A THESIS FOR THE DEGREE OF MASTER OF SCIENCE

Application of superheated steam for inactivation of foodborne pathogens on cantaloupe and watermelon surfaces.

과열수증기의 수박과 캔탈롭 표면에서의 식중독균 저감화 적용

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Department of Agricultural Biotechnology

Seoul National University

Sun Ah Kwon

석사학위논문

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지도교수 강동현

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2017 년 2 월

위원장 최 상 호 (인)

부위원장 강 동 현 (인)

위원 하 남 출 (인)

ABSTRACT

The purpose of this study was evaluation of the effectiveness of superheated steam (SHS) on inactivation of *Escherichia coli* O157:H7, *Salmonella* Typhimurium and *Listeria monocytogenes* on fresh produce, cantaloupes and watermelons. Saturated steam (SS) treatment was performed at 100°C and that of SHS at 150 and 200°C. *E. coli* O157:H7, *S.* Typhimurium and *L. monocytogenes*-inoculated cantaloupes and watermelons were exposed for a maximum of 30 s and 10 s, respectively. *E. coli* O157:H7, *S.* Typhimurium and *L. monocytogenes* populations on cantaloupes and watermelons were reduced by more than 5 log after 200°C steam treatment for 30 s and 10 s, respectively.

Differences in microbial inactivation efficiency were investigated with SEM images and a noncontact 3D surface profiler, and seemed to be associated with surface characteristics, especially surface roughness.

The effect of superheated steam on quality was also assessed by measuring color and texture change during storage. After SHS treatment of watermelons for maximum treatment time, color and maximum load values were not significantly ($P > 0.05$) different from those of untreated controls. On the other hand, color a* and b* values of treated cantaloupes are different from those of untreated controls.

Thus, the sanitizing effect of combination of steam and acid is evaluated to achieve 5 log reduction of pathogens on cantaloupes preventing quality deterioration. When LA-SHS treatments were applied to cantaloupes for 20 s, 200°C SHS effected greater than 5 log reduction to below the detection limit of *E. coli* O157:H7, *S.* Typhimurium, and *L.* monocytogenes on cantaloupes.

This research demonstrated that SHS treatment leads to effective inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L.* monocytogenes on watermelons. LA-SHS treatment leads to effective inactivation of these pathogens on cantaloupes. SHS treatment of watermelon and LA-SHS treatment of cantaloupes can yield more than a 5-log reduction without quality loss.

Keywords: **superheated steam, saturated steam, food-borne pathogens, cantaloupe, watermelon, acid, combination**
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I. INTRODUCTION

Cantaloupes (Cucumis melo L. var. reticulatus NAUD) and watermelons (Citrullus lanatus (Thunb.) var. lanatus) are popular fruits enjoyed worldwide (Tian et al., 2007; Lamikanra et al., 2005). People enjoyed melons for various reasons. Melons are an excellent source of beta-carotene, vitamin C, and potassium. Also, melons have no cholesterol, and are low in fat and sodium (Lester, 1997). While watermelons are an excellent source of the phytochemical lycopene (Perkins-Veazie et al., 2004.).

Of importance is that cantaloupes and watermelons are frequently associated with foodborne pathogen infections. Since melons develop on the soil surface, their outer surfaces can easily become contaminated with foodborne pathogens during production and processing (Bowen et al., 2006). Melon-associated outbreaks increased from 0.5 outbreaks per year during 1973–1991 to 1.3 during 1992–2011, and during 1973-2011, cantaloupes were the most common melon type implicated in outbreaks (19 outbreaks, 56% of total), followed by watermelons (13, 38%) (Walsh et al., 2014).

Foodborne pathogens of high public health concern, including *Escherichia coli* O157:H7, *Salmonella* Typhimurium, and *Listeria monocytogenes* are able to grow on the outside of intact cantaloupes and

watermelons. Melon-associated outbreaks were most often caused by *Salmonella*. (Walsh et al., 2014). In 2012, a multistate outbreak of *S.* Typhimurium and *S.* Newport infections linked to cantaloupes resulted in 94 illnesses and 3 deaths (CDC, 2012). Also, *L.* monocytogenes and *E. coli* O157:H7 outbreaks are frequently associated with consumption of melons. In 2011, there was a multistate outbreak of *L. monocytogenes* in the US resulted in 147 illnesses and 33 deaths (CDC, 2012). An August, 1993-outbreak was linked to cantaloupes contaminated with *E. coli* O157:H7 (Del Rosario and Beuchat, 1995). A watermelon-borne *E. coli* O157:H7 outbreak in 2000 was attributed to cross-contamination with a raw meat product. (CDC, Foodborne Disease Outbreak Surveillance System (unpublished data) 2013). Thus controlling these foodborne pathogens is one of the most important challenges facing in the food industry.

A previous study involving thermal treatment of whole cantaloupe at 76°C for 3 min resulted in a reduction of *E. coli* populations in excess of 5 log CFU/cm^2 (Annous et al., 2004). But there is still potential for contamination during cutting or other processing. Nonthermal pasteurization technologies have been studied extensively because of the need to minimize quality loss. UV-C illumination at 4.1 kJ/cm^2 produced 1–1.5 log reduction in bacterial populations on fresh-cut watermelon (Fonseca & Rushing, 2006).

Intense light pulse treatments with an overall full spectrum energy of 12 J/cm^2 reduced E. coli populations on inoculated fresh-cut watermelon by 3.01 log (Ramos-Villarroel et al, 2012). But results of these studies were not enough to ensure safety of the product, so investigations targeting 5-log reduction seem to be needed.

Superheated steam (SHS) is steam which has been given additional sensible heat to raise its temperature above the saturation temperature at a constant pressure. Until the temperature of SHS is higher than saturation point at the processing pressure, a drop in temperature of SHS will not result in condensation of steam (Cenkowski et al., 2007). SHS pasteurization is an emerging technology that has the potential to replace commonly used heat treatments (Bari et al., 2010). SHS pasteurization is a time and energy saving and also environmentally friendly technology in terms of avoiding the use of chemical compounds (Pronyk et al., 2004; Van Deventer & Heijmans, 2001) Still, Inactivation of foodborne pathogens by SHS has rarely been studied, especially for fresh food.

To improve the ability of inactivating foodborne pathogens on cantaloupes and 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 at inactivating microorganisms than

the use of any single factor alone (Leistner, 2000). In this study, lactic acid (LA) was used with steam treatment to make hurdle effect and increase disinfection efficacy. In fresh produce industry, two methods of sanitizer application (dipping, and spraying) were commonly used. Thus, study of comparison of spraying treatments and immersion treatments is also needed. In fresh produce industry, two methods of sanitizer application (dipping, and spraying) were commonly used. Thus, study of comparison of spraying treatments and immersion treatments is also needed.

Therefore, the objective of this study is evaluate the influence of SHS on the quality changes and microbial populations of cantaloupe and watermelon surfaces inoculated with *E. coli* O157:H7, *S.* Typhimurium and *L. monocytogenes.* Also, incorporating LA with steam treatment is being evaluated for possible synergistic effect.

II. MATERIALS AND METHODS

2.1. Bacterial cultures and cell suspension

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 (SNCC; Seoul, Republic of Korea), were used in this experiment. 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.

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 x-***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% peptone water to a concentration of approximately 10^7-10^8 CFU ml^{-1}. The cell concentration was determined by plating aseptically 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, respectively.

2.2. Sample preparation

Cantaloupes and watermelons were purchased at a local grocery store (Seoul, South Korea) the day before each experiment and stored at 4°C until use. Cantaloupes and watermelons were washed by dipping them in distilled water for 2 min to remove dust and were air dried at room temperature for 60 min in a laminar flow hood with the fan running to remove excess moisture. Samples were cut into cubes (2 cm × 5 cm × 1cm length) including the rind 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 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 a room temperature (22 ± 2°C).

2.3. Experiments of comparison of steam efficacy between cantaloupes and watermelon surfaces.

2.3.1. Saturated steam (SS) and superheated steam (SHS) treatment

Dried inoculated cantaloupes and watermelons were spread into a single layer on a stainless steel treatment grid inside a stainless steel basket and placed in an insulated steam treatment chamber (external diameter 23 cm; external height, 32 cm; internal diameter, 17 cm; internal height, 22.5 cm). Steam passed through a flexible hose and into the chamber by opening a steam valve. Cubed cantaloupes were exposed to SS or SHS on the rind surface (2 cm × 5 cm surface) for 5, 10, 15, 20, 25 or 30 sec, and watermelons cubes were exposed for 1, 3, 5, 7 or 10 sec. SS treatments were conducted at 100°C, and SHS treatments were performed at 150°C and 200°C. During SS or SHS treatments, temperature was controlled automatically by a temperature sensor and an intelligent power module in the steam generator. The basket containing treated samples was immediately removed from the chamber after each treatment, and cantaloupes or watermelon cubes were enumerated.

2.3.2. Surface roughness analysis

To quantify sample surface roughness, scanning interferometry was used. The samples were mounted on a noncontact 3D surface profiler (Nano View-E1000, Nanosystem, Daejeon, Korea), which was used to measure surface roughness of the scan area (125 × 95 μm^2) using a 50 × objective lens.

Average roughness values as topography parameters were acquired using a software package (NanoMap version 2.5.17.0, Nanosystem, Daejeon, Korea) from five randomly chosen scan areas. R_A is the arithmetic mean deviation of the absolute ordinate values within a sampling length (Standard ISO 4287, 1997). R_z value is another commonly used roughness parameter which is defined as the sum of the largest profile peak height and the largest profile valley depth, within a sampling length (Standard ISO 4287, 1997).

2.3.3. Scanning Electron Microscopy (SEM) of cantaloupe and watermelon surfaces.

E. coli O157:H7 inoculated and uninoculated sample surfaces were cut into thin slices (0.5 cm × 0.5 cm). Slices were immersed in 2 %

Karnovskys's fixative for 2 h for primary fixation and washed three times with 0.05 M sodium cacodylate buffer for 10 min each. Next, slices were immersed in a solution of 2% osmium tetroxide mixed with 0.1 M cacodylate buffer (1:1 v/v) for 2 h for post fixation, and briefly washed twice with distilled water. The fixed slices were dehydrated with a graded ethanol series (one change each of 30, 50, 70, 80, and 90 %, and three changes of 100 % ethanol) for 10 min each. Then dehydrated slices were completely dried in a Balzers CPD 030 critical point drying apparatus (BAL-TEC, Balzers, Liechtenstein). Dried sample slices were mounted on aluminum stubs and then sputter-coated with platinum using a vacuum coater (EM ACE200, Leica, Germany). Lastly, photomicrographs were obtained using a Field-Emission Scanning Electron Microscope (SIGMA, Carl Zeiss, German).

2.4. Experiments of combining lactic acid with steam to inactivate foodborne pathogens on cantaloupes surfaces.

2.4.1. Preparation of acid

Lactic acid (LA, above 90.0%; Daejung Chemical Co., Siheung-si, South Korea) was used make treatment solutions of LA (2%, v/v) using sterile distilled water. The solution was prepared within 1 h before experiments. The pH for 2% LA was 2.12.

2.4.2. Combination treatment of steam treatment and acid

Dried inoculated cantaloupes were immersed (in 2% LA or DW) or sprayed (with 2% LA or DW). Treatment solutions for immersion or spraying were applied at RT for 1 min. Then they spread into a single layer on a stainless steel treatment grid inside a stainless steel basket and placed in an insulated steam treatment chamber. Steam passed through a flexible hose and into the chamber by opening a steam valve. Cubed cantaloupes were exposed to SS or SHS on the rind surface (2 cm × 5 cm surface) for 5, 10, 15, or 20 sec. SS treatments were conducted at 100°C, and SHS treatments were performed at 150°C and 200°C. The basket containing treated samples was immediately removed from the chamber after each treatment, and cantaloupes cubes were enumerated as described in the next section. The cantaloupes treated with steam alone and ones immersed into LA alone were used as controls.

2.5. Microbial enumeration

At pre-selected treatment times, each treated sample (10 cm^2 × 1cm length) was immediately transferred into a sterile stomacher bag (Labplas Inc., Sainte-Julie, Quebec, Canada) containing 100 ml of 0.2% PW and homogenized for 2 min with a stomacher (Easy mix; AES Chemunex, Rennes, France). After homogenization, 1 ml of the sample was 10-fold serially diluted in 9ml of 0.2% PW, and 0.1 ml of appropriate diluents were spread plated onto SMAC, XLD, and OAB with antimicrobial supplement to enumerate surviving populations of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes*, respectively. All plates were incubated at 37 °C for 24 h, and then colonies enumerated. To confirm pathogen identity, presumptive colonies were randomly selected from selective media and subjected to biochemical and serological tests, consisting of the *E. coli* O157:H7 latex agglutination assay (Oxoid, Basingstoke, UK), the *Salmonella* latex agglutination assay (Oxoid, Basingstoke, UK), and the API *Listeria* test (BioMérieux, Hazelwood, MO).

2.6. Enumeration of injured cells

Phenol red agar base with 1% sorbitol (SPRAB; Difco) was used to enumerate injured cells of *E. coli* O157:H7 (Rhee et al., 2003). 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 latex agglutination assay mentioned previously.

Injured cells of *S.* typhimurium and *L.* monocytogenes were enumerated using the overlay (OV) method. One hundred µL of sample or diluent was spread-plated 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.

2.7. Color and texture measurement

Color and texture changes of cantaloupes and watermelons following treatments were measured during 7 day-storage at 4°C. The FDA recommends that cut melons be consumed or discarded within 7 days (FDA, 2001). 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 was expressed as L*, a*, and b* values, which indicate lightness, redness, and yellowness, 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 were cut into 2 × 2 × 1 cm cubes. 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 20mm 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.

2.8. Statistical analysis

Texture and surface roughness 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 $P < 0.05$.

