Effect of the precutting process on sanitizing treatments for reducing pathogens in vegetables

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Abstract The effectiveness of sanitizing treatments was investigated on reducing pathogens inoculated in whole or cut fresh vegetables, including Brussels sprouts, carrots, cherry tomatoes, paprika, and lettuce. These products were inoculated with *Escherichia coli* O157:H7, *Salmonella enterica* serovar Typhimurium, and *Listeria monocytogenes* and then treated with chlorine and alcohol sanitizers, followed by the subsequent washing procedure in sterile distilled water at 25°C for 5 min. Alcohol sanitizer was the most effective in inhibiting *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on cut Brussels sprouts, showing bacterial reductions of 4.16, 3.60, and 3.26 log CFU/g, respectively. Interestingly, the effects of sanitizing treatments were significantly lower for fresh cut produce than those for whole products ($p < 0.05$), indicating that the effectiveness of sanitizers would be different, depending on fresh produce and the pre-cut process. Therefore, further information should be obtained to develop an effective sanitizing treatment for fresh produce.

Keywords: sanitizing treatment, pathogen, fresh vegetable, pre-cutting, effectiveness

Introduction

During the last decade, as society seeks healthier lifestyles, the demand for minimally processed fresh produce has led to increases in production (1). The number of foodborne illnesses linked to minimally processed fruits and vegetables has arisen with the increasing consumption of fresh produce (2,3). These foodborne outbreaks have been caused by pathogenic bacteria, including *E. coli* O157:H7, *S. enterica* serovar Typhimurium, and *L. monocytogenes* (4). Minimally processed fruits and vegetables could be contaminated with these pathogens through various routes, including irrigation or washing water, sewage-based fertilizers, infected workers, and food processing facilities with poor sanitation (5). Because fresh produce is routinely consumed without minimal thermal processing, immersion of fresh produce in sanitizers constitute the most practical means of decontamination (6). During sanitization, fresh produce should be effectively treated to kill or reduce the number of pathogenic microorganisms without affecting the quality.

Over the past several decades, many studies evaluated the effectiveness of various chemical washing agents such as chlorine to reduce pathogens on fruits and vegetables in the food service industry (7); dipping fresh vegetables and fruits in chlorine-based sanitizers ranging from 20 to 200 ppm is the most commonly used practice. However, chlorine sanitizers exhibited a limited effect for

reducing the number of pathogenic microorganisms on fresh produce. Several previous studies have reported ≤ 2 or 3 log reductions in the population of pathogens on fresh produce as a consequence of using chlorine sanitizers (8). In particular, chlorine may react with organic matter, resulting in the formation of carcinogenic products in the contacting water (9). Thus, the insufficiency of chlorine as a sanitizer has stimulated an interest in finding safe alternatives and more effective sanitizers (10). It has been reported that alcohol-based sanitizers containing more than 50% ethanol showed the most pronounced antimicrobial effects from (11,12) to (11,13). Moreover, microbial invasion into the inner space of fresh produce (internalization) may occur when these bacteria attach to the cut surfaces or in punctures and cracks in fresh produce (14,15). Pathogens located in the interior tissues of fresh produce are less likely to be removed after sanitization or cleaning, thereby potentially causing foodborne illnesses (16). However, very few studies have investigated the effects of sanitizers for reducing pathogens attached to the surface of pre-cut fresh produce. Therefore, this study investigated the efficacies of sanitizing treatments (chlorine/alcohol sanitizer treatments alone or in combination with the following washing in sterile deionized water) on reducing the number of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* inoculated either on whole or pre-cut fresh produce.

Materials and Methods

Bacterial strains *E. coli* O157:H7 ATCC 35150, ATCC 43895, and ATCC 43890; *S. Typhimurium* ATCC 19585, ATCC 43971, and DT 104; and *L. monocytogenes* ATCC 19114, ATCC 19115, and ATCC 7644 were obtained from the bacterial culture collection of Chung-Ang University (Anseong-si, Korea) and used in this study. The strains were obtained from freezer stocks and activated by cultivation in tryptic soy broth (TSB; Difco Laboratories, Detroit, MI, USA, pH 7.3) at 37°C for 24 h. Cultures were harvested by centrifugation at 13,000×g for 5 min. The supernatant was decanted, and the pellet was resuspended in 0.2% peptone water (Difco). Each group of pathogenic bacteria was mixed to produce culture cocktails of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes*, which were used in the experiment.

