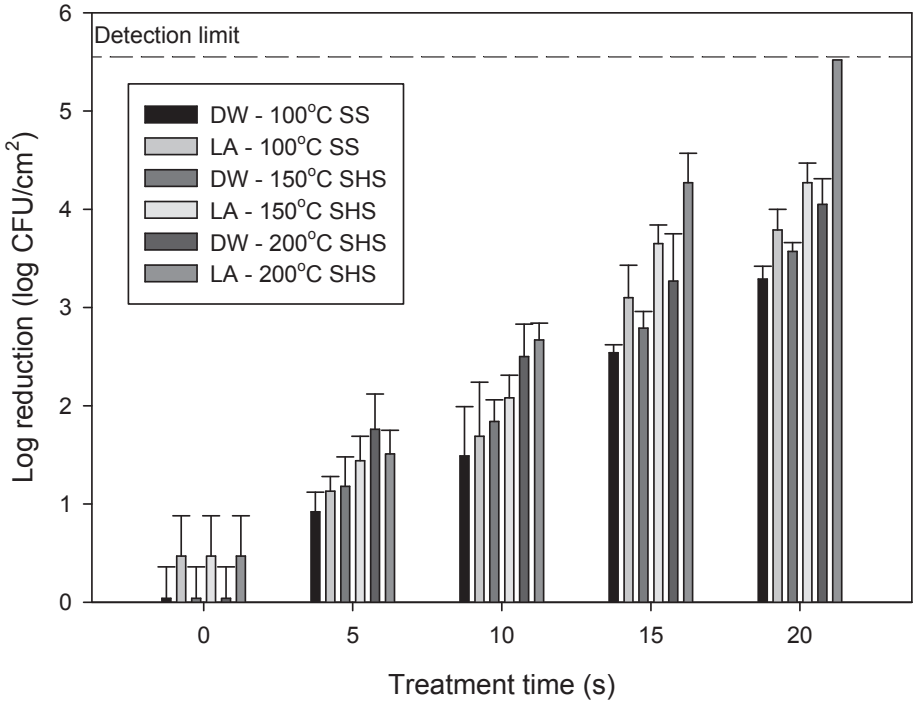


**Fig. 1.** Log reduction (log CFU/cm$^2$) of *E. coli* O157:H7 on cantaloupes treated with the combination of sterilized distilled water (DW) or 2% lactic acid (LA) and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS). The error bars indicate standard deviation calculated from triplicates.