III. RESULTS

3.1. Experiments of comparison of steam efficacy between cantaloupes and watermelon surfaces.

3.1.1. Inactivation of E. coli O157:H7, S. Typhimurium, and L. monocytogenes on cantaloupes and watermelon surfaces.

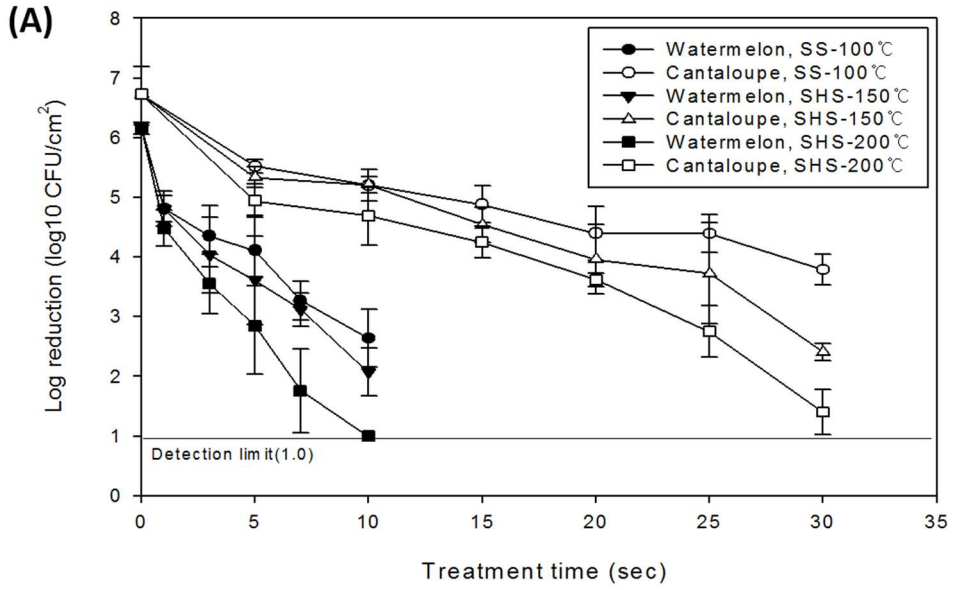
Viable-count reductions of *E. coli* O157:H7*, S.* Typhimurium*, and L.* monocytogenes on cantaloupe and watermelon surfaces during steam treatments are shown in Figures 1 (A), (B), and (c), respectively. Initial inoculum levels of *E. coli* O157:H7, *S.* Typhimurium and *L. monocytogenes* on cantaloupes were 6.72, 6.01, and 5.99 log CFU/cm^2 and those on watermelons were 6.16, 5.99, and 5.89 log CFU/cm^2, respectively. The detection limit for this experiment was 1.00 CFU/cm^2. Populations of the three pathogens on cantaloupes were reduced to below the detection limit when subjected to 200°C SHS for 30 s, whereas these pathogens experienced log reductions of 2.93, 3.95, and 3.61 after SS treatment at 100 °C for the same time interval. SHS treatment caused an additional 1.14–2.29 log reduction of the three pathogens on cantaloupes

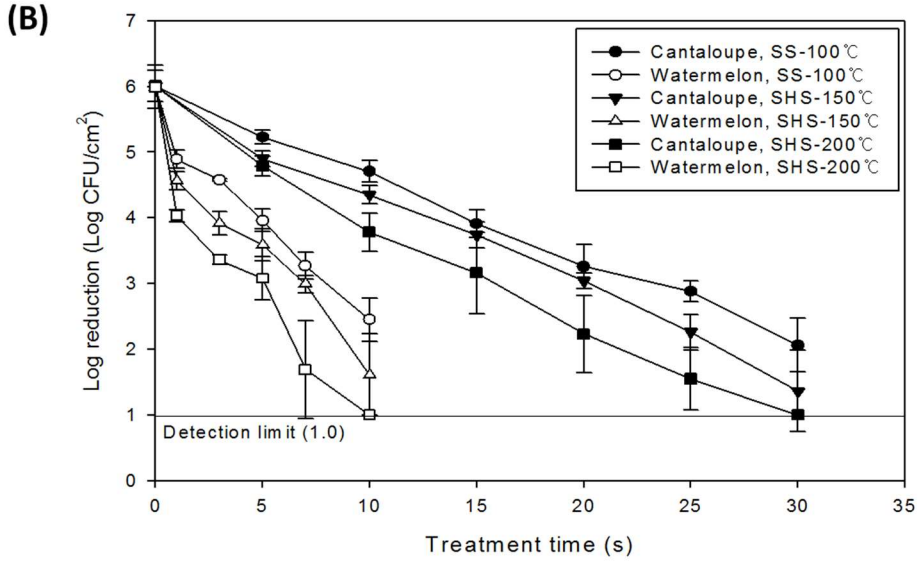
compared to SS treatments. Also, the overall reduction tendencies of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* on watermelons were similar to those on cantaloupes. On watermelon, SHS treatment caused an additional 1.39-1.75 log reduction of the three pathogens compared to SS treatments.

Application of 200°C SHS treatment for 10 s reduced the number of survivors on watermelons to below the detection limit. However, the same treatment on cantaloupes reduced pathogen populations by only 2.03, 2.23, and 1.92 reduction of *E. coli* O157:H7*, S.* Typhimurium*,* and *L. monocytogenes*, respectively. For 5 log reduction of the three foodborne pathogens on cantaloupes, SHS treatments at 200°C for 30 s is needed, while for watermelons just 10 s treatment is enough to satisfy the 5 log reduction target. Compared to watermelons, it was significantly harder for cantaloupes to attain the 5 log pathogen reduction goal.

Tables 1 and 2 show levels of sublethally injured *E. coli* O157:H7 cells on (A) cantaloupe and (B) watermelon surfaces, respectively, after SHS or SS treatment. Injured cell populations of 0.01 to 1.00 log CFU/cm^2 were observed. Overall, slightly lower pathogen reductions were observed on SPRAB than on SMAC. However, these differences were not statistically significant ($P > 0.05$) regardless of treatment conditions. A similar trend was

seen in Tables 3,4, and 5,6, which show levels of injured *S.* Typhimurium and *L. monocytogenes* cells on cantaloupe and watermelon surfaces, respectively.


(A)
Watermelon, SS-100℃
Cantaloupe, SS-100℃
Watermelon, SHS-150℃
Cantaloupe, SHS-150℃
Watermelon, SHS-200℃
Cantaloupe, SHS-200℃
Log reduction (log10 CFU/cm2)
Detection limit(1.0)
Treatment time (sec)


(B)
Cantaloupe, SS-100℃
Watermelon, SS-100℃
Cantaloupe, SHS-150℃
Watermelon, SHS-150℃
Cantaloupe, SHS-200℃
Watermelon, SHS-200℃
Log reduction (Log CFU/cm2)
Detection limit (1.0)
Treatment time (s)

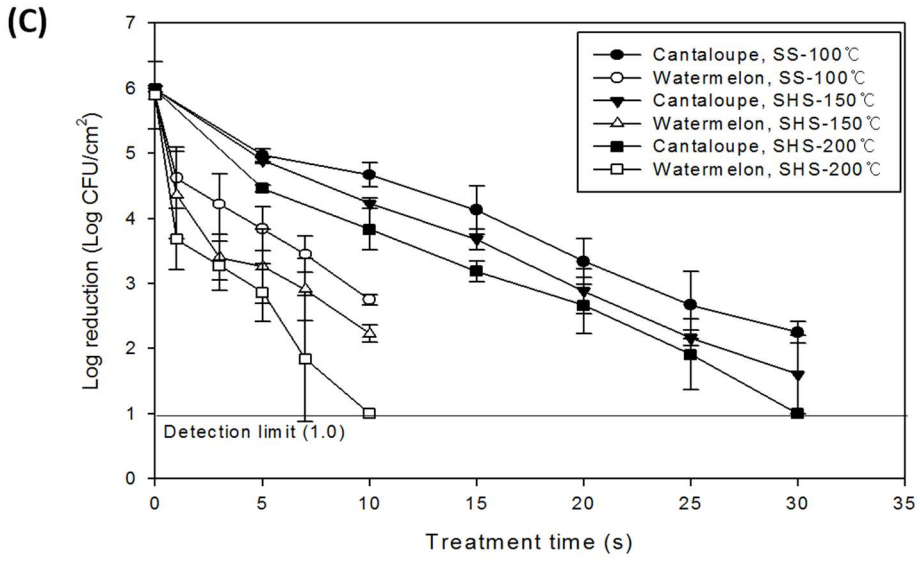


Fig. 1. Survival curves for *E. coli* O157:H7 (A), *S.* Typhimurium (B), and *L. monocytogenes* (C) on watermelons and cantaloupes treated with SS at 100℃ (●, ○), SHS at 150℃ (▼, △), and SHS at 200℃ (□,■).

Table 1. Survival (log CFU/cm^2) of uninjured and injured *Escherichia coli* O157:H7 cells on cantaloupes treated with saturated steam or superheated steam.

Treatment time (s)	Population (log CFU/cm^2)					
	100℃ - SS		150℃ - SHS		200℃ -SHS	
	SMAC	SPRAB	SMAC	SPRAB	SMAC	SPRAB
0	6.72±0.48A[a]	7.04±0.63A	6.72±0.48A	7.04±0.51A	6.72±0.48A	7.04±0.51A
5	5.52±0.11A	5.65±0.48A	5.33±0.17A	5.47±0.20A	4.94±0.28A	5.13±0.34A
10	5.20±0.27A	5.27±0.21A	5.21±0.13A	5.54±0.29A	4.69±0.49A	4.84±0.45A
15	4.88±0.31A	4.78±0.86A	4.54±0.29A	4.95±0.30A	4.25±0.27A	4.59±0.02A
20	4.40±4.45A	4.66±0.71A	3.96±0.58A	4.51±0.76A	3.62±0.11A	3.84±0.56A
25	4.39±0.32A	4.58±0.38A	3.73±0.85A	4.21±0.37A	2.75±0.43A	3.34±0.60A
30	3.79±0.26A	4.34±0.26A	2.41±0.14A	3.02±0.26A	1.40±0.38A	2.40±0.54A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

Table 2. Survival (log CFU/cm^2) of uninjured and injured *Escherichia coli* O157:H7 cells on watermelons treated with saturated steam and superheated steam.

Treatment time (s)	Population (log CFU/cm^2)					
	100℃		150℃		200℃	
	SMAC	SPRAB	SMAC	SPRAB	SMAC	SPRAB
0	6.16±0.10A[a]	6.37±0.23A	6.16±0.10A	6.37±0.23A	6.16±0.10A	6.37±0.23A
1	4.81±0.23A	4.82±0.10A	4.46±0.30A	4.65±0.23A	4.48±0.30A	4.60±0.37A
3	4.35±0.52A	4.50±0.38A	4.03±0.63A	4.25±0.31A	3.55±0.50A	3.93±0.51A
5	4.11±0.59A	4.12±0.59A	3.61±0.74A	3.65±0.40A	2.85±0.81A	3.47±0.82A
7	3.27±0.32A	3.60±0.39A	3.12±0.28A	3.26±0.23A	1.76±0.70A	2.76±0.14A
10	2.64±0.49A	2.75±0.77A	2.07±0.40A	2.94±0.44A	<1.00A	1.99±0.95A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

Table 3. Survival (log CFU/cm^2) of uninjured and injured *Salmonella* Typhimurium cells on cantaloupes treated with saturated steam and superheated steam.

Treatment time (s)	Population (log CFU/cm^2)					
	100℃		150℃		200℃	
	XLD	OV-XLD	XLD	OV-XLD	XLD	OV-XLD
0	6.01±0.24A	6.72±0.23B	6.01±0.24A	6.72±0.23B	6.01±0.24A	6.72±0.23B
5	5.23±0.11A	5.72±0.51A	4.90±0.12A	5.58±0.53B	4.79±0.15A	5.13±0.19A
10	4.71±0.17A	5.31±0.41A	4.35±0.14A	4.88±0.26A	3.78±0.29A	4.64±0.00B
15	3.91±0.21A	4.77±0.11B	3.74±0.20A	4.42±0.44B	3.16±0.62A	3.69±0.44A
20	3.26±0.34A	3.75±0.24A	3.04±0.12A	3.56±0.46A	2.23±0.59A	2.84±0.32A
25	2.88±0.16A	3.06±0.60A	2.23±0.27A	2.85±0.29A	1.55±0.48A	2.15±0.26A
30	2.06±0.41A	2.53±0.58A	1.55±0.62A	1.89±0.52A	< 1.00A	1.30±0.64A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

Table 4. Survival (log CFU/cm^2) of uninjured and injured *Salmonella* Typhimurium cells on watermelons treated with saturated steam and superheated steam.

Treatment time (s)	Population (log CFU/cm^2)					
	100℃		150℃		200℃	
	XLD	OV-XLD	XLD	OV-XLD	XLD	OV-XLD
0	6.16±0.10A[a]	6.37±0.23A	6.16±0.10A	6.37±0.23A	6.16±0.10A	6.37±0.23A
1	4.81±0.23A	4.82±0.10A	4.46±0.30A	4.65±0.23A	4.48±0.30A	4.60±0.37A
3	4.35±0.52A	4.50±0.38A	4.03±0.63A	4.25±0.31A	3.55±0.50A	3.93±0.51A
5	4.11±0.59A	4.12±0.59A	3.61±0.74A	3.65±0.40A	2.85±0.81A	3.47±0.82A
7	3.27±0.32A	3.60±0.39A	3.12±0.28A	3.26±0.23A	1.76±0.70A	2.76±0.14A
10	2.64±0.49A	2.75±0.77A	2.07±0.40A	2.94±0.44A	<1.00A	1.99±0.95A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

Table 5. Survival (log CFU/cm^2) of uninjured and injured *Listeria monocytogenes* cells on cantaloupes treated with saturated steam and superheated steam.

Treatment time (s)	Population (log CFU/cm^2)					
	100℃		150℃		200℃	
	OAB	OV-OAB	OAB	OV-OAB	OAB	OV-OAB
0	5.99±0.04A	6.51±0.46A	5.99±0.04A	6.51±0.46A	5.99±0.04A	6.51±0.46A
5	4.95±0.07A	5.23±0.47A	4.86±0.08A	5.18±0.34A	4.54±0.17A	4.56±0.36A
10	4.69±0.16A	4.76±0.41A	4.29±0.18A	4.65±0.39A	4.07±0.09A	4.34±0.32A
15	4.18±0.39A	4.55±0.33A	3.76±0.26A	4.06±0.38A	3.22±0.20A	3.26±0.48A
20	3.44±0.38A	3.77±0.23A	2.97±0.49A	3.39±0.70A	2.84±0.18A	2.90±0.19A
25	2.66±0.52A	3.06±0.37A	2.42±0.38A	2.51±0.25A	2.22±0.54A	2.32±0.27A
30	2.38±0.07A	2.49±0.26A	2.00±0.35A	1.97±0.41A	< 1.00A	< 1.00A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

Table 6. Survival (log CFU/cm^2) of uninjured and injured *Listeria monocytogenes* cells on watermelons treated with saturated steam and superheated steam.

