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Reduction of *Campylobacter jejuni* on Chicken Wings by Chemical Treatments

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ABSTRACT

Eight chemicals, including glycerol monolaurate, hydrogen peroxide, acetic acid, lactic acid, sodium benzoate, sodium chlorate, sodium carbonate, and sodium hydroxide, were tested individually or in combination for their ability to inactivate *Campylobacter jejuni* at 4°C in suspension. Results showed that treatment for up to 20 min with 0.01% glycerol monolaurate, 0.1% sodium benzoate, 50 or 100 mM sodium chlorate, or 1% lactic acid did not substantially (≤0.5 log CFU/ml) reduce *C. jejuni* populations but that 0.1 and 0.2% hydrogen peroxide for 20 min reduced *C. jejuni* populations by ca. 2.0 and 4.5 log CFU/ml, respectively. By contrast, treatments with 0.5, 1.0, 1.5, and 2.0% acetic acid, 25, 50, and 100 mM sodium carbonate, and 0.05 and 0.1 N sodium hydroxide reduced *C. jejuni* populations by >5 log CFU/ml within 2 min. A combination of 0.5% acetic acid plus 0.05% potassium sorbate or 0.5% acetic acid plus 0.05% sodium benzoate reduced *C. jejuni* populations by >5 log CFU/ml within 1 min; however, substituting 0.5% lactic acid for 0.5% acetic acid was not effective, with a reduction of *C. jejuni* of <0.5 log CFU/ml. A combination of acidic calcium sulfate, lactic acid, ethanol, sodium dodecyl sulfate, and polypropylene glycol (ACS-LA) also reduced *C. jejuni* in suspension by >5 log CFU/ml within 1 min. All chemicals or chemical combinations for which there was a >5-log/ml reduction of *C. jejuni* in suspension were further evaluated for *C. jejuni* inactivation on chicken wings. Treatments at 4°C of 2% acetic acid, 100 mM sodium carbonate, or 0.1 N sodium hydroxide for up to 45 s reduced *C. jejuni* populations by ca. 1.4, 1.6, or 3.5 log CFU/g, respectively. Treatment with ACS-LA at 4°C for 15 s reduced *C. jejuni* by >5 log CFU/g to an undetectable level. The ACS-LA treatment was highly effective in chilled water at killing *C. jejuni* on chicken and, if recycled, may be a useful treatment in chill water tanks for poultry processors to reduce campylobacters on poultry skin after slaughter.

During the past three decades, *Campylobacter jejuni* has emerged as a leading cause of acute bacterial gastroenteritis in the United States and many other developed countries *(11)*. There is an estimated annual incidence of >1 million *Campylobacter* infections in the United States *(15)*. Recent studies have shown that poultry is the dominant food source for *Campylobacter* infection, and contamination rates of *Campylobacter* spp. on poultry purchased at retail establishments in the United States and in the United Kingdom range from 68 to 83% *(10, 12, 14, 19)*.

Campylobacter spp. are commonly present as part of the normal intestinal flora of a wide range of animals and birds *(1, 2, 9)*. Domestic poultry, in particular, have been identified as important reservoirs of *Campylobacter* strains associated with human infection *(9, 16, 18)*. The origin of *Campylobacter* spp. within commercial poultry flocks is unclear, although environmental contamination in the rearing house is thought to play an important role in the organism's transmission. *Campylobacter* contamination of raw poultry meat largely occurs during slaughter and processing operations. A *Campylobacter* contamination rate from 30 to >90% has been reported in various surveys *(10–12, 14, 18, 19)*. The numbers of *C. jejuni* on some poultry products range from 2.00 to 4.26 log CFU/g *(13)*. Cross-contamination of *C. jejuni* via raw poultry products to food contact surfaces and other foods also can occur during food preparation.