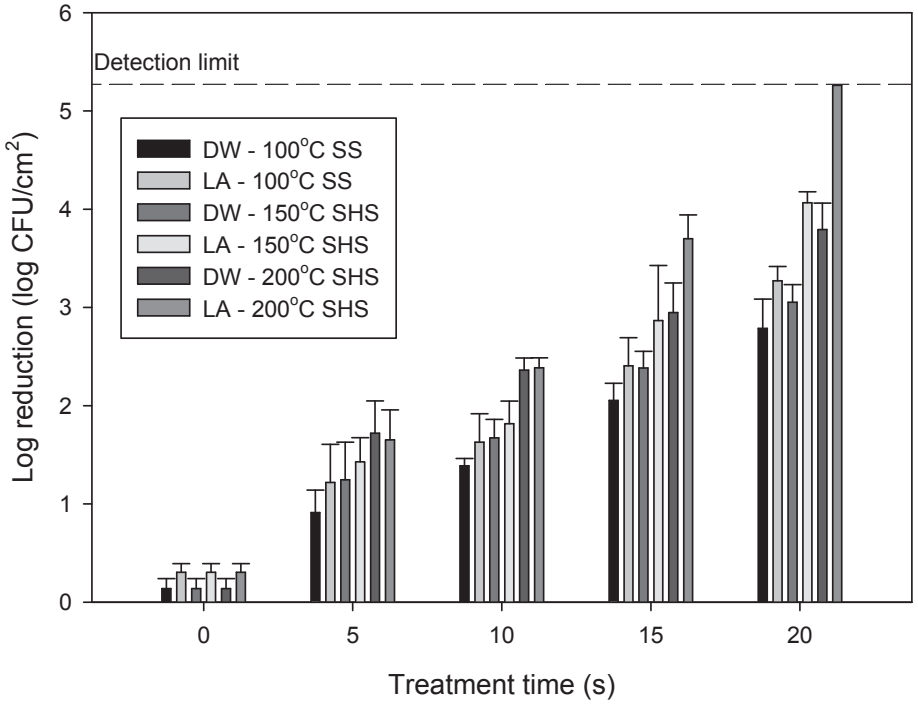


**Fig. 2.** Log reduction (log CFU/cm$^2$) of *S.* Typhimurium on cantaloupes treated with the combination of sterilized distilled water (DW) or 2% lactic acid (LA) and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS). The error bars indicate standard deviation calculated from triplicates.

containing up to 200 ppm free chlorine is commonly practiced in order to reduce microbial contamination of fresh produce. However, this method can only achieve a 1–2 log CFU reduction of native microflora on cantaloupes (Ukuku et al., 2001). Moreover, washing with chlorinated water can generate harmful by-products such as chloramines and trihalomethanes (Richardson et al., 1998). A previous study involving thermal treatment of whole cantaloupe at 76 °C for 3 min resulted in reduction of *Escherichia coli* populations in excess of 5 log CFU/cm$^2$ (Annous et al., 2004). However, this study did not investigate quality changes after conventional heating treatment and also conventional heating is a limited intervention which consumes intensive energy and large amounts of water. Forney et al. (2018) reported that aerated steam treatment at 85 °C for 4 min reduced populations of *Listeria innocua* on cantaloupe rind by 3.9 log CFU/cm$^2$. However, discoloration of rind occurred after steam treatment.

Superheated steam (SHS) is steam at a temperature above the

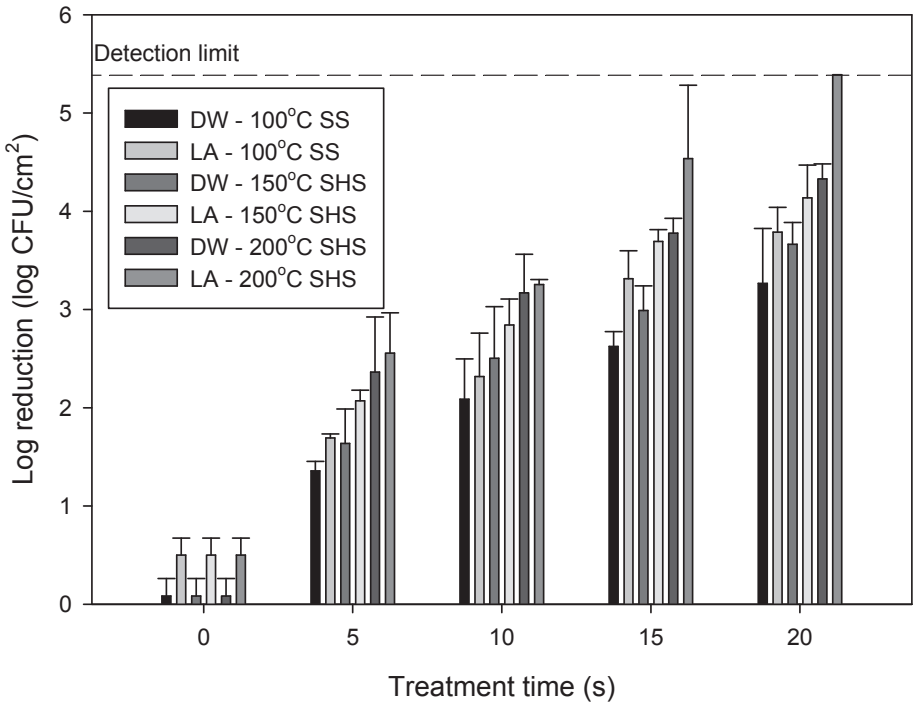


**Fig. 3.** Log reduction (log CFU/cm$^2$) of *L. monocytogenes* on cantaloupes treated with the combination of sterilized distilled water (DW) or 2% lactic acid (LA) and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS). The error bars indicate standard deviation calculated from triplicates.

