

Utilization of Gaseous Ozone for the Decontamination of *Escherichia coli* O157:H7 and *Salmonella* on Raspberries and Strawberries

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MS 06-530: Received 13 October 2006/Accepted 3 January 2007

ABSTRACT

Each year in the United States, there are approximately 76 million foodborne illnesses, and fresh produce is the second most common vehicle for such illnesses. Before going to market, small fruits are not washed or treated in any manner to extend their shelf life. Washing alone is not a viable option, and the use of novel technologies should be investigated. One such technology is ozone treatment, which has been used with drinking water since the late 19th century. The efficacy of gaseous ozone for killing pathogens on strawberries and raspberries, which were used as a model for small fruits, was investigated in this study. Strawberries and raspberries were artificially contaminated with five strains of *Escherichia coli* O157:H7 and *Salmonella enterica*. Fruits were treated with four ozone treatments: (i) continuous ozone flow (5%, wt/wt) for 2, 4, 8, 16, 32, and 64 min; (ii) pressurized ozone (83 kPa) for 2, 4, 8, 16, 32, and 64 min; (iii) continuous ozone (64 min) followed by pressurized ozone (64 min); and (iv) vacuum followed by 64 min of pressurized ozone. Maximum reductions for both strawberries and raspberries were achieved with the third treatment scenario. On strawberries, 2.60- and 2.96-log reductions were achieved for *Salmonella* and *E. coli* O157:H7, respectively. For raspberries, 3.55- and 3.75-log reductions were achieved for *Salmonella* and *E. coli* O157:H7, respectively. These results indicate that gaseous ozone should be a useful treatment for decontamination of small fruits.

In the United States the consumption of fresh fruits has risen from 38.7 to 46.7 kg per person per year over the last 15 years (13). This increase in consumption has been associated with an increase in the number of foodborne illnesses associated with fresh produce. Fresh produce is now the second most common vehicle for foodborne illness, with 428 produce-associated outbreaks between 1990 and 2003 (4).

Small fruits, such as raspberries and strawberries, have been implicated in several outbreaks. Raspberries have been implicated in at least five outbreaks of *Cyclospora cayentanensis* infection (6), and strawberries have been implicated in three outbreaks of hepatitis A (5). Although there have been no recorded bacterial disease outbreaks associated with small fruits, the possibility for this type of disease exists because the contamination routes for other types of pathogens are the same as those for bacterial pathogens. In a U.S. Food and Drug Administration survey, 1 of 143 imported strawberry samples tested positive for *Salmonella* (12). Other research has indicated that both *Salmonella* and *Escherichia coli* O157:H7 are capable of surviving on fresh strawberries for more than 7 days (10).

Throughout the marketing process for small fruits, opportunities for contamination arise due to improper sanitation, infected pickers, contaminated irrigation water, and manure-fertilized fields (3). In spite of these risks, small

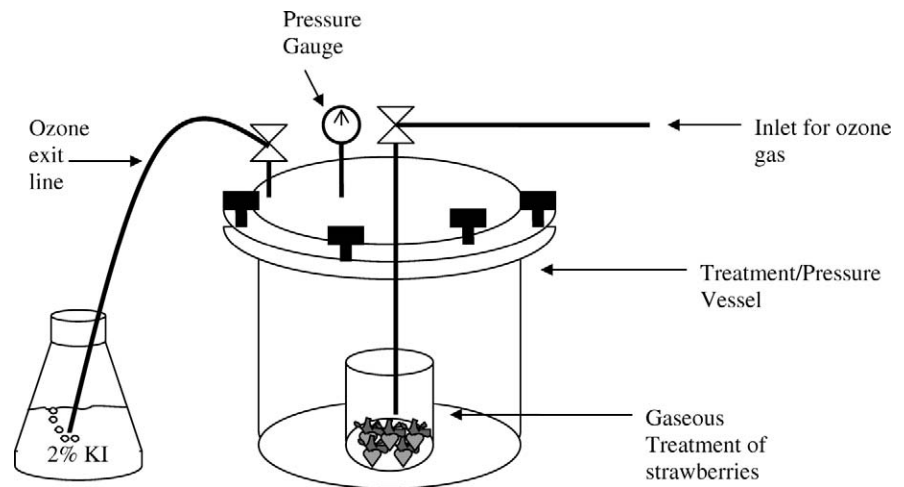
fruits are not washed before delivery to market because of the negative effect on fruit quality and shelf life. Washing alone has limited efficacy for removing both spoilage and pathogenic bacteria from the surfaces of produce (13). Conventional sanitizers also have had a limited effect. Yu et al. (15) compared five sanitizers for their efficacy in reducing populations of *E. coli* O157:H7 on strawberries. Of these five sanitizers, the most effective was hydrogen peroxide, which reduced this pathogen by 2.2 log CFU/g.

