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Monochloramine Versus Sodium Hypochlorite as Antimicrobial Agents for Reducing Populations of Bacteria on Broiler Chicken Carcasses

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ABSTRACT

Studies were conducted to compare the effect of sodium hypochlorite (SH) versus monochloramine (MON) on bacterial populations associated with broiler chicken carcasses. In study 1, nominal populations (6.5 to 7.5 log CFU) of *Escherichia coli, Listeria monocytogenes, Pseudomonas fluorescens, Salmonella* serovars, *Shewanella putrefaciens,* and *Staphylococcus aureus* were exposed to sterilized chiller water (controls) or sterilized chiller water containing 50 ppm SH or MON. SH at 50 ppm eliminated all (6.5 to 7.5 log CFU) viable *E. coli, L. monocytogenes,* and *Salmonella* serovars; 1.2 log CFU of *P. fluorescens*; and 5.5 log CFU of *S. putrefaciens.* MON eliminated all (6.5 to 7.5 log CFU) viable *E. coli, L. monocytogenes, S. putrefaciens,* and *Salmonella* serovars and 4.2 log CFU of *P. fluorescens.* In study 2, chicken carcasses were inoculated with *P. fluorescens* or nalidixic acid–resistant *Salmonella* serovars or were temperature abused at 25°C for 2 h to increase the populations of naturally occurring *E. coli.* The groups of *Salmonella* serovar–inoculated or temperature-abused *E. coli* carcasses were immersed separately in pilot-scale poultry chillers and exposed to tap water (controls) or tap water containing 20 ppm SH or 20 ppm MON for 1 h. The *P. fluorescens*–inoculated group was immersed in pilot-scale poultry chillers and exposed to tap water (controls) or tap water containing 50 ppm SH or 50 ppm MON for 1 h. Carcasses exposed to the SH treatment had nominal increases (0.22 log CFU) in *E. coli* counts compared with controls, whereas exposure to MON resulted in a 0.89-log reduction. Similarly, average nalidixic acid–resistant *Salmonella* serovar counts increased nominally by 34% (41 to 55 CFU/ml) compared with controls on carcasses exposed to SH, whereas exposure to MON resulted in an average nominal decrease of 80% (41 to 8 CFU/ml). *P. fluorescens* decreased by 0.64 log CFU on carcasses exposed to SH and decreased by 0.87 log CFU on carcasses exposed to MON. In study 3, SH or MON was applied to the chiller in a commercial poultry processing facility. *E. coli* counts (for carcass halves emerging from both saddle and front-half chillers) and *Salmonella* prevalence were evaluated. Data from carcasses exposed to SH during an 84-day historical (Hist) and a 9-day prepilot (Pre) period were evaluated. Other carcasses were exposed to MON and tested during a 27-day period (Test). *E. coli* counts for samples collected from the saddle chiller were 25.7, 25.2, and 8.6 CFU/ml for Hist, Pre, and Test, respectively. *E. coli* counts for samples collected from the front-half chiller were 6.7, 6.9, and 2.5 CFU/ml for Hist, Pre, and Test, respectively. *Salmonella* prevalence was reduced from 8.7% (Hist + Pre) to 4% (Test). These studies indicate that MON is superior to SH in reducing microbial populations in poultry chiller water.

Chlorine in the form of sodium hypochlorite (SH), calcium hypochlorite tablets, or chlorine gas is the most commonly used disinfectant in the poultry industry in the United States. The U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) allows for the addition of chlorine to processing waters at levels up to 50 ppm in carcass wash applications and chiller make-up water *(9).* Additionally, FSIS requires the application of chlorinated water containing a minimum of 20 ppm available chlorine on all surfaces of carcasses when the inner surfaces have been reprocessed (because of carcass contamination) other than solely by trimming *(6).*

A major consideration when using chlorine as a disinfectant is that free chlorine (hypochlorous acid, hypochlorite ion, or elemental chlorine) is highly reactive and rapidly oxidizes, bleaches, or otherwise reacts with any number of substances such as fat, blood, fecal material, or protein. When chlorine is used in poultry processing facilities to disinfect equipment surfaces, carcasses, or chiller systems, it encounters a very high organic load. Poultry process waters can have extremely high levels of total organic carbon and a correspondingly high chemical oxygen demand. Any free chlorine added to these high-demand waters is consumed rapidly, becoming unavailable for disinfection. If the chemical oxygen demand in these waters is not satisfied, then a true free chlorine residual cannot be established. A typical poultry chiller can have a chlorine demand of 1,000 to 2,000 ppm that cannot be overcome by 50 ppm (maximum allowable by USDA) chlorine in the make-up water. Experiments conducted at the USDA–Agricultural Research Service (ARS) Western Regional Research Center showed that a free chlorine residual could not be established in a commercial poultry chiller even by adding up to 400 ppm of free chlorine *(5).* When chlorine

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reacts with organic material, it generally loses its microbiocidal properties and can no longer act as a disinfectant *(11)*.