Treatment time (s)	Population (log CFU/cm^2)					
	100°C		150°C		200°C	
	OAB	OV-OAB	OAB	OV-OAB	OAB	OV-OAB
0	5.89±0.52A	6.07±0.43A	5.89±0.52A	6.07±0.43A	5.89±0.52A	5.89±0.52A
1	4.62±0.47A	4.86±0.62A	4.36±0.67A	4.63±0.68A	3.68±0.47A	4.62±0.47A
3	4.22±0.47A	4.73±0.29A	3.40±0.35A	3.83±0.25A	3.27±0.38A	4.22±0.47A
5	3.84±0.34A	4.19±0.46A	3.26±0.57A	3.57±0.28A	2.86±0.44A	3.84±0.34A
7	3.45±0.28A	3.54±0.36A	2.91±0.48A	3.49±0.46A	1.84±0.97A	3.45±0.28A
10	2.75±0.08A	3.13±0.17A	2.23±0.13A	2.72±0.24A	< 1.00A	2.75±0.08A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

3.1.2. Effect of SS and SHS treatment on product quality during storage.

Tables 7 and 8 show color and textural changes of cantaloupes and watermelons, respectively, during storage after SS or SHS treatment. L* values of SS or SHS treated cantaloupes were not significantly ($P > 0.05$) different from those of untreated samples. But, a* and b* values are slightly changed compared with untreated controls. Texture values of treated cantaloupes were also not significantly different from those of untreated controls. In the case of watermelons, color and texture values of treated samples were not significantly ($P > 0.05$) different from those of untreated sample

Table 7. Change of color value and texture value of watermelon treated with 100, 150, 200℃ steam for 30 sec during storage.

Treatment time	Storage time (days) at 4℃		
	0	3	7
Color, L*			
Control	43.30±2.83A[a]	43.60±2.21A	42.26±2.10A
100℃, 10 sec	43.11±3.65A	41.38±1.92A	41.84±0.78A
150℃, 10 sec	42.19±2.15A	40.58±1.57A	41.93±0.15A
200℃, 10 sec	42.61±1.18A	43.16±2.99A	42.64±1.23A
Color, a*			
Control	-14.55±1.29A	-14.82±1.58A	-15.13±1.65A
100℃, 10 sec	-17.84±1.16B	-12.64±1.07A	-13.86±1.51A
150℃, 10 sec	-16.85±1.05B	-13.96±1.78A	-15.06±0.69A
200℃, 10 sec	-18.66±0.91B	-13.73±2.13A	-13.67±0.09A
Color, b*			
Control	22.87±2.82A	23.56±3.00A	23.03±1.37A
100℃, 10 sec	25.28±4.23A	24.26±3.38A	21.87±3.61A
150℃, 10 sec	21.84±1.76A	23.14±2.58A	22.80±1.23A
200℃, 10 sec	23.64±1.33A	25.31±3.55A	22.50±1.53A
Maximum force (N)			
Control	213.32±9.23A	202.52±23.17A	197.85±18.49A
100℃, 10 sec	211.51±5.09A	195.77±6.25A	183.90±15.94A
150℃, 10 sec	203.28±6.65A	192.68±13.60A	192.43±19.83A
200℃, 10 sec	206.63±2.79A	192.92±8.26A	197.27±10.52A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

Table 8. Change of color value and texture value of cantaloupe treated with 100, 150, 200℃ steam for 30 sec during storage.

Treatment time	Storage time (days) at 4℃		
	0	3	7
Color, L*			
Control	57.75±3.36A[a]	54.81±1.31A	55.24±1.95A
100℃, 30 sec	55.68±1.26A	53.70±2.72A	56.03±1.06A
150℃, 30 sec	58.31±1.74A	57.20±1.78A	58.02±1.39A
200℃, 30 sec	58.36±1.76A	57.16±1.81A	56.78±2.00A
Color, a*			
Control	-1.87±1.56AB	-2.00±1.32A	-2.04±2.44A
100℃, 30 sec	-2.58±0.45A	-1.21±0.25AB	0.80±0.49B
150℃, 30 sec	-2.40±0.48A	0.00±0.16B	1.29±0.06B
200℃, 30 sec	-0.47±0.52B	-0.25±0.17B	-0.60±0.29B
Color, b*			
Control	17.22±1.81A	16.26±0.11A	16.20±0.39A
100℃, 30 sec	18.03±0.57A	21.09±1.06BC	20.76±1.92B
150℃, 30 sec	20.20±0.88B	20.02±0.18B	20.86±0.23B
200℃, 30 sec	22.49±0.39C	21.91±0.38C	21.57±1.11B
Maximum force (N)			
Control	177.61±20.60A	174.44±23.25A	164.18±7.11A
100℃, 30 sec	168.67±12.66A	171.61±17.87A	176.58±21.74A
150℃, 30 sec	186.24±20.18A	168.65±16.26A	165.78±8.08A
200℃, 30 sec	183.36±16.19A	172.80±6.62A	180.97±8.29A

The values are means ± standard deviations from three replications.

[a] Means followed by the same letter in the same column are not significantly different (P<0.05).

3.1.3. Effect of surface characteristics on steam efficacy.

Roughness values of cantaloupes and watermelons were measured by a noncontact 3D surface profiler (shown in Table 9 and Fig 2). The average R_A value of cantaloupes was 12.30, while that of watermelons was 0.64. Average R_Z (maximal roughness) values of cantaloupes and watermelons were 308.01 and 114.57, respectively. As shown in Fig 3, cantaloupes had variously sized crevices across their surface, which contributed to significant difference in R_A value.

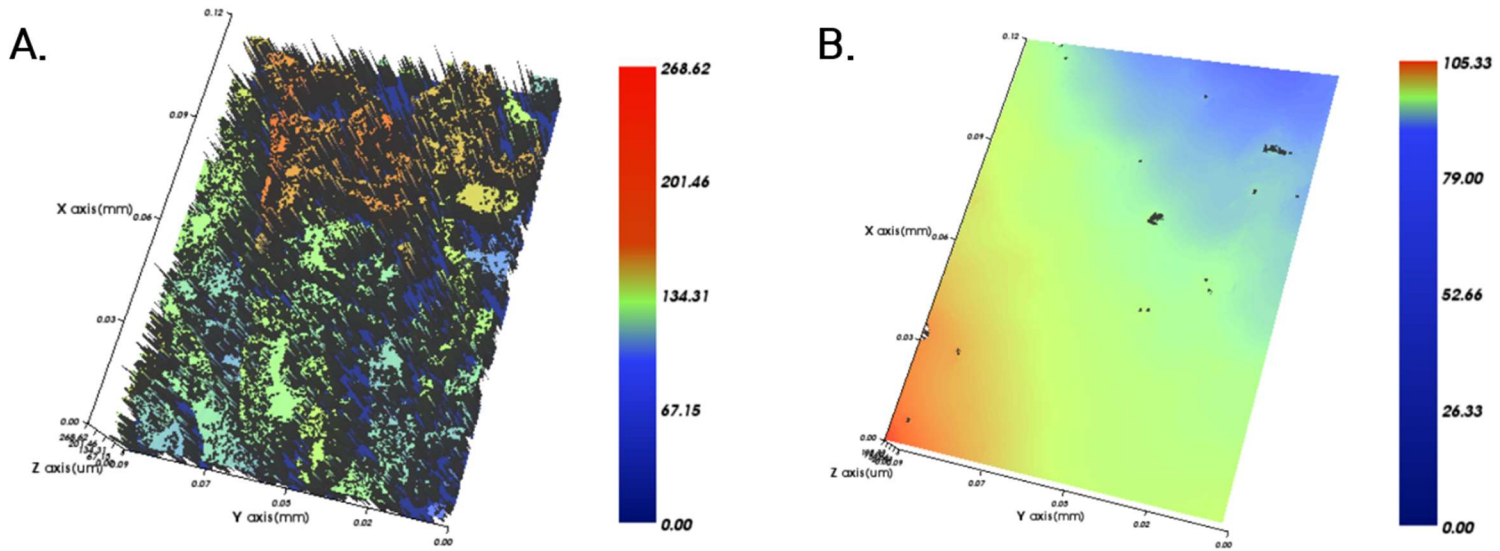


Fig. 2. images of sample surface acquired with a noncontact 3D surface profiler: A) cantaloupe, B) watermelon.

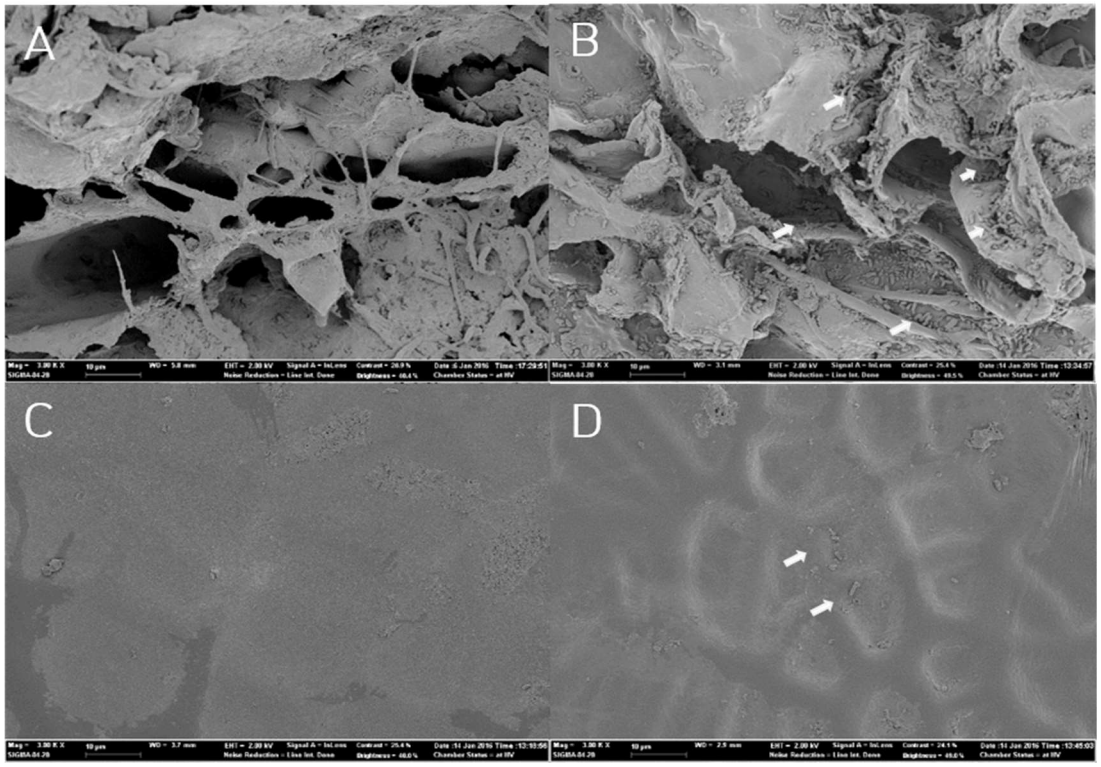


Fig. 3. Scanning Electron Microscopy photomicrographs : surface of a) uninoculated cantaloupe, b) *E. coli* O157:H7-inoculated cantaloupe, c) uninoculated watermelon, d) *E. coli* O157:H7-inoculated watermelon.

Table 9. Average surface roughness values of cantaloupes and watermelons measured by a noncontact 3D surface profiler.

	R_A	R_q	R_t	R_z
Cantaloupe	12.30±1.73A	21.24±3.68A	326.67±22.19 A	308.01±21.58A
Watermelon	0.64±0.09B	1.49±0.65B	192.61±77.47B	114.57±87.55B

[a]Means with different uppercase letters within a row are significantly different ($p < 0.05$).

3.2. Experiments of combining lactic acid with steam to inactivate foodborne pathogens on cantaloupes surfaces.

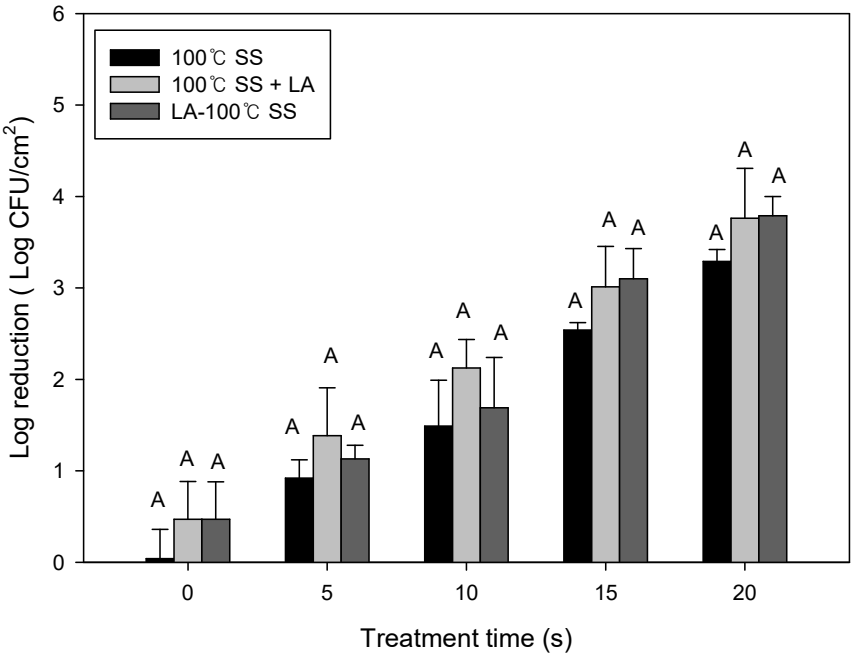
3.2.1. Inactivation of E. coli O157:H7 by combination of lactic acid and steam treatment.