Gaseous decontamination methods have been more successful than wet methods for the decontamination of pathogens on the surfaces of small fruits. Han et al. (9) used chlorine dioxide gas for reduction of *E. coli* O157:H7 and *Listeria monocytogenes* on the surfaces of strawberries. Reductions of 3.0 and 3.6 log CFU per fruit were seen at a concentration of 0.6 mg/liter chlorine dioxide for *E. coli* O157:H7 and *L. monocytogenes*, respectively. Sy et al. (11) also investigated the use of gaseous chlorine dioxide for decontaminating small fruits inoculated with *Salmonella* and found a reduction of 3.6 log CFU/g on strawberries with a gas concentration of 8.0 mg/liter and a time of 120 min. For raspberries, a maximum reduction of 1.52 log CFU/g was achieved under the same conditions. Thus, research indicates that chlorine dioxide may be an effective gaseous decontamination method for small fruits; however, residual chlorine remains on the fruits after treatment.

Because conventional sanitizers have not been effective and gaseous sanitizers such as chlorine dioxide have

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FIGURE 1. Schematic of ozone treatment set up.



shown promise, other dry technologies should be investigated. Ozone has been used as an antimicrobial agent since the late 19th century to purify drinking water (8). Ozone oxidizes organic materials and decays in a short amount of time into harmless oxygen, leaving no chemical residues. Therefore, ozone is considered a process rather than a chemical additive. In 2001, ozone was approved for the treatment of raw commodities (7). Ozone gas has been an effective bactericide for several foodborne pathogens. Whistler and Sheldon (14) found reductions of up to 7 log CFU/ml for both *E. coli* and *Salmonella* Typhimurium when petri dishes were exposed to 1.65% (wt/wt) gaseous ozone. The use of ozone gas to extend the shelf life of fruits also has been reported. Bazarova (2) found that when apples were exposed to 0.06 ppm ozone gas for 4 h each day, there was a reduction in both weight loss and spoilage. An 80% reduction in blackberries spoilage by *Botrytis cinerea* was found when the fruits were exposed to 0.1 and 0.3 ppm ozone gas for 12 days (1). Based on this previous research and the potential food safety risks associated with small fruits, research was undertaken to investigate the efficacy of gaseous ozone for reducing *E. coli* O157:H7 and *Salmonella* on the surfaces of raspberries and strawberries.

MATERIALS AND METHODS

Preparation of inoculum. Five strains of nalidixic acid-resistant *E. coli* O157:H7 and *Salmonella* were obtained from the Center for Food Safety at the University of Georgia. The *E. coli* O157:H7 strains were 932 (human isolate), 994 (salami isolate), E0018 (calf fecal isolate), H1730 (human isolate from an outbreak associated with lettuce), and F4546 (human isolate from an outbreak associated with alfalfa sprouts). The *Salmonella* serotypes used were Agona (human isolate from an outbreak associated with alfalfa sprouts), Baildon (human isolate from an outbreak associated with diced tomatoes), Gaminara (orange juice isolate), Michigan (human isolate from an outbreak associated with cantaloupe), and Montevideo (human isolate from an outbreak associated with tomato). Cultures were grown in tryptic soy broth (Becton Dickinson, Sparks, Md.) supplemented with 50 µg/ml nalidixic acid (Fisher Scientific Co., Fair Lawn, N.J.) at 37°C for 24 h. Mixtures of *E. coli* O157:H7 strains and of *Salmonella* strains were prepared by combining 10 ml of each culture and centrifuging the combination for 15 min at $3,300 \times g$ and 4°C. The supernatant was discarded, and the cells were resuspended in

10 ml of 0.1% peptone water (Difco, Becton Dickinson) to yield an approximate population of 10^8 CFU/ml.