Vegetable preparation Brussels sprouts, carrots, cherry tomatoes, paprika, and lettuce were used for this study. These fresh vegetables were purchased from a local market in Anseong-si, Korea, transported to the laboratory, and used within 1 h following storage at 5°C. Approximately three outer leaves of lettuce were discarded and whole inner leaves and large pieces of leaves were used in experiments (17). Fresh vegetables except cherry tomatoes were cut to approximately 3 cm² using a sterilized knife. Cherry tomatoes with and without the stem were tested.

Inoculation procedure Because the immersion process is a potential point of contamination in the food industry, dip inoculation is the most modest method that can be used to simulate such a process (18). Pre-cut or whole vegetable samples were prepared. Each culture cocktail of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* was diluted in 5 L distilled water to a concentration of 10^{4–6} CFU/mL. Each whole or cut vegetable was submerged in suspensions of each pathogen for 20 min with gentle, continuous agitation, and then fresh products were air-dried in a clean bench flow hood for 40 min.

Treatment procedure Sanitizer treatments were evaluated for their efficacy in reducing the levels of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on fresh vegetables. Commercial alcohol sanitizer (Bio cleanol; Jinro distillers, Ansan-si, Gyeonggi-do, Korea) and chlorine sanitizer (Sanichlo, Hansonhygiene, Yongin-si, Gyeonggi-do, Korea) were used in this study. The sanitizers were prepared just before use by following the manufacturers' instruction. The sanitizer treatments were also evaluated along with distilled water and a no-wash treatment, which were both used as controls. The inoculated whole or cut vegetables were dipped into the assigned sanitizer solution and submerged for 5 min with gentle, continuous agitation. After each treatment, samples were classified as wash or no-wash with distilled water for subsequent microbial enumeration.

Microbiological analysis Treated samples (25 g) were transferred

in sterile plastic stomacher bags and homogenized for 90 s using a stomacher (BagMixer 400; Interscience Laboratory Inc., St. Nom, France). After homogenization, samples were serially 10-fold diluted with 9 mL sterile peptone water, and then 0.1 mL of the aliquots or diluents was spread onto each of the selective media. Sorbitol MacConkey Agar (SMAC; Difco), Xylose-Lysine-Desoxycholate (XLD; Difco) agar, and Oxford medium (OAB; Difco) supplemented with Modified Oxford Antimicrobial Supplement (Difco) were used for enumerating *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes*, respectively. All agar plates were incubated at 37°C for 18–24 h, and then typical colonies showing the characteristic morphology of each pathogen were enumerated. Microbial counts were expressed as log CFU/g for each sample.

Statistical analysis All experiments were repeated three times with duplicate plates, and the averages of the duplicate plate counts from three replications were converted to units of log CFU/g. Data were analyzed by the ANOVA procedure using SAS software (Version 9.1, SAS Institute Inc., Cary, NC, USA) for a completely randomized design. When the effect was significant ($p < 0.05$), mean separation was accomplished via Duncan's multiple-range test.

Results and Discussion

Table 1 shows the effectiveness of alcohol and chlorine sanitizers used alone or combined with the subsequent washing step on reducing the number of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on whole and pre-cut Brussels sprouts. The initial loads of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on Brussels sprout were 5.62, 5.03, and 4.69 log CFU/g, respectively. When *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on Brussels sprouts were treated with 100 ppm chlorine sanitizer for 5 min, it resulted in bacterial reductions of 1.64, 1.22, and 1.29 log CFU/g, respectively. In particular, the numbers of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on Brussels sprouts significantly decreased after treatment with the alcohol sanitizer, showing bacterial reductions of 3.14–4.14, 3.55, and 3.21 log CFU/g, respectively ($p < 0.05$). It appeared that alcohol sanitizer was the most effective in eliminating these pathogenic bacteria inoculated on Brussels sprouts. Reduction levels of pathogens caused by treatment with the alcohol sanitizer were significantly higher than those by the chlorine sanitizer ($p < 0.05$). In addition, the pre-cut procedure did not affect the effectiveness of these sanitizers on reducing pathogens on Brussels sprouts, with the exception that the number of *E. coli* O157:H7 was significantly lower in pre-cut Brussels sprouts (1.48 log CFU/g) than that in whole Brussels sprouts (2.48 log CFU/g) when treated with the alcohol sanitizer ($p < 0.05$).