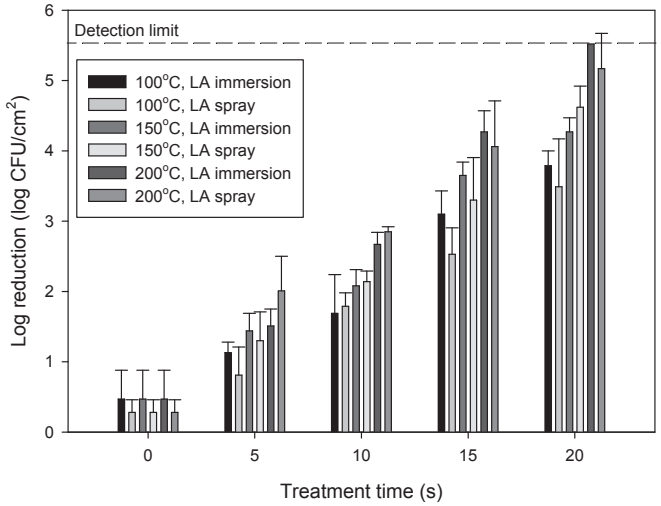


**Fig. 4.** Log reduction (log CFU/cm$^2$) of *E. coli* O157:H7 on cantaloupes treated with the combination of 2% lactic acid (LA) immersion or spray and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS). The error bars indicate standard deviation calculated from triplicates.

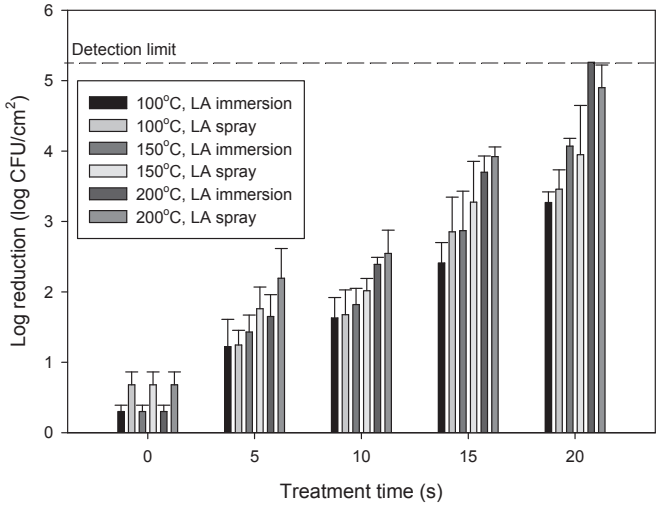


**Fig. 5.** Log reduction (log CFU/cm$^2$) of *S.* Typhimurium on cantaloupes treated with the combination of 2% lactic acid (LA) immersion or spray and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS). The error bars indicate standard deviation calculated from triplicates.

vaporization point at a constant pressure. SHS has higher enthalpy than saturated steam (SS), so it can quickly transfer heat to the material being processed (Alfy et al., 2016). SHS has the advantages of rapid heating, higher efficiency, and lower quality loss. Recently, we reported that *E. coli* O157:H7, *S.* Typhimurium and *Listeria monocytogenes* populations on cantaloupes were reduced by more than 5 log after a 200 °C SHS treatment for 30 s, but a$^*$(redness) and b$^*$(yellowness) values of treated samples varied slightly (Kwon et al., 2018). These quality changes were due to the long treatment time required by SHS. To improve the inactivation of foodborne pathogens on cantaloupes and also minimize quality change, combination treatments of steam with other methods may be useful. It is expected that the use of combined factors will have greater effectiveness for inactivating microorganisms than the use of any single factor alone (Leistner, 2000). In this study, lactic acid (LA) was used with steam treatment to produce a hurdle effect and increase disinfection efficacy. Incorporating LA with steam treatment was evaluated for possible synergistic effects.

Therefore, the objective of this study was (1) to determine and compare the effectiveness of individual treatments (steam or LA) and the combination of steam and LA for reducing microbial populations of cantaloupe surfaces inoculated with *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes*, (2) to compare the combination of spray or immersion treatments of LA with SS or SHS on the reduction of foodborne pathogens, and (3) to determine the effect of the combination treatment on quality factors of cantaloupes.