Inoculation of small fruits. Red raspberries and strawberries were purchased from a local grocery store and left at room temperature for 1 h before inoculation. To inoculate the raspberries, 25 µl of inoculum was deposited on the skin of each fruit. For strawberries, 50 µl of inoculum was deposited on the skin of each strawberry approximately midway between the calyx and cap (15). The fruits were dried in a laminar flow hood for 24 h before further treatment to allow proper attachment of the microorganisms. On both inoculated raspberries and strawberries, *E. coli* O157:H7 and *Salmonella* concentrations were approximately 10^5 CFU/g of fruit.

Production and delivery of ozone. Ozone gas was generated with a lab-scale ozone generator (model H-50, Hess Machines International, Ephrata, Pa.) equipped with an oxygen concentrator. Gas was delivered at a flow rate of 0.34 m³/h and an ozone concentration of 5.00% (wt/wt), which was measured with a Teledyne 450H bench-top analyzer (Teledyne Technologies, Inc., Los Angeles, Calif.). A 1-liter beaker containing the sample was placed in a 17-liter pressure vessel (model 1915X, Wisconsin Aluminum Foundry Co., Inc., Manitowoc, Wis.), which was connected to the ozone gas line (Fig. 1). After the treatment, the ozone gas was passed through a 2% (wt/vol) potassium iodide solution to prevent ozone from being released into the environment. All ozone treatments were performed in a fume hood for safety considerations.

Treatment with ozone. A batch of five strawberries or 18 raspberries was used for each ozone treatment, based on size constraints. Fruits were subjected to four different ozone treatments.

(i) Fruits were exposed to continuous ozone flow for 2, 4, 8, 16, 32, and 64 min.

(ii) Fruits were placed in the treatment vessel with the exit line closed, and ozone gas was introduced until a pressure of 83 kPa was achieved, which took approximately 3 min. Once pressurized, fruits were held for 2, 4, 8, 16, 32, and 64 min at this pressure.

(iii) Fruits were first exposed to a continuous flow of ozone gas for 64 min. The treatment vessel was then pressurized with ozone gas to 83 kPa and held at this pressure for an additional 64 min.

(iv) Fruits were exposed to a vacuum of -85 kPa, and then ozone gas was used to pressurize the treatment vessel to 83 kPa, which was maintained for 64 min.

TABLE 1. Reduction of *Salmonella* populations on raspberries treated with 5% (wt/wt) ozone gas^a

Treatment	Treatment time (min)	Reduction (log CFU/g) ^b
Continuous ozone	2	0.1 ± 0.1 A
	4	0.2 ± 0.2 A
	8	0.5 ± 0.5 A
	16	1.5 ± 0.3 B
	32	1.3 ± 0.3 B
	64	1.6 ± 0.3 B
Pressurized ozone	2	0.1 ± 0.1 A
	4	0.3 ± 0.2 AB
	8	0.8 ± 0.2 BC
	16	1.1 ± 0.4 C
	32	1.3 ± 0.5 CD
	64	2.0 ± 0.3 D
Continuous ozone followed by pressurized ozone	64 + 64	3.6 ± 0.4
Vacuum followed by pressurized ozone	64	2.9 ± 0.5

^a Average weight of raspberries was 17.5 ± 2.5 g.

^b Within the same column and treatment, values not followed by the same letter are significantly different ($P < 0.05$).