The initial levels of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on carrots were 5.46, 5.58, and 2.74 log CFU/g, respectively (Table 2). After treatment with the chlorine sanitizer,

Table 1. Efficacy of various sanitizer treatments on reducing pathogen populations (log CFU/g)¹⁾ on artificially inoculated whole and cut Brussels sprouts

	Shape	Control	Dw ²⁾	Cl	Cl-dw	Al	Al-dw
<i>Escherichia coli</i> O157:H7	Whole	5.62±0.28A ³⁾⁴⁾	5.06±0.24Ba	3.98±0.35Ca	4.13±0.37Ca	2.48±0.50Da	2.13±1.17Ea
	Cut	5.62±0.28Aa	5.09±0.37ABa	4.51±0.22Ba	4.84±0.67ABa	1.48±0.03Db	3.24±0.60Ca
<i>Salmonella</i> Typhimurium	Whole	5.03±0.47Aa	4.48±0.17ABa	3.81±0.35Ba	3.73±0.39Ba	<1.48 ⁵⁾ ±0.00Ca	1.87±0.75Ca
	Cut	5.03±0.47Aa	4.58±0.63ABa	3.90±0.22Ba	3.85±0.47Ba	<1.48±0.00Ca	1.56±0.19Ca
<i>Listeria monocytogenes</i>	Whole	4.69±0.28Aa	4.18±0.38Ba	3.40±0.13Cb	3.50±0.45Ca	1.48±0.03Da	<1.48±0.00Db
	Cut	4.69±0.28Aa	4.63±0.57Aa	3.95±0.30Ba	3.75±0.37Ba	<1.48±0.00Ca	1.94±0.15Ca

¹⁾Data are mean±standard deviation of three measurements.²⁾Dw, distilled water; Cl, chlorine sanitizer; Al, alcohol sanitizer; and -dw, alcohol and chlorine sanitizer without and with subsequent washing with water.³⁾Means with the same letter within a row are not significantly different ($p>0.05$).⁴⁾Means with the same letter between whole or cut vegetable samples are not significantly different ($p>0.05$).⁵⁾Detection limit=1.48 log CFU/g.**Table 2.** Efficacy of various sanitizer treatments on reducing pathogen populations (log CFU/g)¹⁾ on artificially inoculated whole and cut carrots

	Shape	Control	Dw ²⁾	Cl	Cl-dw	Al	Al-dw
<i>Escherichia coli</i> O157:H7	Whole	5.46±0.79A ³⁾⁴⁾	4.03±0.37Ba	3.36±0.81Ba	3.15±0.75Ba	3.85±0.82Ba	3.44±0.53Ba
	Cut	5.46±0.79Aa	4.07±0.69Aa	3.01±0.06BCa	3.19±0.53Ba	2.52±0.20BCa	2.34±0.11Cb
<i>Salmonella</i> Typhimurium	Whole	5.58±0.25Aa	3.37±0.28Ba	1.88±0.42Cb	1.82±0.30Cb	1.80±0.37Ca	1.76±0.54Ca
	Cut	5.58±0.25Aa	3.58±1.41ABa	2.47±0.20CDa	2.80±0.79BCa	1.74±0.34Da	1.51±0.58Da
<i>Listeria monocytogenes</i>	Whole	2.74±0.90Aa	1.48±0.03Ba	<1.48 ⁵⁾ ±0.00Ba	1.48±0.03Ba	<1.48±0.00Ba	<1.48±0.00Ba
	Cut	2.74±0.90Aa	2.60±1.02Aa	1.87±0.75Aa	2.23±0.89Aa	1.69±0.42Aa	<1.48±0.00Aa

¹⁾Data are mean±standard deviation of three measurements.²⁾Dw, distilled water; Cl, chlorine sanitizer; Al, alcohol sanitizer; and -dw, alcohol and chlorine sanitizer without and with subsequent washing with water.³⁾Means with the same letter within a row are not significantly different ($p>0.05$).⁴⁾Means with the same letter between whole or cut vegetable samples are not significantly different ($p>0.05$).⁵⁾Detection limit=1.48 log CFU/g.**Table 3.** Efficacy of various sanitizer treatments on reducing pathogen populations (log CFU/g)¹⁾ on artificially inoculated whole and stemless cherry tomatoes