Figure 4 shows log reduction of *E. coli O157:H7* during steam and LA treatment on cantaloupe surface. The initial level of *E. coli* O157:H7 on cantaloupe surface was 6.52 log CFU/cm^2. Almost no reductions (0.04 log) occurred when inoculated samples were treated with distilled water. It indicated that rough cantaloupe surface provide many protect sites from physical removal. On the other hand, cantaloupe surfaces immersed in LA alone experienced a log reduction of 0.47 for *E. coli* O157:H7. The reduction levels of *E. coli* O157:H7 were 0.92–4.05 log after DW immersion and steam treatment, but were 1.13– over 5.52 log after LA immersion and steam treatment. The 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 superheated-steamed for 20 s at 200°C. The additional log reduction was increased as the temperature and duration of steam treatment increased. At 100°C SS treatment, slight additional reduction was showed,

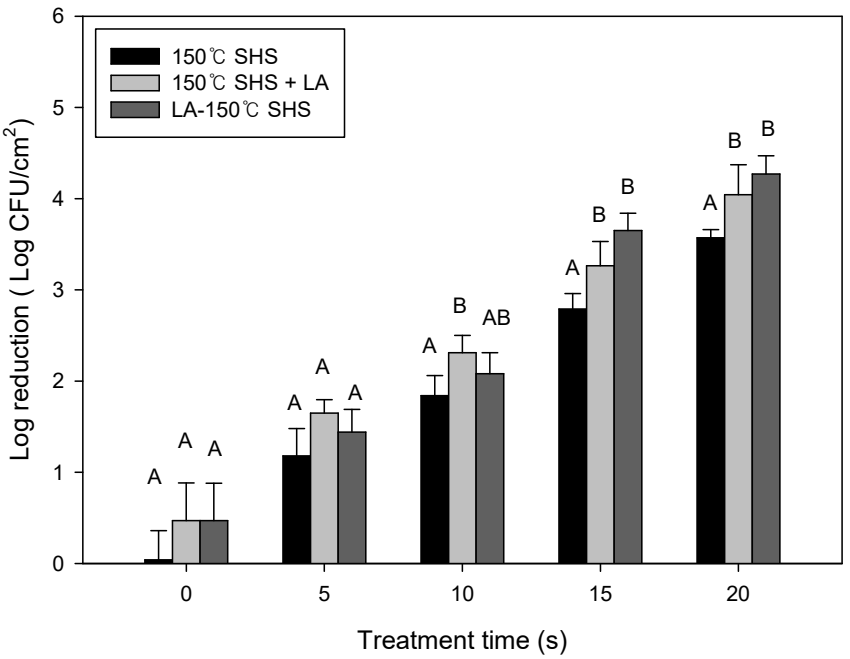
on the contrast, more than 1 log reduction was showed when treated 200° SHS for 20 sec.

Table 10 shows levels of sublethally injured *E. coli* O157:H7 cells on cantaloupe surfaces, after combination of LA (2%) or DW and SHS or SS treatment. When applied steam and LA, injured cell populations of 0.08-0.83 log CFU/cm^2 were observed. Overall, slightly higher pathogen reductions were observed on SPRAB than on SMAC. However, these differences were not statistically significant ($P > 0.05$) except few treatment conditions. As steam duration time increased, injured cells were observed in the combination treatment of LA and steam. But the reduction was still higher than the control of combination DW and steam.

(A)


100℃ SS
100℃ SS + LA
LA-100℃ SS
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A

(B)


150℃ SHS
150℃ SHS + LA
LA-150℃ SHS
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A
B
AB

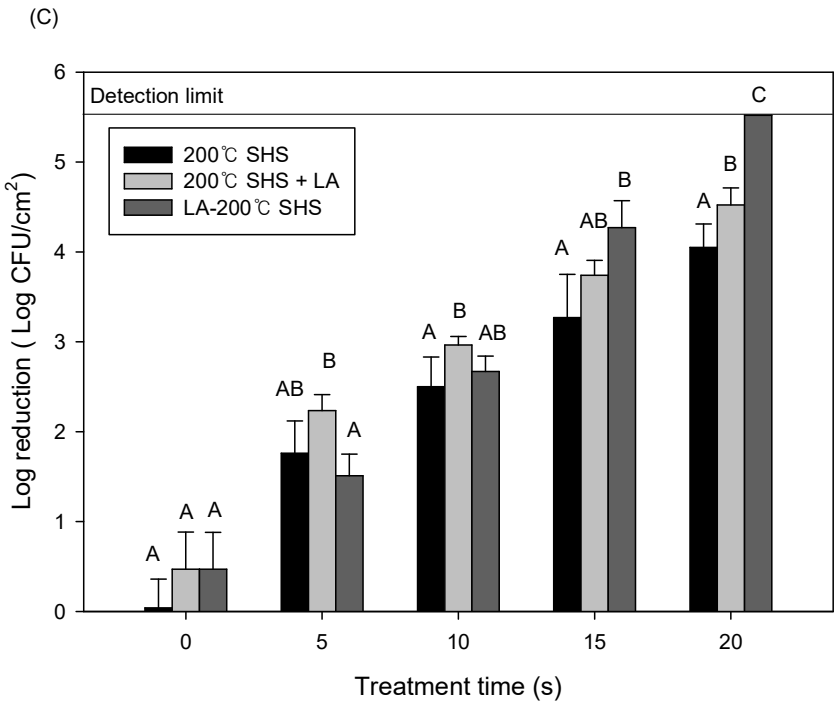


Fig. 4. Log reduction (log CFU/cm^2) of *E. coli* O157:H7 on cantaloupes treated with combination of lactic acid (2%) and (A) 100°C (SS), (B) 150°C (SHS), or (C) 200°C (SHS). The error bars indicate standard deviation calculated from triplicates.

Table 10. Log reduction (log CFU/cm^2) of *E. coli* O157:H7 on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS).

Treatment	Medium	Log reduction (log CFU/cm^2)				
		0 s	5 s	10 s	15	20 s
DW (1 min)-SS (100℃)	SMAC	0.04±0.32Aa [a]	0.92±0.20Ab	1.49±0.50Ac	2.54±0.08Ad	3.29±0.13ABe
	SPRAB	0.22±0.07Aa	1.38±0.12Bb	1.58±0.20Ab	2.43±0.17Ac	2.97±0.34Ad
LA (1 min)-SS (100℃)	SMAC	0.47±0.41Aa	1.13±0.15ABb	1.69±0.55Ab	3.10±0.33Bc	3.79±0.21Cd
	SPRAB	0.26±0.09Aa	1.52±0.13Bb	2.25±0.25Ab	2.60±0.29Ac	3.40±0.17BCd
DW (1 min)-SHS (150℃)	SMAC	0.04±0.32Aa	1.18±0.30Ab	1.84±0.22Ab	2.79±0.17Ac	3.57±0.09Ad
	SPRAB	0.22±0.07Aa	1.55±0.11Ab	1.94±0.14Ac	2.55±0.08Ad	3.42±0.22Ae
LA (1 min)-SHS (150℃)	SMAC	0.47±0.41Aa	1.44±0.25Ab	2.08±0.23ABc	3.65±0.19Bd	4.27±0.20Be
	SPRAB	0.26±0.09Aa	1.52±0.27Ab	2.25±0.23Bc	2.96±0.35Ad	3.64±0.17Ae
DW (1 min)-SHS (200℃)	SMAC	0.04±0.32Aa	1.76±0.36Ab	2.50±0.33Ac	3.27±0.48Ad	4.05±0.26ABe
	SPRAB	0.22±0.07Aa	1.72±0.18Ab	2.30±0.27Ac	2.97±0.34Ad	3.78±0.39Ae
LA (1 min)-SHS (200℃)	SMAC	0.47±0.41Aa	1.51±0.24Ab	2.67±0.17Ac	4.27±0.30Bd	> 5.52Ce
	SPRAB	0.26±0.09Aa	1.70±0.24Ab	2.44±0.06Ac	3.45±0.44Ad	4.69±0.58Be

The values are means ± standard deviations from three replications.

[a]Means with different uppercase letters within a row are significantly different ($p < 0.05$).

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

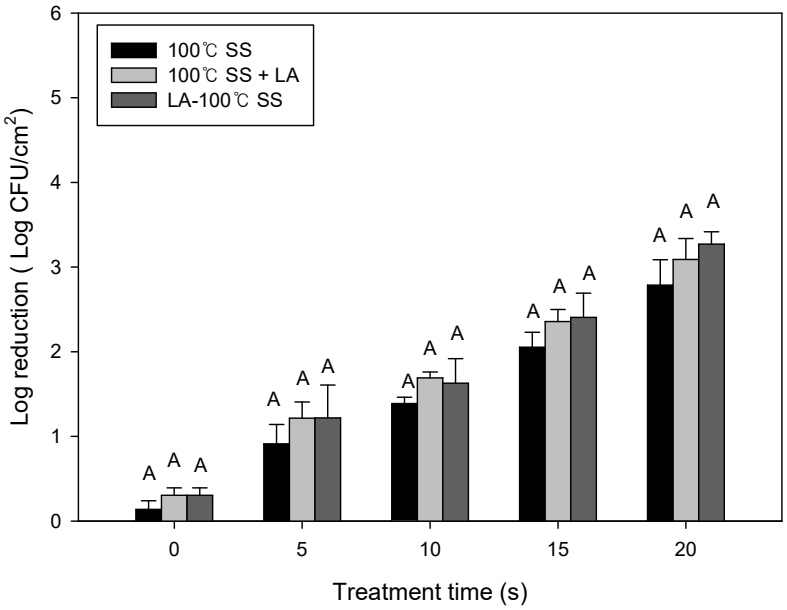
3.2.2. Inactivation of S. Typhimurium by combination of lactic acid and steam treatment.

Figure 5 shows log reduction of *S.* Typhimurium during steam and LA treatment on cantaloupe surface. The initial level of *S.* Typhimurium on cantaloupe surface was 6.26 log CFU/cm^2. Treated with DW alone experienced 0.14 log reduction, while immersed in LA alone experienced a log reduction of 0.30 for *S.* Typhimurium. The reduction levels of *S.* Typhimurium were 0.91–3.79 log after DW immersion and steam treatment, but were 1.22–over 5.26 log after LA immersion and steam treatment. The levels of surviving *S.* Typhimurium on cantaloupe surfaces were reduced to below the detection limit (1.0 log) when immersed in 2% LA and then superheated-steamed for 20 s at 200°C. At 100°C SS treatment, slight additional reduction was showed, on the contrast, more than 1.17 log reduction was showed when treated 200° SHS for 20 sec.

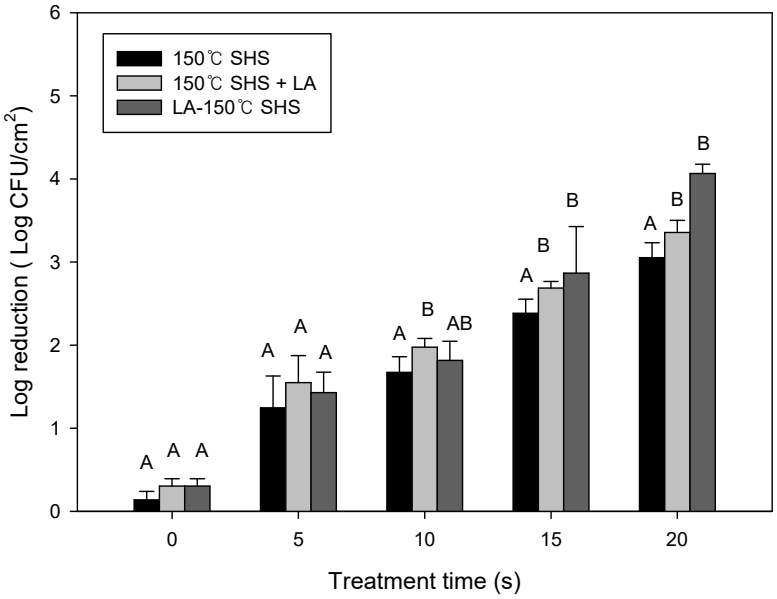
Table 11 shows levels of sublethally injured *S.* Typhimurium cells on cantaloupe surfaces, after combination of LA (2%) or DW and SHS or SS treatment. When applied steam and LA, injured cell populations of 0.04-0.31 log CFU/cm^2 were observed. Overall, slightly higher pathogen reductions

were observed on OV-XLD than on XLD. However, these differences were not statistically significant ($P > 0.05$) regardless of treatment conditions.

(A)


100℃ SS
100℃ SS + LA
LA-100℃ SS
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A A A
A A A
A A A
A A A
A A A

(B)


150℃ SHS
150℃ SHS + LA
LA-150℃ SHS
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A A A
A A A
A B AB
A B B
A B B

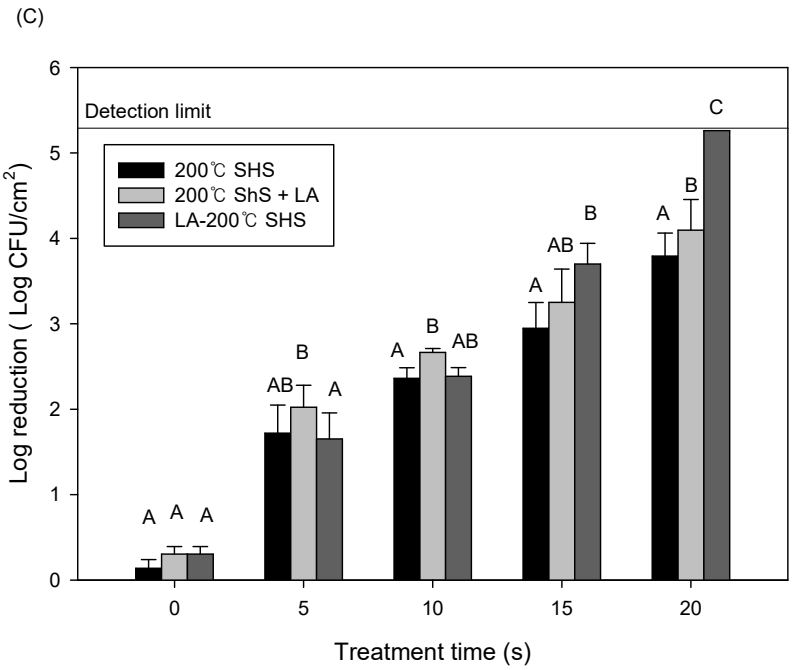


Fig. 5. Log reduction (log CFU/cm^2) of *S.* Typhimurium on cantaloupes treated with combination of lactic acid (2%) and (A) 100°C (SS), (B) 150°C (SHS), or (C) 200°C (SHS). The error bars indicate standard deviation calculated from triplicates.