Microbial analysis. After treatment, strawberries were placed in 100 ml of Dey-Engley (DE) neutralizing broth (Difco, Becton Dickinson), and raspberries were placed in 50 ml of DE broth and pummeled for 1 min in a stomacher. The homogenate was then serially diluted in 0.1% peptone water (Difco, Becton Dickinson) and spiral plated on tryptic soy agar (Difco, Becton Dickinson) supplemented with nalidixic acid at 50 µg/ml with an Autoplate 4000 (Spiral Biotech, Norwood, Mass.). Plates were incubated at 37°C for 24 h, and then colonies were counted with Q-count (version 2.1, Spiral Biotech). Reductions of bacteria were calculated on a per gram of fruit basis. Random colonies of *E. coli* O157:H7 and *Salmonella* were confirmed serologically with the RIM *E. coli* O157:H7 latex test (Remel Microbiology Products, Lenexa, Kans.) and the *Salmonella* O Antiserum A-1 latex agglutination test (Remel).

Quality analysis. To determine whether treatment with ozone had any negative effects on quality, color was analyzed for fruits from the treatment with the highest microbial reduction. A Chromo Meter CR200 colorimeter (Minolta, Ramsey, N.J.) was used to measure the L*a*b* color space, with the following parameters: L*, which indicates the lightness, and a* and b*, which are the chromaticity coordinates. A -a* value indicates a green color, +a* indicates a red color, -b* indicates a blue color, and +b* indicates a yellow color. Before use, the colorimeter was calibrated using a white tile. Two randomly selected spots on each fruit were analyzed and averaged to get an overall measurement; this process was replicated three times.

Statistical analysis. All experiments were replicated three times, and MINITAB statistical software (version 13, MINITAB, State College, Pa.) was used to analyze the mean log reductions. A one-way analysis of variance at a 95% confidence level was used to compare the treatment times and scenarios. Fisher's pairwise comparison was also used to determine significant differences.

TABLE 2. Reduction of *E. coli* O157:H7 populations on raspberries treated with 5% (wt/wt) ozone gas^a

Treatment	Treatment time (min)	Reduction (log CFU/g) ^b
Continuous ozone	2	0.0 ± 0.0 A
	4	0.3 ± 0.2 A
	8	0.9 ± 0.3 B
	16	1.0 ± 0.2 B
	32	1.9 ± 0.2 C
	64	2.6 ± 0.4 D
Pressurized ozone	2	0.3 ± 0.0 A
	4	0.7 ± 0.0 AB
	8	0.7 ± 0.5 ABC
	16	0.9 ± 0.4 ABC
	32	1.7 ± 0.7 B
	64	2.8 ± 0.7 D
Continuous ozone followed by pressurized ozone	64 + 64	3.8 ± 0.2
Vacuum followed by pressurized ozone	64	3.3 ± 0.5

^a Average weight of raspberries was 17.5 ± 2.5 g.

^b Within the same column and treatment, values not followed by the same letter are significantly different ($P < 0.05$).

RESULTS AND DISCUSSION

In this study, the efficacy of gaseous ozone for the inactivation of *E. coli* O157:H7 and *Salmonella* on raspberries and strawberries was evaluated. Ozone was applied in four different treatments to evaluate the effect of continuously applied 5% ozone gas, pressurized ozone gas, a combination of the continuously applied and pressurized ozone gas, and vacuum followed by pressurized ozone gas.