	Shape	Control	Dw ²⁾	Cl	Cl-dw	Al	Al-dw
<i>Escherichia coli</i> O157:H7	Stem	2.96±1.05AB ³⁾⁴⁾	2.89±0.56ABa	3.10±0.30Aa	2.96±0.92ABa	1.62±0.29Ba	2.18±0.88ABa
	Without	2.96±1.05Aa	2.97±0.34Aa	1.71±0.48Bb	2.15±0.96ABa	<1.48 ⁵⁾ ±0.00Ba	1.61±0.30Ba
<i>Salmonella</i> Typhimurium	Stem	2.82±1.21Aa	2.85±0.29Aa	2.78±0.45Aa	1.90±0.39ABa	1.48±0.03Ba	1.97±0.54ABa
	Without	2.82±1.21ABa	3.08±0.63Aa	1.62±0.29BCb	1.99±0.89ABCa	<1.48±0.00Ca	1.48±0.03Ca
<i>Listeria monocytogenes</i>	Stem	2.70±1.42Aa	2.45±0.54Aa	2.54±0.52Aa	1.98±0.51Aa	<1.48±0.00Aa	1.68±0.43Aa
	Without	2.70±1.42Aa	1.84±0.71Aa	<1.48±0.00Ab	1.61±0.30Aa	<1.48±0.00Aa	<1.48±0.00Aa

¹⁾Data are mean±standard deviation of three measurements.²⁾Dw, distilled water; Cl, chlorine sanitizer; Al, alcohol sanitizer; and -dw, alcohol and chlorine sanitizer without and with subsequent washing with water.³⁾Means with the same letter within a row are not significantly different ($p>0.05$).⁴⁾Means with the same letter between whole or cut vegetable samples are not significantly different ($p>0.05$).⁵⁾Detection limit=1.48 log CFU/g.

populations of these pathogens on carrots were significantly reduced by approximately ≤ 4.00 log CFU/g ($p<0.05$). In particular, treatment with the alcohol sanitizer, followed by the subsequent washing, was the most effective in reducing the levels of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on carrots, and it resulted in bacterial reductions of 2.02, 3.82, and 1.26 log CFU/g, respectively. Physical characteristics of fresh produce either in a whole or pre-cut form did not significantly influence the reduction levels of pathogens ($p>0.05$).

Table 3 shows the populations of the three pathogens on cherry tomatoes with or without stems treated with sanitizer. The initial levels of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes*

were 2.96, 2.82, and 2.70 log CFU/g, respectively. Populations of *E. coli* O157:H7 and *S. Typhimurium* were significantly reduced by treatment with the alcohol sanitizer ($p<0.05$), whereas there were no significant reductions after treatment with distilled water ($p>0.05$). *E. coli* O157:H7 and *S. Typhimurium* were reduced by approximately 1.5 and 1.4 log CFU/g, respectively, by treatment with the alcohol sanitizer. Treatment with the chlorine sanitizer produced similar results, but it was slightly less effective than the alcohol sanitizer. Therefore, the level of pathogen reduction was affected by the type of sanitizer. When cherry tomatoes were treated with sanitizers, the levels of pathogen reduction did not differ between stemless and whole tomatoes. However, the chlorine sanitizer reduced the levels

Table 4. Efficacy of various sanitizer treatments on reducing pathogen populations (log CFU/g)¹⁾ on artificially inoculated whole and cut paprika

	Shape	Control	Dw ²⁾	Cl	Cl-dw	Al	Al-dw
<i>Escherichia coli</i> O157:H7	Whole	5.19±0.94A ³⁾⁴⁾	2.35±1.04Bb	1.65±0.37Ba	2.50±0.37Bb	1.90±0.40Bb	2.00±0.53Bb
	Cut	5.19±0.94Aa	5.63±0.21Aa	2.79±2.27Ba	4.80±1.19ABa	4.87±0.15ABa	4.60±1.02ABa
<i>Salmonella</i> Typhimurium	Whole	5.54±0.22Aa	2.39±0.98Bb	1.71±0.48Bb	1.56±0.19Bb	1.68±0.43Bb	1.58±0.17Bb
	Cut	5.54±0.22Aa	5.44±0.26ABa	4.6±0.38ABCa	4.87±0.61ABCa	4.33±0.81Ca	4.44±0.77BCa
<i>Listeria monocytogenes</i>	Whole	5.19±0.24Aa	1.68±0.17Bb	1.55±0.20Bb	<1.48 ⁵⁾ ±0.00Bb	<1.48±0.00Bb	1.48±0.03Bb
	Cut	5.19±0.24Aa	5.01±0.29Aa	3.88±0.62Ca	4.65±0.60ABCa	4.11±0.35BCa	4.79±0.39ABa