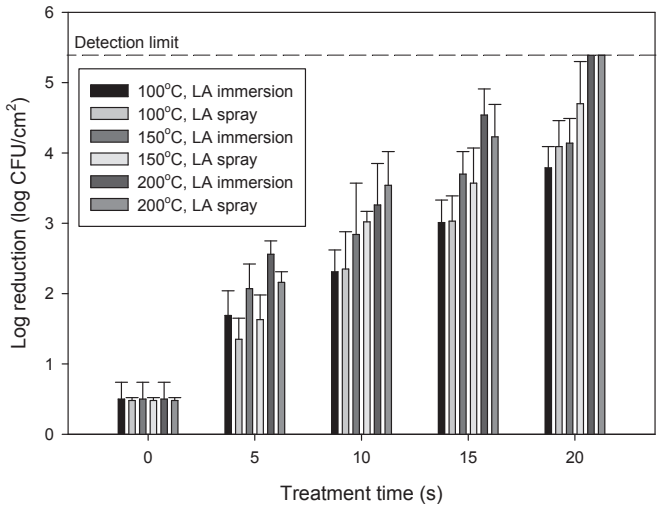


**Fig. 6.** Log reduction (log CFU/cm$^2$) of *L. monocytogenes* on cantaloupes treated with the combination of 2% lactic acid (LA) immersion or spray and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS). The error bars indicate standard deviation calculated from triplicates.

## 2. Materials and methods

### 2.1. Stock cultures

Three strains each of *E. coli* O157:H7 (ATCC 35150, ATCC 43889, ATCC 43890), *S.* Typhimurium (ATCC, 19585, ATCC 43971, DT 104) and *L. monocytogenes* (ATCC 15315, ATCC, 19114, ATCC, 19115), obtained from the bacterial culture collection of Seoul National University (Seoul, Republic of Korea), were used in this experiment. These strains were used in several previous studies which confirmed the effect of pasteurization method on fresh produce (Kim and Rhee, 2018; Kwak et al., 2011; Kwon et al., 2018). Stock cultures were kept frozen at −80 °C in 0.7 ml of tryptic soy broth (TSB; Difco, Becton, Dickinson, Sparks, MD, USA) and 0.3 ml of 50% glycerol. Working cultures were streaked onto tryptic soy agar (TSA; Difco), incubated at 37 °C for 24 h, and stored at 4 °C.

### 2.2. Preparation of pathogen inoculum

Each strain of *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes* was incubated in 5 ml of TSB at 37 °C for 24 h, harvested by centrifugation at 4000 × *g* at 4 °C for 20 min and washed twice with sterile 0.2% peptone (Bacto, Sparks, MD) water (PW). The final pellets were resuspended in sterile 0.2% PW to a concentration of approximately $10^7$–$10^8$ CFU/ml. The cell concentration was determined by plating onto TSA and incubating at 37 °C for 24 h. Suspended pellets of each strain of *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes* were combined to produce a culture cocktail.

### 2.3. Sample preparation and inoculation

Cantaloupes were purchased at a local grocery store (Seoul, South Korea) the day before each experiment and stored at 4 °C until use. Cantaloupes were washed by dipping them distilled water (DW) for 2 min to remove dust and then air dried at room temperature for 60 min in a laminar flow hood with the fan running to remove excess moisture. Cantaloupe rinds were cut into pieces (2 × 5 × 1 cm) using a sterile knife. A spot-inoculation method was used to inoculate *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes* onto samples. Two hundred μl of previously described culture cocktail was inoculated onto the rind side of each sample piece by distributing this volume between 20 droplets deposited at randomly selected locations with a micropipette. All inoculated samples were air-dried for 1 h in a laminar flow biological safety hood before treatment at room temperature (22 ± 2 °C).

### 2.4. Preparation of LA

Lactic acid reagent (LA; Daejung Chemical Co., Siheung-si, South Korea) was used to prepare treatment solutions of LA (2%, v/v) using sterile DW. LA solutions were prepared within 1 h before experiments. The pH of 2% LA was 2.12.