Because of the association of poultry with *C. jejuni* infections in humans, practical methods are needed to substantially reduce *Campylobacter* populations on contaminated carcasses and poultry parts. Several chemical treatments have been evaluated for their effects on *C. jejuni*, including trisodium phosphate and several organic acids, such as lactic, acetic, citric, formic, and propionic acids, and have been shown to inhibit the bacterium's growth *(5–8)*. Lactic and acetic acids are inexpensive, have GRAS (generally recognized as safe) status, are environmentally friendly, and are naturally occurring. Steam treating and freezing were evaluated for their ability to reduce *C. jejuni* on poultry products *(21)*. Results indicate that the surface steaming of poultry can change the surface color of poultry skin, even though the killing of pathogens was achieved (data not shown). Freeze treating the surface of poultry at −196°C for 20 s can reduce *C. jejuni* populations by about 2 log CFU/g *(21)*. The objective of this study was to evaluate the efficacy of chemicals previously approved for use in food or food processing applications at different concentrations and combinations in reducing *C. jejuni* populations by at least 5 log CFU/g on poultry.

MATERIALS AND METHODS

Bacterial strains. Three strains of *C. jejuni*, including WCR, ATCC 49943, and A74C (all originally isolated from poultry),

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were used. Each *C. jejuni* strain was grown as a lawn on *Campylobacter* agar (Difco, Becton Dickinson, Sparks, Md.) containing 5% defibrinated whole-horse blood laked (Quad Five, Ryegate, Mont.) and antibiotics (5.0 mg of vancomycin, 1,250 IU of polymyxin, 2.5 mg of trimethoprim, 1.0 mg of amphotericin B, and 7.5 mg of cephalothin in 500 ml of medium; Campy BAA, Oxoid, Hampshire, UK) under microaerobic conditions (5% oxygen, 10% carbon dioxide, and 85% nitrogen) at 42°C for 24 h. Bacteria were collected by suspending the colonies in 10 ml of 0.1 M phosphate-buffered saline (PBS), pH 7.2. Each bacterial suspension was washed three times in PBS and sedimented by centrifugation at 4,000 × *g* for 20 min. Bacteria were resuspended in PBS and adjusted to an optical density at 630 nm of 1.0 (ca. 10^9 CFU/ml) by spectrophotometric (Spectronic Instruments, Rochester, N.Y.) determination. Approximately equivalent cell numbers of each of the three strains were combined, and the *C. jejuni* cell count was determined on Campy BAA plates.

Chicken wings. Fresh chicken wings were purchased from a local retail store. Representative samples (two chicken wings) selected randomly from the same bag were assayed before inoculation for *C. jejuni* counts by the protocol described below.

Chemicals. Eight chemicals, including 0.01% glycerol monolaurate (Fisher Scientific, Fair Lawn, N.J.), 0.1 and 0.2% hydrogen peroxide (Sigma Chemicals, St. Louis, Mo.), 0.1, 0.5, 1.0, 1.5, and 2.0% acetic acid (EM Science, Gibbstown, N.J.), 0.1 and 1.0% lactic acid (EM Science), 0.1% sodium benzoate (Fisher), 50 and 100 mM sodium chlorate (J. T. Baker, Phillipsburg, N.J.), 50 and 100 mM sodium carbonate (J. T. Baker), 0.05 and 0.1 N sodium hydroxide (Fisher), and acidic calcium sulfate–based solution (ACS-LA) ($Safe_2O$-Poultry Wash, Mionix Corp., Rocklin, Calif.), were used.

Water. Deionized, unchlorinated water was filter sterilized by passing it through a 0.2-μm regenerated cellulose filter (Corning Inc., Corning, N.Y.).