¹⁾Data are mean±standard deviation of three measurements.²⁾Dw, distilled water; Cl, chlorine sanitizer; Al, alcohol sanitizer; and –dw, alcohol and chlorine sanitizer without and with subsequent washing with water.³⁾Means with the same letter within a row are not significantly different ($p>0.05$).⁴⁾Means with the same letter between whole or cut vegetable samples are not significantly different ($p>0.05$).⁵⁾Detection limit=1.48 log CFU/g.**Table 5.** Efficacy of various sanitizer treatments on reducing pathogen populations (log CFU/g)¹⁾ on artificially inoculated whole and cut lettuce

	Shape	Control	Dw ²⁾	Cl	Cl-dw	Al	Al-dw
<i>Escherichia coli</i> O157:H7	Whole	6.09±0.10A ³⁾⁴⁾	5.13±0.76ABa	4.44±0.34Bb	4.55±0.69Ba	4.36±0.86Ba	4.57±0.48Ba
	Cut	6.09±0.10Aa	5.59±0.42ABa	5.18±0.49Ba	4.94±0.24Ba	3.90±0.67Ca	4.90±0.51Ba
<i>Salmonella</i> Typhimurium	Whole	6.08±0.21Aa	5.56±0.56Aa	3.52±0.73Ba	4.01±0.50Ba	3.85±1.29Ba	4.15±0.64Ba
	Cut	6.08±0.21Aa	5.79±0.27ABa	4.65±0.84BCa	4.30±0.54Ca	2.75±1.30Da	4.73±0.31BCa
<i>Listeria monocytogenes</i>	Whole	4.60±1.60Aa	3.90±1.28Aa	2.11±1.18Aa	2.53±0.87Aa	2.90±2.00Aa	3.02±1.28Aa
	Cut	4.60±1.60Aa	4.77±0.95Aa	3.26±1.88Aa	3.23±1.73Aa	3.31±1.69Aa	3.22±1.66Aa

¹⁾Data are mean±standard deviation of three measurements.²⁾Dw, distilled water; Cl, chlorine sanitizer; Al, alcohol sanitizer; and –dw, alcohol and chlorine sanitizer without and with subsequent washing with water.³⁾Means with the same letter within a row are not significantly different ($p>0.05$).⁴⁾Means with the same letter between whole or cut vegetable samples are not significantly different ($p>0.05$).

of all three pathogens to a greater extent in stemless cherry tomatoes than in whole cherry tomatoes ($p<0.05$). Therefore, the effect of pre-cutting and processing, such as removing the stem on a cherry tomato, differed based on the type of sanitizer.

Table 4 shows the results when the experiment was performed using pre-cut and whole paprika. Populations of the three pathogens on whole paprika were significantly reduced by 3.54, 3.83, and 3.64 log CFU/g by the chlorine sanitizer and 3.29, 3.86, and 3.71 log CFU/g by the alcohol sanitizer, respectively ($p>0.05$). However, the level of pathogen reduction was less than 2.40 log CFU/g on cut paprika. Therefore, pre-cut paprika significantly decreased the efficacy of sanitizing treatments.

Results for pre-cut and whole lettuce are shown in Table 5. Treatment with alcohol and chlorine sanitizers significantly reduced the levels of *E. coli* O157:H7 and *S. Typhimurium* ($p<0.05$). However, the population of *L. monocytogenes* was not reduced significantly by any of the sanitizing treatments applied in this study. The alcohol sanitizer reduced the levels of *E. coli* O157:H7 and *S. Typhimurium* on cut lettuce by 2.19 and 3.33 log CFU/g, respectively. However, pre-cut the lettuce did not affect the effectiveness of sanitizing treatments. In general, the efficacy of sanitizing treatments was significantly affected by three major elements, including shape, treatment, and pathogen, for reducing pathogenic bacteria inoculated on some fresh vegetables such as Brussels sprouts, carrots, and cherry tomatoes (Table 6). Furthermore, surface property and the use of a sanitizing solution had a significant influence on the survival of pathogens

contaminating carrots and paprika. These results indicated that the effectiveness of sanitizing treatments could be significantly different in response to a complex interaction with the characteristic (shape) of samples and a research experimental design (sanitizing treatments and pathogens to be tested).