Table 11. Log reduction (log CFU/cm^2) of *S.* Typhimurium on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS).

Treatment	Medium	Log reduction (log CFU/cm2)				
		0 s	5 s	10 s	15	20 s
DW (1 min)-SS (100℃)	XLD	0.14±0.10Aa	0.91±0.23Ab	1.39±0.08Ac	2.05±0.18Ad	2.79±0.30Ae
	OV-XLD	0.29±0.10Aa	1.11±0.29Ab	1.57±0.06Ac	2.24±0.13Ad	3.00±0.32Ae
LA (1 min)-SS (100℃)	XLD	0.30±0.09Aa	1.22±0.39Ab	1.63±0.29Ab	2.41±0.29Ac	3.27±0.15Ad
	OV-XLD	0.78±0.26Ba	1.45±0.18Ab	1.59±0.16Ab	2.24±0.50Ac	3.14±0.45Ad
DW (1 min)-SHS (150℃)	XLD	0.14±0.10Aa	1.25±0.38Ab	1.67±0.19Ac	2.38±0.17Ad	3.05±0.18Ae
	OV-XLD	0.29±0.10Aa	1.39±0.36Ab	1.81±0.11Ac	2.61±0.22ABd	3.03±0.25Ae
LA (1 min)-SHS (150℃)	XLD	0.30±0.09Aa	1.43±0.24Ab	1.82±0.23Ab	2.87±0.56ABc	4.07±0.11Bd
	OV-XLD	0.78±0.26Aa	1.53±0.20Ab	1.88±0.29Ab	3.05±0.22Bc	3.88±0.70Bd
DW (1 min)-SHS (200℃)	XLD	0.14±0.10Aa	1.72±0.33Ab	2.36±0.12Ac	2.95±0.30Ad	3.79±0.27Ae
	OV-XLD	0.29±0.10Aa	1.72±0.15Ab	2.57±0.08Ac	2.95±0.25Ad	3.70±0.31Ae
LA (1 min)-SHS (200℃)	XLD	0.30±0.09Aa	1.65±0.31Ab	2.39±0.10Ac	3.70±0.24Bd	> 5.26Be
	OV-XLD	0.78±0.26Aa	1.84±0.47Ab	2.70±0.29Ac	3.92±0.43Bd	5.03±0.31Be

The values are means ± standard deviations from three replications.

[a]Means with different uppercase letters within a row are significantly different ($p < 0.05$).

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

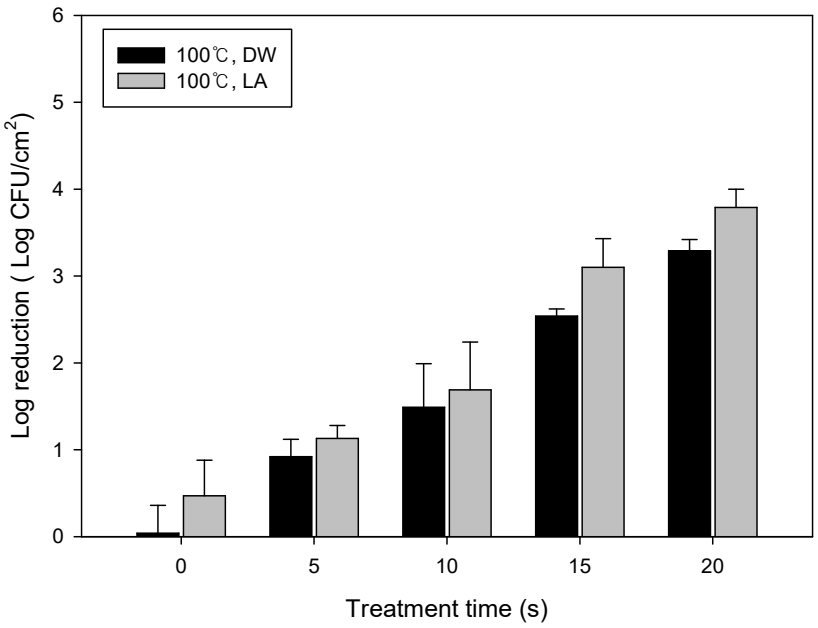
3.2.3. Inactivation of L. monocytogenes by combination of lactic acid and steam treatment.

Figure 6 shows log reduction of *L. monocytogenes* during steam and LA treatment on cantaloupe surface. The initial level of *L. monocytogenes* on cantaloupe surface was 6.39 log CFU/cm^2. Treated with DW alone experienced 0.09 log reduction, while immersed in LA alone experienced a log reduction of 0.50 for *L. monocytogenes*. The reduction levels of *L. monocytogenes* were 1.36–4.33 log after DW immersion and steam treatment, but were 1.69–over 5.39 log after LA immersion and steam treatment. The levels of surviving *L. monocytogenes* on cantaloupe surfaces were reduced to below the detection limit (1.0 log) when immersed in 2% LA and then superheated-steamed for 20 s at 200°C. The additional log reduction was increased as the temperature and duration of steam treatment increased. When applied combination of LA and 200°C SHS for 20 sec, it achieved more than 5 log reduction, which is significantly ($p < 0.05$) different from control treatment of DW and 200°C SHS for 20 sec.

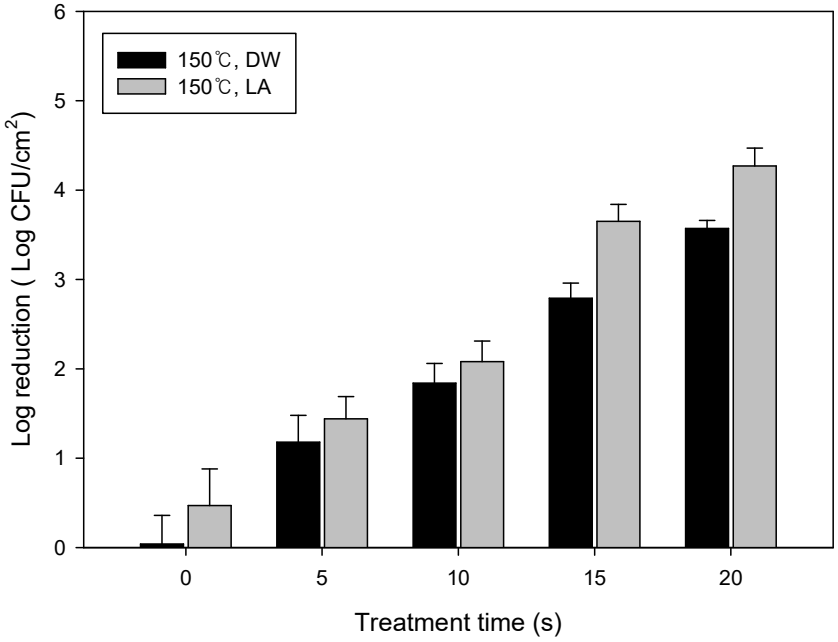
Table 12 shows levels of sublethally injured *L. monocytogenes* cells on cantaloupe surfaces, after combination of LA (2%) or DW and SHS or SS treatment. Overall, slightly higher pathogen reductions were observed on

OV-OAB than on OAB. However, these differences were not statistically significant ($P > 0.05$) regardless of treatment conditions.

(A)


100℃, DW
100℃, LA
Log reduction (Log CFU/cm2)
Treatment time (s)
0
1
2
3
4
5
6
0
5
10
15
20

(B)


150℃, DW
150℃, LA
Log reduction (Log CFU/cm2)
Treatment time (s)
0
1
2
3
4
5
6
0
5
10
15
20

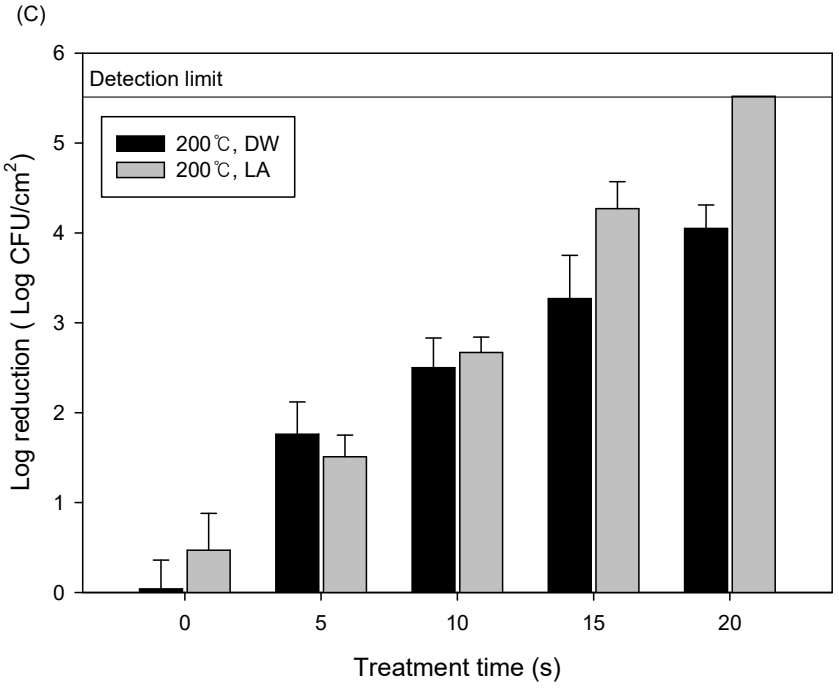


Fig. 6. Log reduction (log CFU/cm^2) of *L. monocytogenes* on cantaloupes treated with combination of lactic acid (2%) and (A) 100°C (SS), (B) 150°C (SHS), or (C) 200°C (SHS). The error bars indicate standard deviation calculated from triplicates.

Table 12. Log reduction (log CFU/cm^2) of *L. monocytogenes* on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS).

Treatment	Medium	Log reduction (log CFU/cm2)				
		0 s	5 s	10 s	15	20 s
DW (1 min)-SS (100℃)	OAB	0.09±0.18Aa[a]	1.36±0.09Ab	2.09±0.42ABc	2.62±0.15Ac	3.27±0.56Ad
	OV-OAB	0.35±0.29ABa	1.48±0.42Ab	1.99±0.39Bbc	2.60±0.76Acd	3.40±0.65Ad
LA (1 min)-SS (100℃)	OAB	0.50±0.24Ba	1.69±0.35Ab	2.31±0.31ABc	3.01±0.32Ad	3.79±0.30Ad
	OV-OAB	0.52±0.13Ba	1.82±0.68Ab	2.74±0.18Bc	3.30±0.51Ac	4.20±0.64Ad
DW (1 min)-SS (100℃)	OAB	0.09±0.18Aa	1.64±0.35Ab	2.50±0.53Ac	2.99±0.25Ac	3.66±0.23Ad
	OV-OAB	0.35±0.29ABa	1.77±0.52Ab	2.51±0.37Ab	3.48±0.62Ac	3.72±0.69Ac
LA (1 min)-SHS (150℃)	OAB	0.50±0.24Ba	2.07±0.35Ab	2.84±0.73Ac	3.70±0.32Ad	4.14±0.35ABe
	OV-OAB	0.52±0.13Ba	2.18±0.61Ab	3.20±0.35Ac	3.66±0.59Ac	4.80±0.37Bd
DW (1 min)-SHS (200℃)	OAB	0.09±0.18Aa	2.36±0.56Ab	3.17±0.40Ac	3.78±0.15Ad	4.33±0.15Ad
	OV-OAB	0.35±0.29ABa	2.14±0.57Ab	2.92±0.68bAc	3.65±0.55Acd	4.39±0.32Ad
LA (1 min)-SHS (200℃)	OAB	0.50±0.24Ba	2.56±0.19Ab	3.26±0.59Ab	4.54±0.37Ac	> 5.39Bd
	OV-OAB	0.52±0.13Ba	2.40±0.58Ab	3.35±0.29Ac	4.31±0.05Ad	5.74±0.32Be

The values are means ± standard deviations from three replications.

[a]Means with different uppercase letters within a row are significantly different ($p < 0.05$).

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

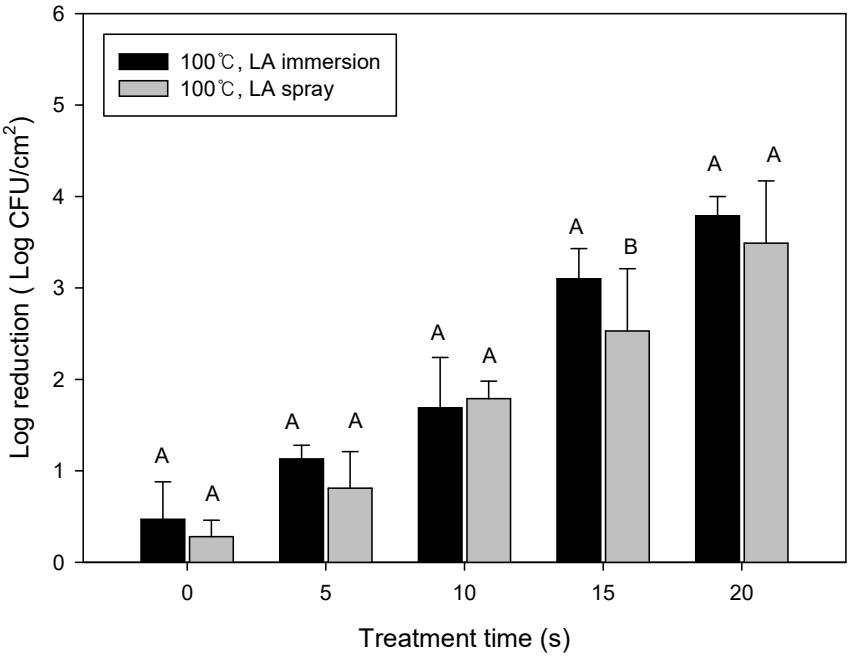
3.2.4. Comparison of inactivation effect of combination of LA spray or immersion and steam.