Assays of *C. jejuni* in suspension. *C. jejuni* (1 ml) was added to 199 ml of chemical solution (4°C) and was stirred with a magnetic stir bar in a 500-ml Erlenmeyer flask. At predetermined sampling times, 1.0 ml of the treated bacterial suspension was removed and mixed with 9.0 ml of neutralizing buffer (0.0425 g of monopotassium phosphate, 0.16 g of sodium thiosulfate, and 5 g of aryl sulfonate complex per liter, pH 7.2; Difco, Becton Dickinson). Bacteria were serially (1:10) diluted in 0.1% peptone water, and 0.1 ml of each dilution was surface plated in duplicate on *Campylobacter* agar (Difco, Becton Dickinson) containing 5% defibrinated whole-horse blood laked (Quad Five). The plates were held at 42°C for 24 h under microaerobic conditions, and *Campylobacter* colonies were enumerated. Colonies randomly selected from plates with the highest dilution were confirmed as *Campylobacter* by an immunolatex assay (Dryspot Campylobacter Test, Oxoid). All experiments were duplicated, and results are reported as means ± standard deviations.

Inoculation of poultry wings and enumeration of *C. jejuni*. Chicken wings (each ca. 8 cm long, 4.5 cm wide, and ca. 45 to 50 g) were submerged in a beaker containing 100 ml of *C. jejuni* (ca. 10^8 CFU/ml, grown in Campy BAA for 24 h and harvested immediately before use as an inoculum) for 5 s. Inoculated wings were air dried for 20 min in a laminar flow hood and then individually placed in a 500-ml beaker containing 200 ml of precooled (4°C) chemical solution for treatment. Contact times with the chemicals were 1, 3, 5, 10, and 20 min at 4°C. Following chemical treatment, each chicken wing was placed in a Whirl-Pak bag containing 50 ml of neutralizing buffer. The bag was agitated in a vertical shaker for 2 min at 150 rpm. The cell suspension (1 ml) was serially (1:10) diluted in 9 ml of 0.1% peptone, and 0.1-ml portions of each dilution were surface plated in duplicate on Campy BAA. Campy BAA plates were incubated microaerobically at 42°C for 48 h. Colonies grown on Campy BAA plates were counted as presumptive *Campylobacter*, and five colonies selected randomly from plates with the highest dilution were confirmed as *Campylobacter* by the immunolatex assay. An additional study was performed with chicken wings on which campylobacters were held at 4°C for 24 h before treatment with ACS-LA. Twenty-four chicken wings were added to 100 ml of *C. jejuni* suspension (10^8 CFU/ml) in a beaker, and campylobacters were distributed on the surface of each wing by hand massaging the wings with gloved hands for 2 min. The chicken wings were then held at 4°C for 24 h and were thereafter individually treated with selected chemical solutions according to the protocol described above. All experiments were duplicated, and the results are reported as means ± standard deviations.

Statistical analysis. The least-square means of *C. jejuni* counts (log CFU per milliliter or gram) in samples of phosphate buffer–treated and chemical-treated solution or chicken wings were analyzed by the General Linear Models procedure of the Statistical Analysis System (SAS Institute, Cary, N.C.). The value used for statistical analysis when treatments with chemicals were undetectable by the direct plating method was 1.6 log CFU/ml or 1.6 log CFU/g.

RESULTS

Results showed that treatment at 4°C for up to 20 min with 0.01% glycerol monolaurate, 0.1% sodium benzoate, 50 or 100 mM sodium chlorate, or 1% lactic acid did not substantially (<0.5 log CFU/ml, $P > 0.05$) reduce *C. jejuni* populations (Table 1); that 0.1 or 0.2% hydrogen peroxide reduced *C. jejuni* by ca. 1.0 and 3.0 log CFU/ml ($P < 0.05$), respectively; and that 0.1% acetic acid reduced *C. jejuni* by 2 log CFU/ml ($P < 0.05$). Increasing the acetic acid concentration to 0.5, 1.0, 1.5, or 2.0% resulted in a reduction of >5 log *C. jejuni* CFU/ml (undetectable by the direct plating method, $P < 0.01$) within 1 min. Treatment at 4°C with 25, 50, or 100 mM sodium carbonate, 0.05 or 0.1 N sodium hydroxide, or ACS-LA reduced *C. jejuni* populations by >5 log CFU/ml within 1 min ($P < 0.01$, undetectable by the direct plating method) (Table 1).