### 2.5. Combination treatment of steam treatment and acid

Dried inoculated cantaloupes were immersed in or sprayed with 2% LA or sterile DW. Treatment solutions for immersion or spraying were applied at room temperature (22 ± 2 °C) for 1 min. Then, cantaloupe pieces were spread in a single layer (rind side up) on a stainless steel treatment grid inside a stainless steel basket and placed in an insulated steam treatment chamber. A steam generator apparatus previously described by Ban et al. (2014) and Kwon et al. (2018) was used. Steam passed through a flexible hose and into the chamber by opening a steam valve. Pathogen-inoculated cantaloupe rinds were exposed to SS or SHS for 5, 10, 15, or 20 s. SS treatments were conducted at 100 °C, and SHS treatments were performed at 150 °C or 200 °C. The basket containing treated samples was immediately removed from the chamber after each treatment, and surviving bacteria on cantaloupe pieces were enumerated as described in the next section. Cantaloupes treated with steam combined with sterile DW and those immersed in LA alone were

**Table 1**
Change of L*, a*, b* and maximum load values (N) of cantaloupes treated with the combination of distilled water (DW) or 2% lactic acid (LA) and 100 °C (SS), 150 °C (SHS), or 200 °C (SHS).

| Treatment | L* | a* | b* | Maximum load (N) |
|---|---|---|---|---|
| Control | 65.24 ± 2.11A | −0.24 ± 0.66A | 21.55 ± 1.12A | 211.59 ± 18.54A |
| DW immersion | 65.49 ± 1.73A | 0.07 ± 0.75A | 22.40 ± 1.35A | 213.08 ± 12.46A |
| LA immersion | 63.74 ± 3.44A | −0.12 ± 0.51A | 21.99 ± 1.86A | 214.51 ± 11.92A |
| LA spray | 65.05 ± 2.02A | −0.65 ± 0.51A | 21.19 ± 1.44A | 217.02 ± 19.30A |
| DW immersion-100 °C, 20 s | 65.42 ± 3.84A | −0.60 ± 1.80A | 21.42 ± 0.68A | 216.76 ± 18.35A |
| LA immersion-100 °C, 20 s | 62.15 ± 0.98A | −0.19 ± 0.57A | 20.65 ± 0.39A | 214.85 ± 22.11A |
| LA spray-100 °C, 20 s | 64.13 ± 1.24A | −0.34 ± 0.62A | 21.16 ± 0.71A | 213.25 ± 20.83A |
| DW immersion-150 °C, 20 s | 65.58 ± 2.16A | −0.15 ± 0.88A | 21.38 ± 1.02A | 212.15 ± 16.33A |
| LA immersion-150 °C, 20 s | 63.89 ± 1.71A | −0.14 ± 0.10A | 21.46 ± 1.19A | 217.24 ± 21.84A |
| LA spray-150 °C, 20 s | 64.34 ± 0.69A | −0.77 ± 0.79A | 21.44 ± 1.03A | 217.05 ± 21.83A |
| DW immersion-200 °C, 20 s | 65.04 ± 1.67A | 0.04 ± 0.63A | 22.75 ± 2.15A | 209.46 ± 20.25A |
| LA immersion-200 °C, 20 s | 63.32 ± 0.17A | 0.02 ± 0.41A | 21.92 ± 0.39A | 215.07 ± 19.02A |
| LA spray-200 °C, 20 s | 64.09 ± 0.99A | −0.58 ± 1.58A | 21.16 ± 1.86A | 210.76 ± 16.50A |

The values are means ± standard deviations from three replications.
Means with different uppercase letters within a column are significantly different ($P < 0.05$).

used as controls.