To investigate the effects of the pre-cutting process on the effectiveness of sanitizing treatments, fresh produce, which is separated into whole or pre-cut produce, were artificially inoculated with *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes*, and then treated with the chlorine and alcohol sanitizers. Sanitizing treatments with alcohol or chlorine significantly reduced the levels of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* on all tested vegetables, but the alcohol sanitizer had an efficacy similar to or higher than that of the chlorine sanitizer. Bae *et al.* (19) reported that alcohol sanitizers were more effective than chlorine sanitizers for reducing *E. coli* O157:H7 within biofilms on the surface of stainless steel coupons. Similarly, log reductions of ≤ 1.50 were achieved when *L. monocytogenes* and *Staphylococcus aureus* on stainless steel were treated with 100 ppm chlorine for 5 min (20). In a study conducted by Lee *et al.* (21), treatment of *E. coli* O157:H7 on media with aerosolized chlorine resulted in log reduction of 0.18. In contrast, although the chlorine sanitizer sufficiently reduced *E. coli* O157:H7 on fresh-cut lettuce in a study conducted by López-Gálvez *et al.* (1), chlorine-based sanitizers achieved less than 1.00 log CFU/g reduction of *E. coli* O157:H7 on lettuce (8).

The sanitizing treatments were less effective on pre-cut than on

Table 6. Efficacy of sanitization according to three factors (shape, treatment, and pathogen) combined with each other on fresh produce

	Brussels sprout	Carrot	Cherry tomato	Paprika	Lettuce
Shape (S) ¹⁾	0.0337⁴⁾	<0.0001	0.0058	<0.0001	0.0964
Treatment (T) ²⁾	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Pathogen (P) ³⁾	<0.0001	<0.0001	0.0242	0.1433	<0.0001
S×T	0.0505	0.0004	0.0710	<0.0001	0.4338
S×P	0.3029	0.1220	0.7174	0.2957	0.7137
T×P	0.8549	0.0002	0.8555	0.2685	0.8036
S×T×P	0.1313	0.9409	0.9857	0.7541	0.9978

¹⁾Means of whole and cut fresh produce.

²⁾Means of Control, Dw, Cl, Cl-dw, Al, and Al-dw.

³⁾Means of *Escherichia coli* O157:H7, *Salmonella* Typhimurium, and *Listeria monocytogenes*.

⁴⁾Means of the same fresh produce and different factors or combinations with bold letters are significantly different ($p < 0.05$).

un-cut paprika because pathogens can easily attach to inner periplasmic spaces through the contact with cut surfaces (22). Tian *et al.* (23) reported that the reduction levels of *E. coli* O157:H7, *S. Typhimurium*, and *S. aureus* on cut apple surfaces were significantly lower than those on unblemished apple surfaces ($p < 0.05$). It seemed plausible that surface properties of fresh produce would play a key role on the attachment of pathogens. In this study, the numbers of *S. Typhimurium* and *L. monocytogenes* inoculated on whole Brussels sprouts were higher than those on pre-cut products after treatment with chlorine and alcohol sanitizers (Table 1). Furthermore, removal of the stem of cherry tomatoes significantly affected the efficacy of sanitizers ($p < 0.05$). Some studies have also reported that reduction of pathogens depended on the initial inoculating spots on fresh produce, with the greatest log reductions being observed in samples that were spot-inoculated (8,24-27). These results indicated that the major factor that limits the antibacterial effects of sanitizers is the attachment of pathogenic cells to inaccessible sites on the surface of damaged fresh produce (28-30). In this study, the efficacy of sanitizers against pathogens on fresh produce was affected mainly by the surface properties of fruits and vegetables, depending on the strains of pathogenic bacteria. Based on the result of statistical analysis shown in Table 6, the treatment itself was the most effective factor. Therefore, the type of sanitizer was an important factor affecting the reduction of all tested pathogens on fresh produce. The shape and pre-cut process significantly affected the effectiveness of sanitizing treatment for certain types of fresh produce, such as carrots and paprika.

In conclusion, this study revealed that pre-cut vegetables did not generally affect the efficacy of sanitization, though it is recommended that paprika be sanitized before cutting. Treatment with the alcohol sanitizer proved to be highly effective for reducing the levels of pathogens in vegetables. However, an additional study is needed to determine the influence of alcohol sanitizer treatments on the sensory qualities of treated products. Although the alcohol sanitizer reduced pathogens more effectively than the chlorine sanitizer, the effectiveness of sanitizing treatments of whole vs. pre-cut vegetables differed based on the type of vegetable. Therefore, further studies need to be conducted for other vegetables in order to identify an

effective sanitizing treatment for each type of produce.

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