A combination of 0.5% acetic acid with 0.05% potassium sorbate or 0.05% sodium benzoate at 4°C for 20 min reduced *C. jejuni* populations by >5 log CFU/ml ($P < 0.01$) (Table 2). Substituting 0.5% lactic acid for 0.5% acetic acid was not an effective treatment, showing a reduction of only about 1 log CFU/ml ($P > 0.05$) in *C. jejuni* populations within 20 min, whereas the ACS-LA poultry wash solution reduced *C. jejuni* by >5 log CFU/ml within 1 min at 4°C ($P < 0.01$) (Table 2).

Chemicals for which there was a reduction of >5 log CFU/g were evaluated for their ability to inactivate *C. jejuni* on fresh chicken wings. A treatment at 4°C with 2% acetic acid for up to 45 s reduced *C. jejuni* populations by ca. 1.4 log CFU/g ($P < 0.05$) (Table 3), and 100 mM so-

TABLE 1. *Chemical inactivation of a three-strain mixture of* Campylobacter jejuni *in suspension at 4°C*[a]

Chemical	pH	*C. jejuni* (log CFU/ml), inoculated	*C. jejuni* (log CFU/ml) at min: 1	3	5	10	20
0.1% acetic acid	2.9	8.9 ± 0.3	7.5 ± 0.3	7.4 ± 0.3	7.3 ± 0.3	7.0 ± 0.3	6.9 ± 0.3*
0.5% acetic acid	2.8	8.9 ± 0.5	<1.7[b]	<1.7	<1.7	<1.7	<1.7*
1% acetic acid	2.7	8.1 ± 0.1	<1.7	<1.7	<1.7	<1.7	<1.7*
1.5% acetic acid	2.6	8.4 ± 0.3	<1.7	<1.7	<1.7	<1.7	<1.7*
2% acetic acid	2.6	8.4 ± 0.3	<1.7	<1.7	<1.7	<1.7	<1.7*
25 mM sodium carbonate	10.6	8.7 ± 0.7	<1.7	<1.7	<1.7	<1.7	<1.7*
50 mM sodium carbonate	10.9	8.4 ± 0.2	<1.7	<1.7	<1.7	<1.7	<1.7*
100 mM sodium carbonate	11.1	8.4 ± 0.1	<1.7	<1.7	<1.7	<1.7	<1.7*
0.05 N sodium hydroxide	11.9	8.1 ± 0.1	<1.7	<1.7	<1.7	<1.7	<1.7*
0.1 N sodium hydroxide	12.4	8.1 ± 0.1	<1.7	<1.7	<1.7	<1.7	<1.7*
$Safe_2O$-Poultry Wash (ACS-LA)[c]	2.1	8.4 ± 0.1	<1.7	<1.7	<1.7	<1.7	<1.7*
0.1% hydrogen peroxide	6.8	8.2 ± 0.2	7.1 ± 0.1	7.1 ± 0.1	6.8 ± 0.1	6.2 ± 0.6	6.2 ± 0.5*
0.2% hydrogen peroxide	6.8	8.6 ± 0.2	5.1 ± 0.2	4.5 ± 0.4	4.5 ± 0.5	4.0 ± 0.4	4.1 ± 0.4*
1% lactic acid	5.4	8.8 ± 0.2	8.3 ± 0.2	8.3 ± 0.1	8.1 ± 0.3	8.3 ± 0.1	8.3 ± 0.1**
0.01% glycerol monolaurate	6.6	8.0 ± 0.1	7.8 ± 0.2	7.8 ± 0.1	7.9 ± 0.3	7.9 ± 0.3	8.0 ± 0.1**
0.1% sodium benzoate	5.9	8.5 ± 0.5	8.0 ± 0.1	8.1 ± 0.2	8.2 ± 0.2	8.1 ± 0.1	8.0 ± 0**
50 mM sodium chlorate	5.6	8.3 ± 0	8.1 ± 0.1	8.0 ± 0.1	7.7 ± 0.1	7.7 ± 0.1	7.9 ± 0.1**
100 mM sodium chlorate	5.5	8.3 ± 0	7.6 ± 0	8.0 ± 0	7.7 ± 0.1	7.6 ± 0.1	8.0 ± 0**
PBS	7.2	8.4 ± 0.1	8.7 ± 0.2	8.3 ± 0.7	8.5 ± 0.2	8.4 ± 0.2	8.3 ± 0.5