### 2.6. Bacterial enumeration

At pre-selected treatment times, each treated sample was immediately transferred into a sterile stomacher bag (Labplas Inc., Sainte-Julie, Quebec, Canada) containing 100 ml of 0.2% PW at 4 °C and homogenized for 2 min with a stomacher (Easy mix; AES Chemunex, Rennes, France). After homogenization, 1 ml of the sample was serially diluted 10-fold in 9 ml of 0.2% PW, and 0.1 ml of appropriate diluents were spread plated onto Sorbitol MacConkey agar (SMAC; Difco), Xylose Lysine Desoxycholate agar (XLD; Difco), and Oxford Agar Base with antimicrobial supplement (OAB; MB Cell) to enumerate surviving populations of *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes*, respectively. When low bacterial numbers were anticipated, 250 μl of undiluted cell suspension was plated onto four plates of each respective medium. All plates were incubated at 37 °C for 24 h, and then colonies enumerated.

### 2.7. Enumeration of injured cells

Injured cells of *S.* Typhimurium and L. *monocytogenes* were enumerated using the overlay (OV) method. Sample portions of 100 μl from homogenates or diluents were spread onto TSA and incubated at 37 °C for 2 h to allow injured cells to resuscitate before overlaying with 7 ml of XLD (OV-XLD) or OAB (OV-OAB) for *S.* Typhimurium or L. *monocytogenes*, respectively. The plates were incubated at 37 °C for 22 h after the overlay solidified. To enumerate injured cells of *E. coli* O157:H7, phenol red agar base with 1% sorbitol (SPRAB; Difco) was used. Typical white colonies characteristic of *E. coli* O157:H7 were enumerated after incubation at 37 °C for 24 h. Randomly selected isolates from SPRAB plates were subjected to serological confirmation as *E. coli* O157:H7 using the *E. coli* O157:H7 latex agglutination assay (RIM; Remel, Lenexa, KS), because SPRAB is not a typical selective-differential agar for *E. coli* O157:H7.

### 2.8. Color and texture measurement

Color and texture changes of cantaloupes following treatments were measured. CIE $L^*$, $a^*$, and $b^*$ color values of samples were measured with a Minolta colorimeter (model CR300, Minolta Co., Osaka, Japan) at 3 locations on each sample at 0, 3, and 7 days after treatment. Color attributes were quantified from the values of $L^*$, $a^*$, and $b^*$, which indicate the color lightness, redness, and yellowness of the sample, respectively. A TA-XT2i texture analyzer (Stable Microsystems Ltd., Surrey, England) was used to quantify sample texture by means of texture profile analysis (TPA). Samples (2 × 5 × 1 cm) were cut into 2 × 2 × 1 cm cuboids including the rind. The operating parameters, pre-test speed, test speed, post-test speed and compression strain, were 2.00 mm/s, 1.00 mm/s, 2.00 mm/s, and 50%, respectively. A 20 mm diameter aluminum cylindrical probe was used. The time interval and trigger force were 5 s and 0.05 N, respectively. Maximum load value, an indicator of texture change, was measured by reading the maximum peak value of the deformation curve. Color experiments were replicated three times and texture experiments were replicated five times.

### 2.9. Statistical analysis

Texture analysis was replicated five times. Other experiments were repeated three times. Data were analyzed by ANOVA using the Statistical Analysis System (SAS Institute, Cary, NC, USA) and separation of means by Duncan's multiple range test at a probability level of $P < 0.05$.