Treatment of raspberries. To investigate the lethality of ozone for pathogenic microorganisms, inoculated raspberries were exposed to ozone gas continuously for 2, 4, 8, 16, 32, and 64 min. Reductions in *Salmonella* populations (Table 1) ranged from 0.1 to 1.6 log CFU/g. Treatment times of 16, 32, and 64 min produced log reductions that were significantly higher than those for shorter treatment times. However, there was no significant difference in the reductions resulting from these longer treatments (1.5, 1.3, and 1.6 log CFU/g for 16, 32, and 64 min, respectively). Reductions of *E. coli* O157:H7 are shown in Table 2 and ranged from 0.3 to 2.6 log CFU/g. Treatment times of 32 and 64 min produced log reductions which were significantly higher than those for shorter treatment times (1.9 and 2.6 log CFU/g for 32 and 64 min, respectively). When comparing the lethality of ozone gas to that of other novel gaseous treatments, such as chlorine dioxide, the use of gaseous ozone appears to produce greater log reductions. Sy et al. (11) treated *Salmonella*-inoculated raspberries with chlorine dioxide for 60 min and obtained a maximum reduction of 1.1 log CFU/g. The comparable treatment time for continuously applied ozone gas in this study of 64 min produced reductions of 1.6 log CFU/g for *Salmonella* and 2.6 log CFU/g for *E. coli* O157:H7, although no comparable data are available for the inactivation of *E. coli* O157:H7 on raspberries.

TABLE 3. Reduction of *Salmonella* populations on strawberries treated with 5% (wt/wt) ozone gas^a

Treatment	Treatment time (min)	Reduction (log CFU/g) ^b
Continuous ozone	2	0.0 ± 0.0 A
	4	0.1 ± 0.1 AB
	8	0.1 ± 0.1 AB
	16	0.1 ± 0.1 AB
	32	0.4 ± 0.4 B
	64	0.9 ± 0.1 C
Pressurized ozone	2	0.3 ± 0.1 A
	4	0.6 ± 0.1 AB
	8	0.8 ± 0.4 AB
	16	0.9 ± 0.5 AB
	32	1.4 ± 0.5 BC
	64	2.2 ± 0.3 C
Continuous ozone followed by pressurized ozone	64 + 64	2.6 ± 0.9
Vacuum followed by pressurized ozone	64	1.7 ± 0.2

^a Average weight of strawberries was 110 ± 5 g.

^b Within the same column and treatment, values not followed by the same letter are significantly different ($P < 0.05$).

In the second ozone treatment, the concentration of ozone was increased by increasing the pressure. Fruits were exposed to ozone gas at 83 kPa for 2, 4, 8, 16, 32, and 64 min to force the ozone between the drupelets of the fruit. Reductions for raspberries treated with ozone at 83 kPa are shown in Tables 1 and 2 for *Salmonella* and *E. coli* O157:H7, respectively. Reductions of *Salmonella* ranged from 0.1 to 2.0 log CFU/g. The treatment times of 32 and 64 min resulted in reductions that were significantly greater ($P < 0.05$) than those obtained with shorter treatment times (1.3- and 2.0-log reductions, respectively). However, the reductions obtained with these two treatment times were not significantly different ($P > 0.05$). For *E. coli* O157:H7, reductions ranged from 0.3 to 2.8 log CFU/g. The 64-min treatment produced significantly greater reductions ($P < 0.05$) than did the other treatment times.

The third treatment used to decontaminate raspberries was a combined continuous and pressurized ozone treatment; where raspberries were exposed to 64 min of continuous ozone and then 64 min of pressurized ozone. Reductions of *Salmonella* and *E. coli* O157:H7 are shown in Tables 1 and 2, respectively. A 3.6-log reduction was achieved for *Salmonella* and a 3.7-log reduction was attained for *E. coli* O157:H7. The final treatment involved replacing the air in the pores of the fruits with ozone via a vacuum. Reductions were 2.9 and 3.3 log CFU/g for *Salmonella* and *E. coli* O157:H7, respectively.

These results suggest that for both *Salmonella* and *E. coli* O157:H7 the most effective treatment is 64 min of continuous ozone exposure followed by 64 min of exposure to pressurized ozone. This treatment resulted in 3.56- and 3.8-log reductions of *Salmonella* and *E. coli* O157:H7, respectively. When the results for the four treatment scenarios producing maximum log reductions were analyzed with

TABLE 4. Reduction of *E. coli* O157:H7 populations on strawberries treated with 5% (wt/wt) ozone gas^a