[a] Values are means ± standard deviations; means of two trials. * Significant difference, $P < 0.05$; ** no significant difference, $P > 0.05$.
[b] Minimum detection limit (1.7 log CFU/ml).
[c] Combination of acidic calcium sulfate, lactic acid, ethanol, sodium dodecyl sulfate, and polypropylene glycol.

dium carbonate for 15, 30, or 45 s reduced *C. jejuni* by 1.5, 1.6, and 1.6 log CFU/g, respectively ($P < 0.05$) (Table 3). When compared with the control (PBS only), a treatment at 4°C with 0.1 N sodium hydroxide for 15 or 30 s reduced *C. jejuni* populations by 3.6 and 3.7 log CFU/g, respectively ($P < 0.01$) (Table 3). Treatment with ACS-LA poultry wash solution for 15, 30, or 45 s reduced *C. jejuni* by 5.1, 4.6, and 5.0 log CFU/g, respectively ($P < 0.01$) (Table 3). An additional study was performed with chicken wings that were heavily contaminated with *C. jejuni* (10^8 CFU/g) and held at 4°C for 24 h before treatment with ACS-LA. Results showed that this treatment inactivated *C. jejuni* by >5.5 log/g ($P < 0.01$, to an undetectable level), as determined by a direct plating method for contact times of 15, 30, or 45 s (Table 4).

DISCUSSION

Generally, *C. jejuni* is susceptible to a variety of environmental conditions, including pasteurization temperatures, drying, normal levels of atmospheric oxygen, low pH, and radiation *(3, 9, 17).* Previous studies *(3, 5, 6)* have shown that *Campylobacter* spp. are susceptible to low lev-

TABLE 2. *Chemical inactivation of a three-strain mixture of* Campylobacter jejuni *in suspension at 4°C*[a]

Chemical combination	pH	*C. jejuni* (log CFU/ml), inoculated	*C. jejuni* (log CFU/ml) at min: 1	3	5	10	20
0.5% acetic acid + 0.05% potassium sorbate	3.0	8.6 ± 0	<1.7[b]	<1.7	<1.7	<1.7	<1.7*
0.5% acetic acid + 0.05% sodium benzoate	2.9	8.6 ± 0	<1.7	<1.7	<1.7	<1.7	<1.7*
$Safe_2O$-Poultry Wash (ACS-LA)[c]	2.1	8.1 ± 0.1	<1.7	<1.7	<1.7	<1.7	<1.7*
0.5% lactic acid + 0.05% potassium sorbate	5.6	8.3 ± 0.2	7.3 ± 0.2	7.4 ± 0.1	7.3 ± 0.2	7.4 ± 0.1	7.2 ± 0.1*
0.5% lactic acid + 0.05% sodium benzoate	5.5	8.3 ± 0.2	7.3 ± 0	7.3 ± 0.1	7.3 ± 0	7.3 ± 0	7.4 ± 0.1*
0.1% acetic acid + 0.05% potassium sorbate	3.4	8.3 ± 0.3	8.1 ± 0.3	8.0 ± 0.4	8.1 ± 0.4	8.0 ± 0.4	7.9 ± 0.3**
0.1% acetic acid + 0.05% sodium benzoate	3.2	8.3 ± 0.3	8.0 ± 0.4	8.2 ± 0.4	8.1 ± 0.5	8.0 ± 0.4	7.9 ± 0.4**
PBS	7.2	8.6 ± 0.1	8.5 ± 0.2	8.1 ± 0.7	8.5 ± 0.2	8.4 ± 0.2	8.2 ± 0.5

[a] Values are means ± standard deviations; means of two trials. * Significant difference, $P < 0.05$; ** no significant difference, $P > 0.05$.
[b] Minimum detection limit (1.7 log CFU/ml).
[c] Combination of acidic calcium sulfate, lactic acid, ethanol, sodium dodecyl sulfate, and polypropylene glycol.