Viable-count reductions of *E. coli* O157:H7*, S.* Typhimurium*,* and *L.* monocytogenes on cantaloupe surfaces when applied LA spray or immersion and steam treatments are shown in Figures 7, 8, and 9, respectively. Showing inactivation of *S.* Typhimurium*, and L.* monocytogenes, there was no significant difference ($p < 0.05$) of log reduction between LA immersion and LA spray regardless of steam duration time and temperature. For inactivation of *E. coli* O157:H7, No significant differences were observed between LA immersion or LA spray except few treatments. When applied 150 and 200 SHS for 15 s, LA immersion treatment was experienced higher reduction than LA spray treatment.

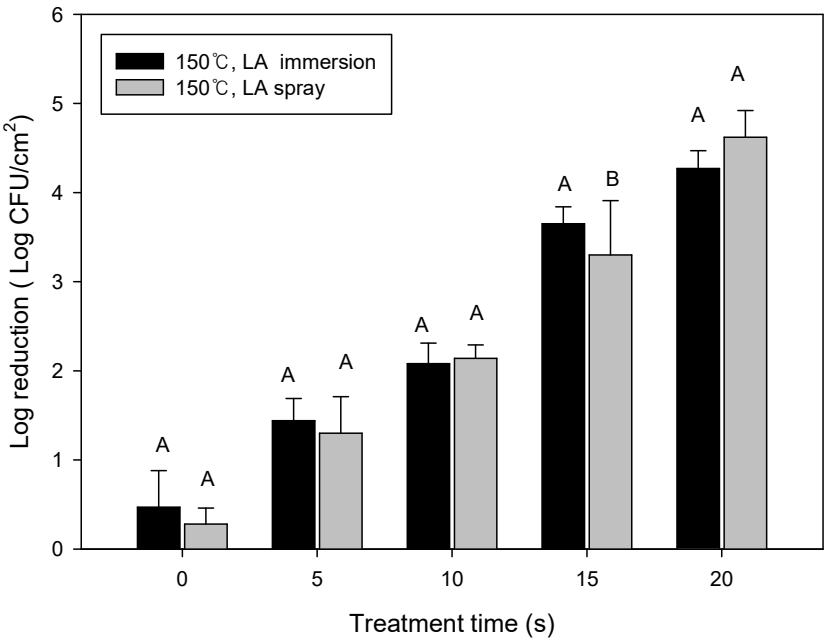
Tables 13, 14, and 15 shows levels of sublethally injured *E. coli* O157:H7*, S.* Typhimurium*,* and *L. monocytogenes* cells on cantaloupe surfaces, after combination of LA and steam treatment. For SHS-LA combined treatment (both spraying and dipping treatment), there were no significant ($P < 0.05$) differences between the reduction levels enumerated on the selective agar (SMAC, XLD, and OAB) versus those on the agar used for recovery (SPRAB, OV-XLD, and OV-OAB) except few treatments. Only

in case of *E. coli* O157:H7 cells, 3 of total 15 treatment conditions made significantly different injured cell.

(A)


100℃, LA immersion
100℃, LA spray
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A
A
A
A
A
A
A
A
A
B

(B)


150℃, LA immersion
150℃, LA spray
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A
A
A
A
A
A
A
A
A
B
A

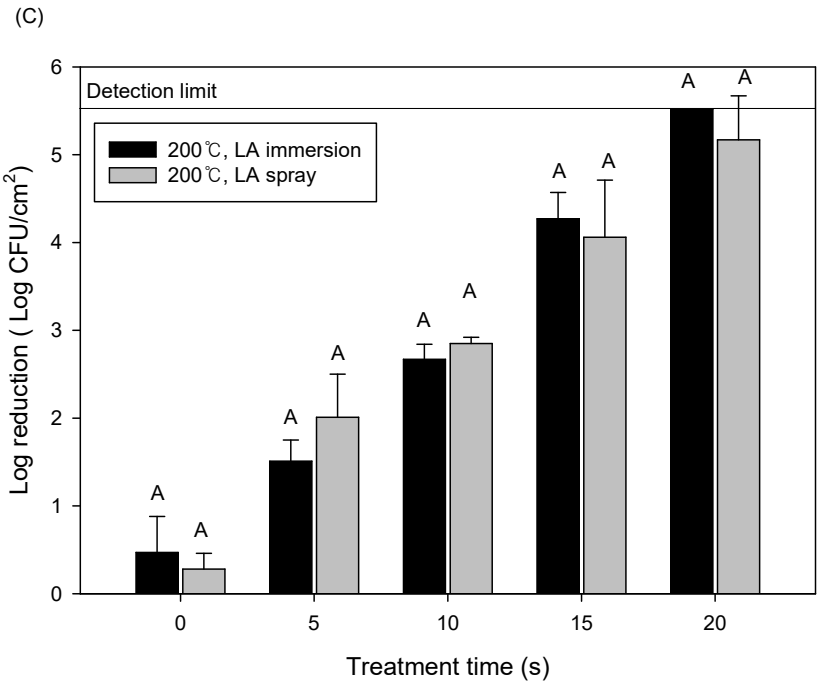
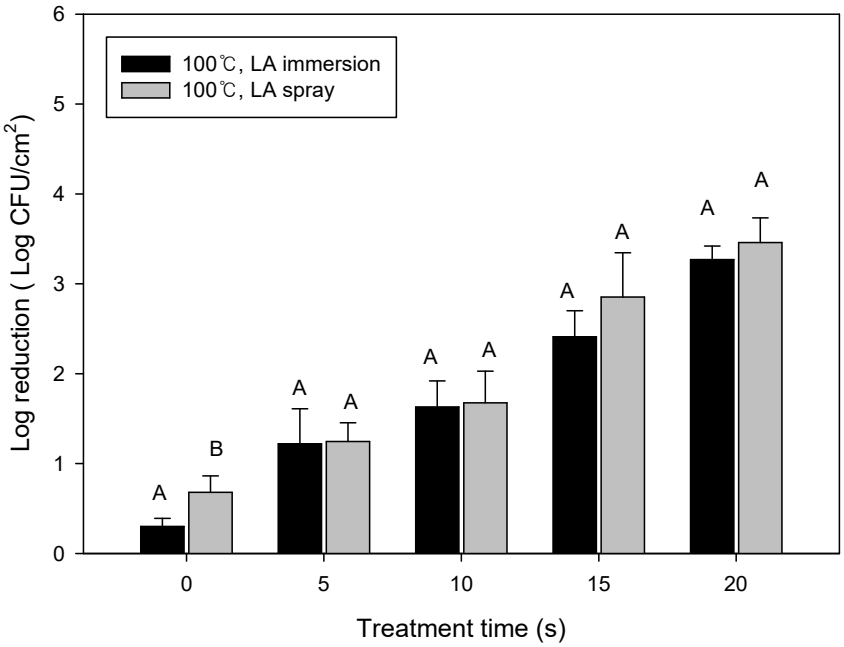
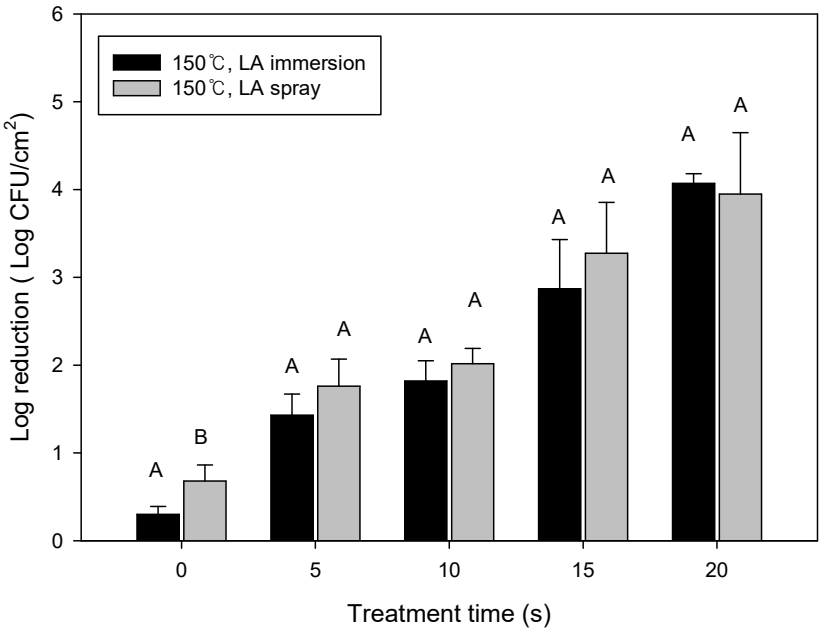


Figure 7. Log reduction (log CFU/cm^2) of *E. coli* O157:H7 on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS). The error bars indicate standard deviation calculated from triplicates.

(A)


100℃, LA immersion
100℃, LA spray
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A
B
A
A
A
A
A
A
A
A

(B)


150℃, LA immersion
150℃, LA spray
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A
B
A
A
A
A
A
A
A
A

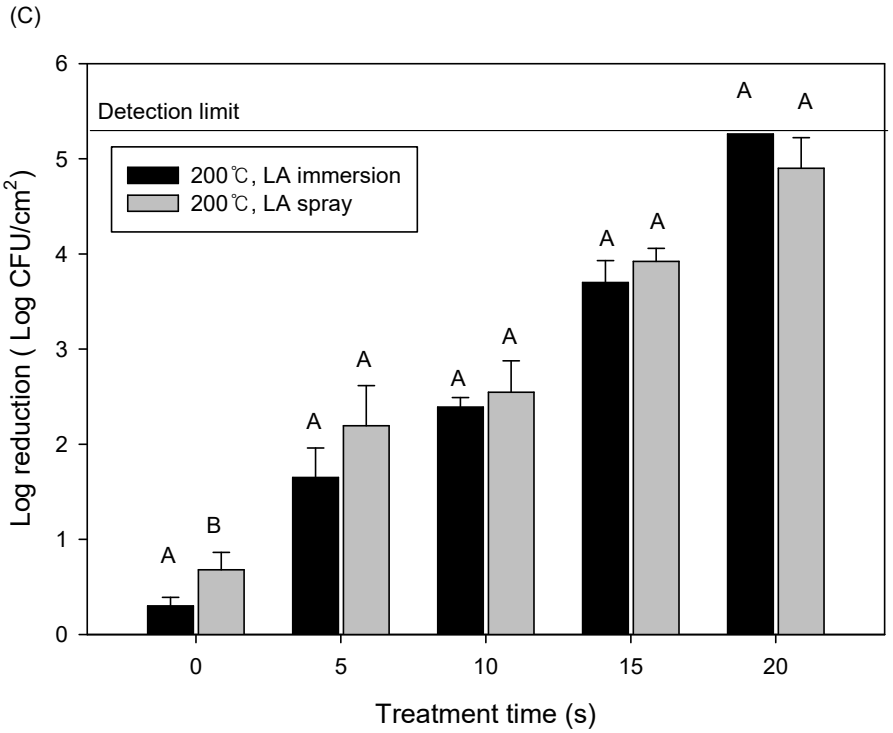
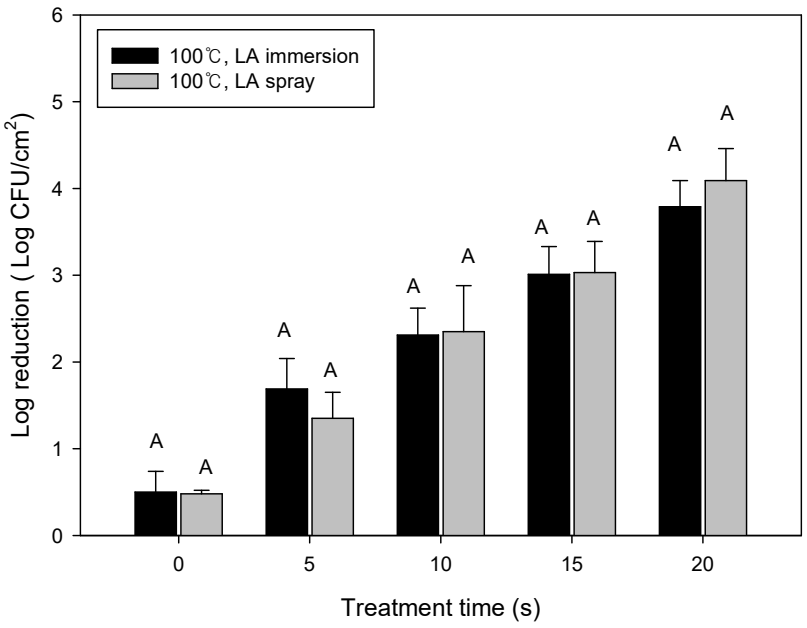
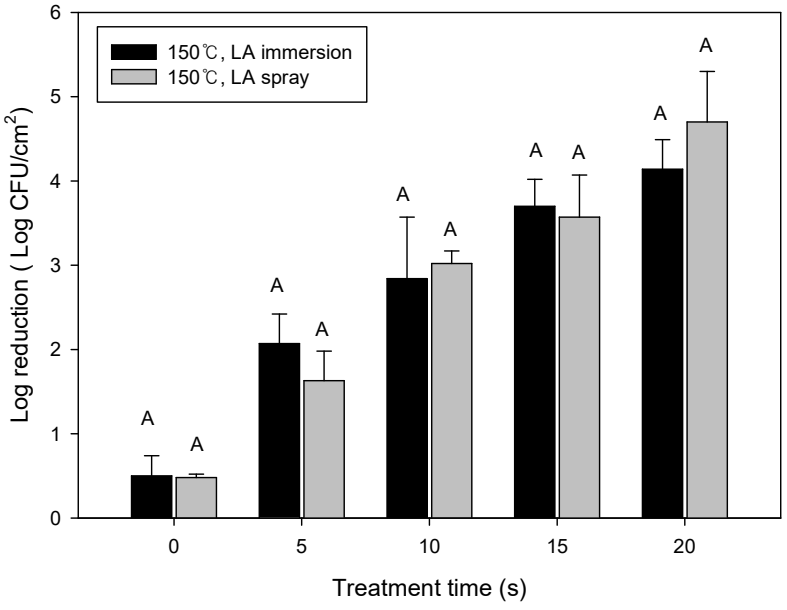


Figure 8. Log reduction (log CFU/cm^2) of *S.* Typhimurium on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS). The error bars indicate standard deviation calculated from triplicates.