## 3. Results

### 3.1. Inactivation of pathogens by combination of lactic acid and steam treatment

Fig. 1 shows log reduction of *E. coli* O157:H7 following steam and LA treatment of cantaloupe surfaces. The initial level of *E. coli* O157:H7 on cantaloupe surfaces was 6.52 log CFU/cm$^2$. No appreciable reduction (0.04 log) in viable cell numbers occurred when inoculated samples were treated with sterile DW. This suggests that rough cantaloupe surfaces provide many protected sites for bacteria thereby impeding their physical removal. On the other hand, for the cantaloupe pieces immersed in LA alone, a 0.47 log reduction was observed for *E. coli* O157:H7. Levels of *E. coli* O157:H7 were reduced by 0.92–3.29 log after the combination treatment of DW immersion and SS (100 °C) treatment and 1.18 to 3.57 and 1.76 to 4.05 log after sterile DW immersion combined with SHS treatment at 150 and 200 °C, respectively. However, populations of *E. coli* O157:H7 were reduced by 1.13–3.79 after the combination treatment of 2% LA immersion and SS (100 °C) treatment and 1.44 to 4.27 and 1.51 to > 5.52 log after 2% LA immersion combined with SHS treatment at 150 and 200 °C, respectively. Levels of surviving *E. coli* O157:H7 on cantaloupe surfaces were reduced to below the detection limit (1.0 log) when immersed in 2% LA and then subjected to SHS for 20 s at 200 °C. As would be expected, log reductions of surviving cells increased as temperature and duration of steam treatment increased. The combination treatment of LA and SS resulted in a slight additional reduction compared to that of the combination treatment of DW immersion and SS treatment; by contrast, the combination treatment of 2% LA immersion and SHS (200 °C) for 20 s reduced this pathogen 1 log more than that of DW and 200 °C SHS. Log reductions of *S.* Typhimurium and L. *monocytogenes* on cantaloupe surfaces are shown in Figs. 2 and 3, respectively. The reduction trends were similar to that of *E. coli* O157:H7. The combination treatment of 2% LA and 200 °C SHS for 20 s reduced these pathogens to under the detection limit (1.0 log CFU/cm$^2$). The combination treatment of LA and steam showed an apparent synergistic effect when 200 °C SHS was applied for 20 s, which resulted in additional ~1 log reduction ($P < 0.05$) in the number of survivors. In the case of injured cells, slightly higher pathogen reductions were observed on SMAC, XLD or OAB than on SPRAB, OV-XLD or OV-OAB. However, these differences were not statistically significant ($P > 0.05$) regardless of treatment conditions (data not shown).

### 3.2. Comparison of application method on the effectiveness of LA-steam treatments

Viable-count reductions of *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes* on cantaloupe surfaces subjected to LA delivered as a spray or by immersion prior to steam treatments are shown in Figs. 4–6, respectively. Regarding the inactivation of *E. coli* O157:H7, *S.* Typhimurium and L. *monocytogenes*, no significant log reduction differences ($P > 0.05$) were observed between LA application methods regardless of steam duration or temperature.

### 3.3. Effect of LA and steam treatment on product quality

Table 1 shows color and textural changes of cantaloupes after combinations of DW, LA immersion or LA spray with SS or SHS treatment. Although $L^*$ values decreased slightly after LA treatment, differences were not significant ($P > 0.05$). Similarly, $a^*$ and b* values were not significantly ($P > 0.05$) different from those of untreated samples. Maximum load values varied slightly but there were no significant differences between non-treated (control) and treated samples.

## 4. Discussion

Cantaloupes are commonly linked to outbreaks of foodborne disease. In fact, from 1973 to 2011, cantaloupes were the most common melon type implicated in outbreaks involving such commodities (19 outbreaks, 56% of the total events) (Walsh et al., 2014). Many studies involving pasteurization of cantaloupes have focused on chemical sanitizers or conventional heat treatment (Annous et al., 2004; Richardson et al., 1998; Ukuku et al., 2001). However, only a few studies have evaluated the quality of cantaloupes following such sanitization treatments to eliminate foodborne pathogens (Forney et al., 2018; Kwon et al., 2018).

Compared to other conventional steam treatments, SHS has the advantage of rapid heating, however, this process also has inherent disadvantages which include high capital cost, equipment complexity, and high temperature of processed products (important when processing temperature-sensitive products) (Pronyk et al., 2004). Therefore, it may be economically advantageous to use steam in combination with other methods to inactivate foodborne pathogens. Organic acids are often used as a sanitizers or preservatives and are generally recognized as safe (GRAS) (Akbas and Ölmez, 2007). LA is an organic acid that readily forms in naturally fermented foods. Several studies have demonstrated the antibacterial effect of lactic acid. Park et al. (2011) reported that LA showed stronger antimicrobial efficacy than propionic, acetic and malic acids. Akbas and Ölmez (2007) compared the effect of LA and chlorine to reduce *L. monocytogenes* on iceberg lettuce, and found LA (0.5%) to be more effective than chlorine (100 mg/l). Recently, we reported that SHS reduced the numbers of three pathogens on cantaloupe rind by more than 5 log, but the color values of treated samples were adversely affected (Kwon et al., 2018). Therefore, the present study was conducted to evaluate the efficacy of LA-SHS treatment for the inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* on fresh cantaloupe without inducing quality changes.