TABLE 3. *Chemical inactivation of* Campylobacter jejuni *on chicken wings at 4°C*[a]

Chemical	Treatment time (s)	*C. jejuni* count (log CFU/g) on wings	*C. jejuni* count (log CFU/ml) in solution
2% acetic acid	15	5.6 ± 0.1*	2.0 ± 0.1*
	30	5.5 ± 0.1*	2.0 ± 0.1*
	45	5.4 ± 0.1*	1.9 ± 0.0*
100 mM sodium carbonate	15	5.3 ± 0.1*	2.1 ± 0.1*
	30	5.2 ± 0.2*	2.1 ± 0.1*
	45	5.2 ± 0.2*	2.1 ± 0.1*
0.1 N sodium hydroxide	15	3.2 ± 0.2*	2.3 ± 0.1*
	30	3.1 ± 0.2*	1.7 ± 0.0*
	45	3.3 ± 0.1*	1.7 ± 0.0*
$Safe_2O$-Poultry Wash (ACS-LA)[b]	15	1.7 ± 0.1*	<1.7[c]
	30	2.2 ± 0.2*	<1.7*
	45	1.8 ± 0.2*	<1.7*
PBS only	15	6.8 ± 0.4	6.3 ± 0.3
	30	6.8 ± 0.4	6.3 ± 0.3
	45	6.8 ± 0.4	6.3 ± 0.3
Chicken wings only	15	7.1 ± 0.5	
	30	7.1 ± 0.5	
	45	7.1 ± 0.5	

[a] Values are means ± standard deviations; means of two trials. * Significant difference, $P < 0.05$.
[b] Combination of acidic calcium sulfate, lactic acid, ethanol, sodium dodecyl sulfate, and polypropylene glycol.
[c] Minimum detection limit (1.7 log CFU/ml).

els of pH and that they are killed readily at pH 2.3. In our study, we evaluated eight chemicals for their bactericidal effect on suspensions of *C. jejuni.* Results showed that several of the chemicals, including 0.01% glycerol monolaurate, 100 mM sodium chlorate, and 0.1% sodium benzoate, had little-to-no significant bactericidal effect ($P > 0.05$) on *C. jejuni* in suspension at 4°C for 20 min. Hydrogen peroxide at 0.1 or 0.2% had a significant ($P < 0.05$) but minimal effect on inactivating *C. jejuni* and was concentration dependent.

Acetic acid was considerably more bactericidal to *C. jejuni* than lactic acid at an equivalent concentration of 1.0%; however, the pH of the acetic acid treatment was 2.7 compared with pH 5.4 for lactic acid. It is likely that this difference in pH was a contributing factor in the lack of efficacy provided by lactic acid.

Our results showed that highly alkaline chemicals, such as sodium carbonate and sodium hydroxide, were highly bactericidal to *C. jejuni* (with a reduction of >6 log CFU/ml within 1 min) in suspension at 4°C. Similarly, Capita et al. *(4)* reported a bactericidal effect by trisodium phosphate, which is highly alkaline, on foodborne pathogens and determined that trisodium phosphate is more active on gram-negative pathogens (e.g., *Salmonella*, *Escherichia coli*, *Campylobacter* spp.) than against gram-positive pathogens (e.g., *Staphylococcus aureus*, *Listeria monocytogenes*).