Treatment	Treatment time (min)	Reduction (log CFU/g) ^b
Continuous ozone	2	0.3 ± 0.2 A
	4	0.5 ± 0.3 A
	8	0.7 ± 0.3 AB
	16	0.8 ± 0.4 AB
	32	1.5 ± 0.6 BC
	64	1.8 ± 0.2 C
Pressurized ozone	2	0.4 ± 0.3 A
	4	0.2 ± 0.3 AB
	8	0.6 ± 0.4 ABC
	16	1.1 ± 0.2 ACD
	32	1.5 ± 0.3 D
	64	2.3 ± 0.1 E
Continuous ozone followed by pressurized ozone	64 + 64	2.9 ± 0.4
Vacuum followed by pressurized ozone	64	0.9 ± 0.0

^a Average weight of strawberries was 110 ± 5 g.

^b Within the same column and treatment, values not followed by the same letter are significantly different ($P < 0.05$).

Fisher's pairwise comparison, the combined continuous plus pressurized ozone treatment produced significantly greater reductions of *E. coli* O157:H7 ($P < 0.05$) than did the 64-min continuous ozone treatment or the 64-min pressurized ozone treatment, with a reduction of 3.8 log CFU/g compared with 2.6 and 2.8 log CFU/g, respectively.

Results for strawberries. Strawberries inoculated with *E. coli* O157:H7 and *Salmonella* were treated with continuously applied 5% ozone gas for 2, 4, 8, 16, 32, and 64 min. Reductions of *Salmonella* (Table 3) ranged from 0.1 to 0.9 log CFU/g. Treatment times of 32 and 64 min resulted in significantly greater reductions ($P < 0.05$) than did shorter treatment times, with 0.4- and 0.9-log reductions, respectively. However, there was no significant difference ($P > 0.05$) between the results for these two treatment times. Somewhat greater reductions were obtained for *E. coli* O157:H7, ranging from 0.3 to 1.8 log CFU/g (Table 4). As for *Salmonella*, the 32- and 64-min treatments resulted in significantly greater reductions of *E. coli* O157:H7 ($P < 0.05$) than did other treatments. Reductions of 1.5 and 1.8 log CFU/g were attained for 32- and 64-min treatments, respectively. However, there was no significant difference ($P > 0.05$) between the results for these two treatment times. When the lethality of gaseous ozone was compared with that of gaseous chlorine dioxide, ozone produced slightly smaller reductions. Sy et al. (11) achieved reductions of 3.3 log CFU/g for *Salmonella* on the surfaces of strawberries after treatment with chlorine dioxide for 60 min, whereas in the present study the reduction in *Salmonella* after treatment with continuously applied ozone was 0.9 log CFU/g. Han et al. (9) achieved reductions of 4.5 log CFU/g for *E. coli* O157:H7 after treatment with chlorine dioxide gas for 30 min, whereas in the present study exposure to gaseous ozone for 32 min yielded a maximum

reduction of 1.4 log CFU/g and exposure for 64 min yielded a reduction of 1.8 log CFU/g for *E. coli* O157:H7.

When strawberries were treated with pressurized ozone at 83 kPa, reductions were greater for both *Salmonella* and *E. coli* O157:H7 (Tables 3 and 4) with reductions ranging from 0.3 to 2.2 log and from 0.2 to 2.3 log CFU/g, respectively. For strawberries inoculated with *Salmonella*, treatments times of 32 and 64 min produce significantly greater reductions ($P < 0.05$) than did other treatment times, with reductions of 1.4 and 2.2 log CFU/g, respectively. However, there was no significant difference ($P > 0.05$) between the results for these two treatment times. For fruits inoculated with *E. coli* O157:H7, the only treatment that produced a significantly greater reduction ($P < 0.05$) was the 64-min treatment, with a reduction of 2.3 log CFU/g. When comparing this treatment with that of continuous ozone flow alone, the disparity between the *Salmonella* population reduction and the *E. coli* O157:H7 population reduction is no longer significant. The *Salmonella* reductions achieved with the pressurized ozone are significantly greater ($P < 0.05$) than those obtained with continuous nonpressurized ozone exposure, indicating that for *Salmonella* pressure plays an integral role in inactivation. Pressure does not seem to have the same effect on *E. coli* O157:H7. There was no significant difference ($P > 0.05$) in log reductions when comparing the two treatments.