In this study, it was confirmed that LA and SHS showed the synergistic effect on inactivation of foodborne pathogens on cantaloupe rind under several conditions. Numerous studies investigating the efficacy of combinations of thermal treatment and chemical sanitizers on other foods also found synergistic antimicrobial effects. Song et al. (2014) reported that the combination treatment of ozone and mild heat had a synergistic bactericidal effect on *E. coli* O157:H7 in apple juice of varying soluble solids content. Kim and Kang (2017a, 2017b) used essential oils (carvacrol, carvone, eugenol, thymol and citral) in combination with ohmic heating to inactivate pathogens in salsa. Results from that study indicated a synergistic effect between carvacrol treatments with ohmic heating. Ban and Kang (2016b) reported that sanitizers combined with steam treatment effectively reduced pathogens in a biofilm on stainless steel.

Pasteurization treatment can result in non-lethal injury to surviving microbial cells. These injured cells can grow on non-selective but cannot multiply on selective media (Wuytack et al., 2003). Selective agars contain antimicrobial agents such as dyes, antibiotics, or bile salts which interfere with growth of injured cells (Prentice and Clegg, 1974), whereas injured cells can recover under favorable conditions on non-selective media. For these reasons, the inactivation effect of pasteurization interventions can be overestimated when using selective agar media. Several methods have been developed to confirm the presence of injured cells. The liquid resuscitation method used by Moon et al. (2017) and the overlay plating method used by Ha and Kang (2018) are the most commonly used recovery methods. In this research we also used the overlay plating method to enumerate injured cells of *S.* Typhimurium and L. *monocytogenes*, whereas SPRAB was used to confirm recovery of injured cells of *E. coli* O157:H7, since this medium has been used for this purpose in other investigations (Ha and Kang, 2018; Lee and Kang, 2001; Rhee et al., 2003). The results of this study suggest that LA-SHS treatment effectively inactivated foodborne pathogens on cantaloupe surfaces without causing appreciable injury to surviving bacteria except under some conditions in the case of *E. coli* O157:H7.

When LA-SHS treatments were applied to cantaloupes for 20 s at 200 °C, SHS showed greater than 5 log reduction (to below the detection limit) for *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes*. There was no significant difference between spray-treated and immersion-treated samples. Pyatkovskyy et al. (2017) reported that the efficacy of Pro-San L (0.66% citric acid and 0.036% sodium dodecyl sulfate) for inactivation of *Escherichia coli* O157:H7 on spinach differed depending on application method. They reported that dipping was more effective than spraying treatment. Spray applications are more cost-effective than dipping in terms of needed volumes of water and sanitizers required. Moreover, the dipping method presents the possibility of cross-contamination. Thus, spraying is preferable for combining with steam treatment.

Pasteurization can have deleterious effects on the quality of fresh produce. Song et al. (2016) reported that pasteurization of radish seeds by heat treatment resulted in decreased germination rate. Palekar et al. (2004) reported that electron beam irradiation reduced firmness and $L^*$ values of cantaloupe. Recently, we reported that 30 s SHS treatment can result in color changes to cantaloupe (Kwon et al., 2018). But in the present study, LA-SHS treatment did not affect the color and texture (maximum load) of cantaloupes. The main reason for this result was likely the short exposure time required for the combination treatment. Ban and Kang (2016a) reported that short time treatment with SHS did not affect the quality of almonds and pistachios. In this study, we used SHS for up to only 20 s.

In conclusion, this research demonstrated that the combination treatment of LA and SHS leads to effective inactivation of foodborne pathogens on cantaloupes without incurring quality loss. LA-SHS treatment of cantaloupes for 20 s can reduce viable cell numbers of bacterial foodborne pathogens by more than 5 log. This combination treatment can reduce the time required for the SHS treatment, thereby limiting damage to heat sensitive cantaloupe components. LA-SHS combination treatment can help to ensure microbial safety for the fresh produce industry leading to effective inactivation of foodborne pathogens after short treatment time, thus preventing quality deterioration.

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