(A)


100℃, LA immersion
100℃, LA spray
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A

(B)


150℃, LA immersion
150℃, LA spray
Log reduction (Log CFU/cm2)
Treatment time (s)
0
5
10
15
20
A

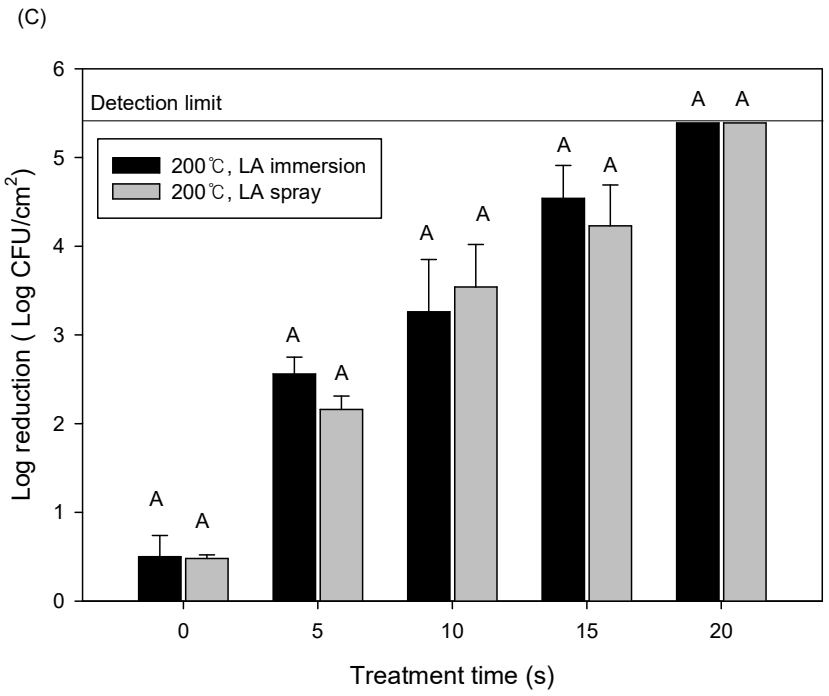


Figure 9. Log reduction (log CFU/cm^2) of *L. monocytogenes* on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS). The error bars indicate standard deviation calculated from triplicates.

Table 13. . Log reduction (log CFU/cm^2) of uninjured and injured cells of *E. coli* O157:H7 on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS).

Treatment	Medium	Log reduction (log CFU/cm2)				
		0 s	5 s	10 s	15	20 s
LA spray–SS (100℃)	SMAC	0.28±0.18a	0.81±0.40a	1.79±0.19a	2.53±0.68a	3.49±0.68a
	SPRAB	0.15±0.06a	0.91±0.32a	2.05±0.51a	2.92±0.29b	3.59±0.37a
LA (1 min)-SS (100℃)	SMAC	0.47±0.41a	1.13±0.15a	1.69±0.55a	3.10±0.33b	3.79±0.21a
	SPRAB	0.26±0.09a	1.52±0.13a	2.25±0.25a	2.60±0.29ab	3.40±0.17a
LA spray–SHS (150℃)	SMAC	0.28±0.18a	1.30±0.41a	2.14±0.15a	3.30±0.61a	4.62±0.30b
	SPRAB	0.15±0.06a	1.40±0.60a	2.49±0.58a	3.32±0.31a	3.99±0.06b
LA (1 min)-SHS (150℃)	SMAC	0.47±0.41a	1.44±0.25a	2.08±0.23a	3.65±0.19a	4.27±0.20b
	SPRAB	0.26±0.09a	1.52±0.27a	2.25±0.23a	2.96±0.35a	3.64±0.17a
LA spray–SS (200℃)	SMAC	0.28±0.18a	2.01±0.49a	2.85±0.07a	4.06±0.65a	5.17±0.50a
	SPRAB	0.15±0.06a	1.77±0.67a	2.92±0.37a	3.95±0.56a	5.04±0.11a
LA (1 min)-SHS (200℃)	SMAC	0.47±0.41a	1.51±0.24a	2.67±0.17ab	4.27±0.30a	> 5.52a
	SPRAB	0.26±0.09a	1.70±0.24a	2.44±0.06b	3.45±0.44a	4.69±0.58a

The values are means ± standard deviations from three replications.

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

Table 14. Log reduction (log CFU/cm^2) of uninjured and injured cells of *S.* Typhimurium on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS).

Treatment	Medium	Log reduction (log CFU/cm2)				
		0 s	5 s	10 s	15	20 s
LA spray–SS (100℃)	XLD	0.68±0.18ab	1.24±0.21a	1.67±0.35a	2.85±0.49a	3.46±0.27a
	OV-XLD	0.35±0.25a	1.18±0.51a	2.23±0.79a	2.86±0.24a	3.68±0.31a
LA (1 min)-SS (100℃)	XLD	0.30±0.09a	1.22±0.39a	1.63±0.29a	2.41±0.29a	3.27±0.15a
	OV-XLD	0.78±0.26b	1.45±0.18a	1.59±0.16a	2.24±0.50a	3.14±0.45a
LA spray–SHS (150℃)	XLD	0.68±0.18ab	1.76±0.31a	2.02±0.17a	3.27±0.58a	3.95±0.70a
	OV-XLD	0.35±0.25a	1.72±0.34a	2.57±0.76a	3.58±0.15a	4.23±0.34a
LA (1 min)-SHS (150℃)	XLD	0.30±0.09a	1.43±0.24a	1.82±0.23a	2.87±0.56a	4.07±0.11a
	OV-XLD	0.78±0.26b	1.53±0.20a	1.88±0.29a	3.05±0.22a	3.88±0.70a
LA spray–SS (200℃)	XLD	0.68±0.18ab	2.19±0.42a	2.55±0.33a	3.92±0.14a	>4.90a
	OV-XLD	0.35±0.25a	1.96±0.29a	2.97±0.55a	4.23±0.82a	5.10±0.56a
LA (1 min)-SHS (200℃)	XLD	0.30±0.09a	1.65±0.31a	2.39±0.10a	3.70±0.24a	>5.26a
	OV-XLD	0.78±0.26b	1.84±0.47a	2.70±0.29a	3.92±0.43a	5.03±0.31a

The values are means ± standard deviations from three replications.

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

Table 15. Log reduction (log CFU/cm^2) of uninjured and injured cells of *L. monocytogenes* on cantaloupes treated with combination of lactic acid (2%) and saturated steam (SS) or superheated steam (SHS).

Treatment	Medium	Log reduction (log CFU/cm2)				
		0 s	5 s	10 s	15	20 s
LA spray–SS (100°C)	OAB	0.48±0.04a	1.35±0.30a	2.35±0.53a	3.03±0.36a	4.09±0.37a
	OV-OAB	0.39±0.13a	1.66±0.11a	2.24±0.80a	2.97±0.52a	3.96±0.36a
LA (1 min)-SS (100°C)	OAB	0.50±0.24a	1.69±0.35a	2.31±0.31a	3.01±0.32a	3.79±0.30a
	OV-OAB	0.52±0.13a	1.82±0.68a	2.74±0.18a	3.30±0.51a	4.20±0.64a
LA spray–SHS (150°C)	OAB	0.48±0.04a	1.63±0.35a	3.02±0.15a	3.57±0.50a	4.70±0.60a
	OV-OAB	0.39±0.13a	1.91±0.11a	2.80±0.80a	3.18±0.52a	4.52±0.36a
LA (1 min)-SHS (150°C)	OAB	0.30±0.09a	1.43±0.24a	1.82±0.23a	2.87±0.56a	4.07±0.11a
	OV-OAB	0.78±0.26a	1.53±0.20a	1.88±0.29a	3.05±0.22a	3.88±0.70a
LA spray–SS (200°C)	OAB	0.48±0.04a	2.16±0.15a	3.54±0.48a	4.23±0.46a	>5.39a
	OV-OAB	0.39±0.13a	2.17±0.23a	3.07±0.46a	4.51±0.40a	5.25±0.21a
LA (1 min)-SHS (200°C)	OAB	0.50±0.24a	2.56±0.19a	3.26±0.59a	4.54±0.37a	>5.39a
	OV-OAB	0.52±0.13a	2.40±0.58a	3.35±0.29a	4.31±0.05a	5.74±0.32a

The values are means ± standard deviations from three replications.

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

3.2.5. Effect of LA and steam treatment on product quality during storage.

Table 16 shows color and textural changes of cantaloupes during storage after combination of DW, LA immersion or LA spray and SS or SHS treatment. L*, a*, and b* values of all treated cantaloupes were not significantly ($P > 0.05$) different from those of untreated samples. Texture values of treated cantaloupes were also not significantly ($P > 0.05$) different from those of untreated controls.

Table 16. Change of color value and texture value of cantaloupe treated with combination of LA and steam for 20 sec during storage. –(A) Color L* value, (B) Color a* value, (C) Color b* value, and (D) texture value.

(A) Color L* value

Treatment	Storage time (days) at 4℃		
	0	3	7
Control	65.24±2.11Aa	64.82±1.37Aa	63.95±1.56Aa
DW immersion	65.49±1.73Aa	64.15±1.21Aa	64.62±1.16Aa
LA immersion	63.74±3.44Aa	64.41±1.21Aa	63.61±2.64Aa
LA spray	65.05±2.02Aa	64.02±1.55Aa	63.45±1.51Aa
DW-100℃, 30 sec	65.42±3.84Aa	64.05±1.49Aa	64.16±2.43Aa
LA immersion-100℃, 30 sec	62.15±0.98Aa	64.52±1.03Aa	63.35±1.61Aa
LA spray-100℃, 30 sec	64.13±1.24Aa	64.19±2.20Aa	63.77±1.41Aa
DW-150℃, 30 sec	65.58±2.16Aa	65.08±0.72Aa	64.53±2.00Aa
LA immersion-150℃, 30 sec	63.89±1.71Aa	64.95±2.05Aa	63.88±1.45Aa
LA spray-150℃, 30 sec	64.34±0.69Aa	64.12±2.42Aa	63.48±2.12Aa
DW-200℃, 30 sec	65.04±1.67Aa	64.30±0.89Aa	64.73±1.33Aa
LA immersion-200℃, 30 sec	63.32±0.17Aa	64.23±1.21Aa	63.49±1.80Aa
LA spray-200℃, 30 sec	64.09±0.99Aa	64.78±0.44Aa	63.97±0.48Aa

(B) Color a* value

Treatment	Storage time (days) at 4℃		
	0	3	7
Control	-0.24±0.66Aa	-0.35±0.92Aa	-0.38±0.56Aa
DW immersion	0.07±0.75Aa	-0.27±0.39Aa	-0.29±0.43Aa
LA immersion	-0.12±0.51Aa	-0.35±0.86Aa	-0.24±0.47Aa
LA spray	-0.65±0.51Aa	-0.53±1.33Aa	-0.24±0.54Aa
DW-100℃, 30 sec	-0.60±1.80Aa	-0.17±1.42Aa	-0.43±0.32Aa
LA immersion-100℃, 30 sec	-0.19±0.57Aa	-0.04±0.63Aa	-0.36±0.33Aa
LA spray-100℃, 30 sec	-0.34±0.62Aa	-0.36±1.27Aa	-0.46±0.81Aa
DW-150℃, 30 sec	-0.15±0.88Aa	-0.10±1.20Aa	-0.14±0.89Aa
LA immersion-150℃, 30 sec	-0.14±0.10Aa	-0.27±1.14Aa	-0.17±0.73Aa
LA spray-150℃, 30 sec	-0.77±0.79Aa	-0.46±1.02Aa	-0.28±0.51Aa
DW-200℃, 30 sec	0.04±0.63Aa	-0.64±0.56Aa	-0.33±0.68Aa
LA immersion-200℃, 30 sec	0.02±0.41Aa	-0.12±1.15Aa	-0.27±0.36Aa
LA spray-200℃, 30 sec	-0.58±1.58Aa	-0.16±0.72Aa	-0.20±0.59Aa

(C) Color b* value

Treatment	Storage time (days) at 4℃		
	0	3	7
Control	21.55±1.12Aa	21.60±1.24Aa	22.11±1.08Aa
DW immersion	22.40±1.35Aa	21.43±0.94Aa	22.36±1.42Aa
LA immersion	21.99±1.86Aa	22.12±1.18Aa	21.42±1.15Aa
LA spray	21.19±1.44Aa	21.43±1.39Aa	21.53±0.93Aa
DW-100℃, 30 sec	21.42±0.68Aa	22.50±1.46Aa	21.42±0.68Aa
LA immersion-100℃, 30 sec	20.65±0.39Aa	21.65±0.69Aa	21.33±1.23Aa
LA spray-100℃, 30 sec	21.16±0.71Aa	21.94±1.52Aa	21.32±0.78Aa
DW-150℃, 30 sec	21.38±1.02Aa	21.59±1.31Aa	21.38±1.02Aa
LA immersion-150℃, 30 sec	21.46±1.19Aa	21.88±0.61Aa	21.29±0.91Aa
LA spray-150℃, 30 sec	21.44±1.03Aa	21.83±1.53Aa	21.96±0.83Aa
DW-200℃, 30 sec	22.75±2.15Aa	22.55±0.86Aa	22.75±2.15Aa
LA immersion-200℃, 30 sec	21.92±0.39Aa	22.07±2.64Aa	21.09±1.33Aa
LA spray-200℃, 30 sec	21.16±1.86Aa	21.93±1.74Aa	21.31±1.17Aa

(D) texture value.