Recently, a poultry wash ($Safe_2O$-Poultry Wash), which is principally based on acidic calcium sulfate but also contains lactic acid, ethanol, sodium dodecyl sulfate, and polypropylene glycol, was formulated specifically for the treatment of poultry carcasses to reduce pathogen contamination. Our results showed that this solution had a major

TABLE 4. *Inactivation at 4°C of* Campylobacter jejuni *by $Safe_2O$-Poultry Wash on chicken wings inoculated with* Campylobacter jejuni *24 h before treatment and held at 4°C*[a]

Treatment	Treatment time (s)	*C. jejuni* count (log CFU/g) on chicken wings	*C. jejuni* count (log CFU/ml) in solution
$Safe_2O$-Poultry Wash (ACS-LA)[b]	15	<1.7*[c]	<1.7*
	30	<1.7*	<1.7*
	45	<1.7*	<1.7*
PBS only	15	7.2 ± 0.1	7.1 ± 0.1
	30	7.2 ± 0.1	7.1 ± 0.1
	45	7.2 ± 0.1	7.1 ± 0.1
Chicken wings only	45	7.4 ± 0.0	

[a] Values are means ± standard deviations; means of two trials. * Significant difference, $P < 0.05$.
[b] Combination of acidic calcium sulfate, lactic acid, ethanol, sodium dodecyl sulfate, and polypropylene glycol.
[c] Minimum detection limit (1.7 log CFU/g or 1.7 log CFU/ml).

bactericidal effect on *C. jejuni* on poultry. Generally, a long exposure time (several hours) would increase the adhesion and entrapment of *C. jejuni* on poultry skin, thereby providing greater protection to the bacterium; however, our results showed that *C. jejuni* following a 24-h preexposure on chilled chicken skin was more sensitive to inactivation by certain chemicals, such as $Safe_2O$. The chicken wings, following the inoculation of *C. jejuni*, held at 4°C were in beakers covered with parafilm for 24 h. Air in the beaker may have influenced the sensitivity of *C. jejuni* to antimicrobial activity, but this environment attempts to simulate that in which chicken is exposed following processing.

Dickens et al. *(8)* evaluated the effect of $Safe_2O$-Poultry Wash as a pre- and postevisceration carcass wash to reduce microbial contamination. After treatment and chilling for 45 min, carcasses were assayed for microbial counts. Results showed that $Safe_2O$-Poultry Wash spray treatment reduced total aerobic bacteria counts, *E. coli*, *Salmonella*, and *Campylobacter* by 1.69, 2.16, 1.83, and 2.39 log CFU/ml of carcass rinse, respectively. Our results yielded a greater killing effect on *Campylobacter* treated with $Safe_2O$-Poultry Wash, likely because the cell numbers of *Campylobacter* we inoculated on wings were approximately 5 log CFU greater than those initially present on the carcasses in the Dickens et al. study.

C. jejuni is sensitive to extremes in pH, especially acidic conditions *(5, 6, 8)*. One advantage of ACS-LA is its highly effective antimicrobial activity on different pathogens *(7, 20)* and spoilage microorganisms on poultry *(7)*. The cost of ACS-LA is approximately $5.00/liter, which may necessitate its recycling for cost-effective use in commercial operations.

The superchilling of chicken wings to cool meat quickly to an internal temperature of −3.3°C at different freezing temperatures can reduce *C. jejuni* populations; however, the level of *Campylobacter* reduction is temperature dependent. *C. jejuni* counts were reduced by 0.5 log CFU/g at −80°C, 0.8 log CFU/g at −120°C, 0.5 log CFU/g at −160°C, and 2.4 log CFU/g at −196°C *(21)*. A relatively small cell number (<1 log CFU/g) of *C. jejuni* was inactivated on poultry surfaces under freezing conditions of −80 to −160°C; hence, superchilling cannot be relied on as a treatment to substantially reduce *C. jejuni* counts on poultry.

Our laboratory-based results indicate that acidic calcium sulfate–lactic acid poultry wash, which kills large populations of *C. jejuni* on poultry at 4°C, is useful for treating poultry submersed in chill water tanks to serve as a critical control point in a hazard analysis critical control point (HACCP) system that includes a substantial reduction of *C. jejuni* on poultry products. Additional studies are needed in poultry-processing facilities to validate the efficacy of this treatment under actual use conditions.

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