To further investigate the possible synergistic effect between ozone and pressure, strawberries were treated with continuously applied ozone gas for 64 min and then with pressurized ozone for another 64 min. Reductions of *Salmonella* averaged 2.6 log CFU/g (Table 3), and those for *E. coli* O157:H7 averaged 2.9 log CFU/g. When this treatment was compared with the 64-min continuous treatment, for *Salmonella* the combined ozone treatment resulted in significantly greater reductions ($P < 0.05$), 0.9 versus 2.6 log CFU/g. However, there was no significant difference ($P > 0.05$) between the results of the 64-min pressurized ozone treatment and those of the combined ozone treatment. However, the combined ozone treatment resulted in significantly greater reductions ($P < 0.05$) of *E. coli* O157:H7 than did both the 64-min continuous ozone treatment and the 64-min pressurized ozone treatment (2.9 versus 1.8 and 2.3 log CFU/g, respectively).

The final treatment was conducted based on the assumption that replacing the air in the crevices of the fruit with ozone would increase the lethality of the treatment. However, this treatment did not result in significantly greater log reductions ($P > 0.05$) than were obtained with the other three treatment scenarios. Reductions were 1.7 and 0.8 log CFU/g for *Salmonella* and *E. coli* O157:H7, respectively. For *Salmonella*, there was no significant difference ($P > 0.05$) between the results for this treatment and those for the other three treatments. For *E. coli* O157:H7, this treatment resulted in significantly smaller log reductions ($P < 0.05$) than did the other three treatments.

Color measurement. Fruits from the most effective treatments and times were analyzed for color to determine whether ozone treatment had any negative effects. A 64-

min continuous ozone treatment followed by a 64-min pressurized ozone treatment was selected as the most effective overall treatment. Treated raspberries had mean L*, a*, and b* values of 34.24, +26.67, and +14.55 compared with the untreated raspberries, which had values of 31.13, +26.31, and +12.35, respectively. None of the differences were significant. For strawberries, the mean L*, a*, and b* values were 37.81, +32.44, and +21.85, which were not significantly different from those of the untreated strawberries, which had values of 36.15, +34.25, and +22.27, respectively.

These results indicate that ozone gas treatment can be used as a decontamination method for small fruits against both *Salmonella* and *E. coli* O157:H7. Continuously applied ozone gas resulted in maximum reductions of 1.5 and 0.9 log CFU/g for *Salmonella* on raspberries and strawberries, respectively. For raspberries and strawberries inoculated with *E. coli* O157:H7, maximum reductions of 2.6 and 1.8 log CFU/g were achieved. Treatment with ozone under pressure yielded greater reductions in both *E. coli* O157:H7 and *Salmonella*. Reductions on raspberries of 1.9 and 2.8 log CFU/g were achieved for *Salmonella* and *E. coli* O157:H7, respectively. Reductions on strawberries were 2.2 and 2.3 log CFU/g for *Salmonella* and *E. coli* O157:H7, respectively. Combined continuous and pressurized ozone treatment yielded even greater reductions of 3.6 and 3.8 log CFU/g for *Salmonella* and *E. coli* O157:H7, respectively, on raspberries and 2.6 and 2.9 log CFU/g for *Salmonella* and *E. coli* O157:H7, respectively, on strawberries. The final treatment consisted of vacuum exposure followed by pressurized ozone treatment, which did not produce a significantly greater reduction in the pathogen population for either fruit. These results indicate that ozone gas could be used for the decontamination of small fruits. However, more research is needed to evaluate the effects of ozone treatment under higher pressures.

ACKNOWLEDGMENTS

This research was funded by the Pennsylvania Experiment Station. We are thankful to Hess Machine International (Ephrata, Pa.) for providing the ozone generator used in this study.

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