Treatment	Storage time (days) at 4℃		
	0	3	7
Control	211.59±18.54Aa	212.01±10.01Aa	213.82±17.51Aa
DW immersion	213.08±12.46Aa	213.07±8.19Aa	214.50±22.12Aa
LA immersion	214.51±11.92Aa	213.12±5.36Aa	216.08±12.43Aa
LA spray	217.02±19.30Aa	215.03±15.23Aa	212.32±15.55Aa
DW-100℃, 30 sec	216.76±18.35Aa	212.26±12.43Aa	214.28±22.78Aa
LA immersion-100℃, 30 sec	214.85±22.11Aa	210.07±7.10Aa	211.20±22.51Aa
LA spray-100℃, 30 sec	213.25±20.83Aa	215.17±13.87Aa	215.32±19.60Aa
DW-150℃, 30 sec	212.15±16.33Aa	217.81±15.22Aa	212.47±10.16Aa
LA immersion-150℃, 30 sec	217.24±21.84Aa	216.52±10.59Aa	212.32±15.61Aa
LA spray-150℃, 30 sec	217.05±21.83Aa	215.48±15.77Aa	212.99±10.53Aa
DW-200℃, 30 sec	209.46±20.25Aa	216.00±16.94Aa	215.13±14.25Aa
LA immersion-200℃, 30 sec	215.07±19.02Aa	217.56±15.12Aa	216.52±16.76Aa
LA spray-200℃, 30 sec	210.76±16.50Aa	214.65±16.16Aa	214.85±19.62Aa

The values are means ± standard deviations from three replications.

Means with different uppercase letters within a row are significantly different ($p < 0.05$).

Means with different lowercase letters within a column are significantly different ($p < 0.05$).

IV. DISCUSSION

Cantaloupes and watermelons are commonly linked with outbreaks of foodborne pathogens (FAO, 2011; Walsh et al., 2014). The US Food and Drug Administration(FDA) continually strives to enhance the safety of cantaloupes (FDA, 2013). This study has evaluated the effectiveness of SHS against foodborne pathogens on cantaloupes and watermelons to assess its ability to control pathogens.

SHS has higher enthalpy than SS, so it can quickly transfer heat to the material being processed (Anto et al., 2014). When SS and SHS were applied to cantaloupe and watermelon surfaces, significant reductions were observed. For food processing, SHS has the advantages of rapid heating, lower quality loss, and higher efficiency. SHS has been used by the food industry for drying (Pronyk et al.,2005; Van Deventer et al., 2001), inactivation of pathogens (Ban et al., 2014), and enzyme inactivation (Satou et al., 2010). SHS microbial inactivation has not been studied extensively; in particular for the decontamination of fresh foods. Therefore, this research was conducted to compare the efficacy of SHS and SS treatment for the inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* on fresh-cut fruits.

Some previous studies verified the inactivation efficiency of SHS. For almonds and pistachios, SHS treatment attained an additional 1.8–4.2 log reduction of *E. coli* O157:H7, *S.*Typhimurium, *S.* Enteritidis phage type 30, and *L. monocytogenes* compared to SS (Ban & Kang, 2016). In the case of PVC and stainless steel coupons, SHS attained an additional 0.05–2.6 log reduction of *E.* O157:H7, *S.* Typhimurium, and *L. monocytogenes* biofilms compared to SS (Ban et al., 2014). In the present study, *E. coli* O157:H7, *S.* Typhimurium, and *L.* monocytogenes on watermelon and cantaloupes were reduced by more than 5 log after 200°C steam treatment for 10 s and 30 s, respectively.

SHS facilitated greater reductions than did SS treatment. For instance, to kill 99.9 % of *E. coli* O157:H7 on cantaloupe surfaces, more than 30 s at 100°C SS was required, while 150°C SHS treatment needed 25 s and 200°C SHS treatment needed less than 20 s. When 30 s SS and SHS treatments were applied to watermelons, 100°C SS resulted in only 3.52 log reduction, while 200°C SHS effected greater than 5 log reduction to below the detection limit.

Comparing steam inactivation efficiency between cantaloupes and watermelons (Figure 1), watermelons exhibited higher microbial reductions following steam treatment. Cantaloupes needed additional time to satisfy the

5 log reduction target for *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes*. SHS treatment at 200°C for 10 s reduced, *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* populations on watermelons by more than 5 log, but in the case of cantaloupes only 1.92-2.23 log reduction occurred. This significant difference in steam efficacy may be attributed to surface characteristics.

Several researchers have studied the influence of surface characteristics on microbial adhesion and removal (Hilbert et al, 2003; Jullien et al, 2003; Medilanski et al, 2002). Especially, several studies have indicated that surface roughness (R_A) can influence the ability of some organisms to attach to surfaces. Barnes et al (1999) investigated the adhesion of *Staphylococcus aureus t*o polished as well as untreated stainless steel and observed that a greater number of *S. aureus* cells adhered to untreated steel which had a rougher surface. For this reason, in liquid food processing, an R_A value of 0.8 μm or less has been recommended for food contact surfaces (Hauser et al., 1993). Some studies with stainless steel have been published, however, there have been few reports on the effect of surface roughness of fresh produce on bacterial adhesion.

To investigate the correlation between our results and surface roughness, roughness values of cantaloupes and watermelons were measured (shown in

Table 9). As shown in Fig 2&3, cantaloupes had variously sized crevices across their surface, while watermelons had a flatter, smoother structure with few crevices. These crevices and peaks contributed to significant difference in R_A value. Since cantaloupes had a higher R_A value, *E. coli* O157:H7 could have more protected sites on cantaloupes, resulting in lower steam inactivation efficacy, which conforms to the findings of other research studies. Even in the case of SHS, substrates which have a rougher surface need more treatment time to obtain a 5 log reduction of pathogens. Wang et al (2009) indicated that there was a positive correlation between R_A and adhesion rate of *E. coli O157:H7*, and a negative correlation between R_A and inactivation efficacy of sanitizers on fruit surfaces including cantaloupes. Also, in the study by Faille et al (2002), widely used roughness parameters R_A and R_Z were related to the number of adherent cells.

To visually compare the adhesion rate of *E. coli* O157:H7 on cantaloupes and watermelons, SEM images were obtained (Fig 3). SEM images of both uninoculated and *E. coli* O157:H7-inoculated cantaloupes and watermelons were examined. There were many cracks, crevices, and pores on cantaloupe surfaces, while watermelons had a smooth surface. After inoculation, bacterial cells were easily observed both individually and in clusters on cantaloupe surfaces, especially in crevices. However, few bacteria were

noticed on watermelon surfaces. These finding could support the hypothesis that foodborne pathogens adhere more strongly to cantaloupe surfaces which have a higher R_A value than that of watermelons.

Fransisca and Feng (2012) studied the correlation between *E. coli* population reduction by several sanitizers and surface roughness of several types of seeds. As surface roughness increased, log reduction decreased. But this trend did not apply to all treatments, because surface roughness was not found to be the only factor that influenced bacterial removal from seeds. Also, in the present study, the difference in SHS efficacy between cantaloupes and watermelons is associated with surface roughness, but surface roughness may not be the only factor.

In the fresh produce industry, decontamination treatment resulting in quality loss cannot not be commercialized. Appearance and texture changes are used as measures of freshness and quality decline by fresh-cut research and industry (Cantwell and Suslow, 2002). The L*, a*, and b* values of SS or SHS treated cantaloupes and watermelons were not significantly ($P > 0.05$) different from those of untreated fruit, except for a*, b* values of cantaloupes. The a* and b* values of treated samples varied slightly, but there was no overall tendency. Color values (L*, a*, b*) of all samples varied more from piece to piece, and sample to sample than between

treatments. In fresh-cut watermelon, *a** and *b** values are directly correlated to lycopene and carotene concentrations in stored tissue (Saftner et al., 2007). Also, loss of color may be attributed to oxidation of β-carotene. In our study, no change observed in color may indicate no loss of lycopene and carotene. Texture values of treated cantaloupes and watermelons showed no significant change related to storage time regardless of treatment condition. After SHS treatment for up to 30 and 10 s on cantaloupes and watermelons, respectively, color values and maximum load were not significantly ($P > 0.05$) different from those of untreated controls.

In conclusion, this research demonstrated that SHS treatment leads to effective inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L.* monocytogenes on cantaloupes and watermelons. SHS treatment of cantaloupes and watermelons can yield more than a 5-log reduction after a short treatment time. It was more difficult for cantaloupes to obtain a 5-log reduction of pathogens, which may be due to surface characteristics. Surface roughness is associated with bacterial adhesion and SHS efficiency. Still, SHS treatment is a very promising technology for the fresh-cut industry leading to significant inactivation of foodborne pathogens with short treatment time.

For food processing, SHS has the advantages of rapid heating and lower quality loss. But disadvantages of the SHS processing technique include high capital cost, complexity of the equipment, and high temperature of processed products (important when processing temperature-sensitive products) (Pronyk et al., 2004). It is economically beneficial to use steam in combination with other methods to inactivate foodborne pathogens. (Chen, 2007).

Hence, steam treatment needs to be developed as a practical and effective short-time food processing intervention for inactivating and detaching foodborne pathogens in combination with other control methods. Also, 200℃ SHS treatment for 30 s obtained 5 log reduction on cantaloupe surface, however, color values of a* and b* are different from those of untreated controls. Therefore, further research was conducted to evaluate the efficacy of LA-SHS treatment for the inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* on cantaloupe.

The mechanism of inhibition of microorganisms by organic acids, such as lactic acid, is related to several factors including reduction in pH, the ratio of the undissociated form of the acid, chain length, degree of branching, cell physiology and metabolism (Doores, 1995). In fresh produce industry, two methods of sanitizer application (dipping, and spraying) were commonly

used. Also, the comparison of sanitizing efficacy of spray and immersion treatments was evaluated.

When LA-SHS treatments were applied to cantaloupes for 20 s, 200°C SHS effected greater than 5 log reduction to below the detection limit of *E. coli* O157:H7, *S.* Typhimurium, and *L.* monocytogenes on cantaloupes. These results indicate that the combination of steam treatment and lactic acid has a lethal effect on foodborne pathogens. There was no significant difference between spray treated and immersion treated samples. Spraying method is more cost-effective than dipping method in terms of needed water. Dipping method also has possibility of cross-contamination. Thus, spraying is more recommended when combined with steam treatment.

Besides microbiological analyses, control and treated samples were also submitted to the evaluation of some quality parameters, such as color and firmness (Table 16). In the fresh produce industry, the quality of fresh cantaloupe is important considerations for any pathogens reduction technique. The L*, a*, and b* values of treated cantaloupes were not significantly ($P > 0.05$) different from those of untreated fruit. Also, texture values of treated cantaloupes showed no significant change related to storage time.

In conclusion, this research demonstrated that SHS treatment leads to effective inactivation of *E. coli* O157:H7, *S.* Typhimurium, and *L.* monocytogenes on watermelons. LA-SHS treatment leads to effective inactivation of these pathogens on cantaloupes. SHS treatment of watermelon and LA-SHS treatment of cantaloupes can yield more than a 5-log reduction without quality loss.

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VI. 국문초록

과열 증기는 포화 압력 그대로 더욱 가열하여 포화 온도 이상으로 한 증기를 말한다. 과열 증기는 포화 증기에 비해 이용할 수 있는 잠열이 크기 때문에 이를 이용하여 식품 병원성균 저감화에 응용 할 수 있는 잠재력이 큰 기술임에도 불구하고, 이에 대한 연구는 미미한 실정이다. 따라서 이 연구에서는 과열 증기를 이용하여 신선 식품에서의 식중독 균의 저감과 식품의 품질 변화에 미치는 영향을 살펴보았다. 식중독균으로는 대표적으로 문제가 되고 있는 병원성 균 중에서 *Escherichia coli* O157:H7, *Salmonella enterica* serovar Typhimurium 과 *Listeria monocytogenes* 를 선택하여 연구를 진행하였다.

먼저, 포화 증기와 과열 증기를 이용하여 수박과 캔탈롭에서 식중독균의 저감 효율성을 실험하였다. 과열증기는 포화증기에 비해 추가적인 저감화를 일으켰으며, 과열 증기의 온도와 처리 시간이 증가할수록 병원균의 수가 유의적으로 감소하는 것을 확인할 수 있었다. 과열 증기 200℃로 수박에 10 초,

캔탈롭에는 30 초 처리시 세 균에서 모두 5 로그 이상의 저감화를 달성하였다.

수박과 캔탈롭에서 병원균 저감화 효율성 차이를 해석하기 위해 표면 특성을 연구하였다. 표면 거칠기 측정기를 통해 캔탈롭의 거칠기가 수박에 비해 유의적으로 ($p > 0.05$) 크다는 것을 확인 할 수 있었다. 또한 주사전자 현미경을 통해 수박은 매끈한 표면을 가져 균들이 바깥에 쉽게 노출되어 있으나, 캔탈롭은 거친 표면을 가져 균들이 쉽게 노출되지 않고 틈 속에 숨어있는 것을 확인 할 수 있었다. 이를 통해 캔탈롭에서 증기의 살균 효율성이 수박에 비해 낮은 것을 표면 특성으로 설명할 수 있었다.

신선 식품에서 살균 기술을 적용하는 데 있어서 미생물 저감화 만큼이나 품질에 대한 영향성도 매우 중요하다. 수박의 경우 품질 영향성이 없었지만, 캔탈롭의 경우 5 로그를 달성했던 처리 조건에서 품질 저하가 나타났다. 이에 따라 캔탈롭에서 품질 변화없이 미생물 5 로그 저감화를 달성하기 위한 방법의 필요성을 느껴 추가적으로 산과의 복합 처리를 진행하였다. 캔탈롭에 유기산의 일종인 젖산 처리 후, 증기 처리하여 추가저감화가 일어나는 지를 연구한 결과, 젖산 처리 후 200℃ 과열증기를 20 초

처리하였을 때, 개별 처리를 더한 것에 비해 시너지 효과를 나타내어 병원균들이 검출한계 이하 (1.00 log CFU/cm^2) 로 감소하였다. 산 처리 방법으로는 침지 방법과 분무 방법 두가지로 진행하였는데, 두 가지 방법은 미생물 저감화 효율성에 있어 유의적인 차이를 나타내지 않았다 ($p > 0.05$). 산과 증기의 병행 처리 후 캔탈롭 품질에 미치는 영향을 살펴본 결과, 처리하지 않은 대조군과 비교해 처리군의 색도와 텍스쳐와의 유의적인 차이는 발견되지 않았다.

종합적으로 과열 증기를 이용한 미생물 저감화 기술이 신선 식품 산업에서 병원균을 빠르고 효과적으로 제어할 수 있는 기술임을 확인하였으며, 저감화가 어려운 식품의 경우, 산과의 병행처리를 통해 살균 효율성을 높일 수 있음을 확인하였다.

주요어: 과열수증기, 식품매개 병원균, 수박, 메론, 산, 병행 처리
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