One disinfectant that has gained widespread acceptance and use in municipal potable water treatment facilities is monochloramine (MON). The controlled mixing of chlorine and ammonia in water generates this chlorine species. MON is tasteless, odorless, stable, highly soluble, persistent in water, and biocidal *(10)*, and unlike free chlorine, it does not react readily with organic material *(11)*. Because of these behavioral differences, many municipal potable water plants switched from chlorine to MON in their distribution systems to lower the quantities of trihalomethanes (possible carcinogens) produced and, in so doing, have brought water plants into compliance with U.S. Environmental Protection Agency (EPA) requirements *(11)*. Chloramine residuals of 4 ppm are approved by the EPA for potable water supplies *(8)* and by the U.S. Food and Drug Administration for bottled water *(7)*.

Although the characteristics of MON have been well known for many years, its use as a biocide has not been widely pursued beyond the potable water treatment arena because it is simply not generally regarded as an efficacious water treatment. The reasons for this widely held view are twofold: MON is a slow-reacting biocide, and the specific lethality of MON is 200 times less than free chlorine (hypochlorous acid) in inactivating enteric bacteria *(11)*. Although there is no known research that addresses the use of MON to reduce microbial levels on food, the authors hypothesize that, in systems in which long contact times and high organic loads exist, such as in poultry processing plant immersion chillers, the increased efficacy and persistence of MON make it a more effective disinfectant than free chlorine.

The purpose of these studies was to compare the efficacy of SH with MON on populations of bacteria associated with broiler chicken carcasses in a model system and to compare the efficacy of SH to MON during immersion chilling in a model system and in a commercial poultry operation.

MATERIALS AND METHODS

The experimental design for study 1 was 3 × 3 × 6 × 5 (replication, treatment, bacterium, and tube, respectively). The experimental design for study 2 was 3 × 4 × 10 (replication, treatment, and carcass, respectively). In study 3, data were collected during three phases: historical (Hist), prepilot (Pre), and pilot (Test). The experimental design was 2 × 127 or 75 (treatment and carcass [Hist + Pre and Test]) for *Salmonella* and 2 × 3 × 421, 39, or 110 (sample location, treatment, and carcass [Hist, Pre, and Test]) for *Escherichia coli* (EC) in the front-half chiller and 2 × 3 × 651, 60, or 216 (sample location, treatment, and carcass [Hist, Pre, and Test]) for *E. coli* in the saddle chiller. Results were analyzed by subjecting the data to *t* tests with SAS software *(4)* in studies 1 and 2. Treatment means were separated by Fisher's least significant difference option (study 2) of SAS *(4)*. For study 3, bacterial count data were transformed by log transformation, NCFU = ln(CFU + 0.1). The purpose of the addition of 0.1 was to keep NCFU defined when CFU = 0. This transformation leads to more symmetric distributions and homogeneity of variance. Data were then analyzed with the Proc ANOVA procedure of SAS.

The SH treatments throughout these studies were either 6 or 12.5% solutions. Monochloramine was manufactured at the time of use by the controlled mixing of 6 or 12.5% SH and a solution of Food Chemical Codex–grade ammonium chloride or 2% ammonium hydroxide in tap water. Treatment concentrations were measured and verified by multiple methods, and devices including ATI (Analytical Technology, Inc., Collegeville, Pa.) model A15/79 total Cl_2 monitors, a Severn Trent (Charlotte, N.C.) 17T2000 amperometric titrator, a Hach (Chicago, Ill.) DPD colorimetric analyzer, a Hach Odyssey DR/2500 spectrophotometer, or Hach model CN-21P high-range chlorine test kits with sulfite I and sulfamic acid powder pillows and sodium thiosulfate reagents.

Study 1: Effect of MON on pathogenic, indicator, and spoilage bacteria in a model system. *E. coli*, *Listeria monocytogenes* (LM), *Salmonella* serovars, and *Staphylococcus aureus* were obtained from the Poultry Microbiological Safety Unit laboratory of the USDA-ARS. These pathogenic and indicator bacterial isolates were originally collected from commercial broiler carcasses. Each isolate was assayed for Gram reaction, cytochrome oxidase activity, and production of catalase and was identified with either the Vitek (bioMérieux Vitek, Inc., Hazelwood, Mo.), Biolog (Biolog, Inc., Hayward, Calif.), or Micro-ID (Organon Teknika Corporation, Durham, N.C.) rapid identification methods.

Pseudomonas fluorescens and *Shewanella putrefaciens* spoilage bacterial isolates were obtained by collecting broiler carcasses from processing plants in Georgia, Arkansas, California, and North Carolina. These carcasses were individually bagged in sterile polyethylene bags (3,000 ml O_2 at 22.8 EC/m^2/24 h at 1 atm) and held on ice until arrival at the laboratory. Carcasses were allowed to spoil under controlled conditions at 3 ± 0.5°C for 15 days. After spoilage, the carcasses were rinsed with 100 ml of sterile deionized water. The rinse fluid was diluted to 10^{-6}, 10^{-7}, and 10^{-8} with a sterile 1% solution of Bacto Peptone (Difco, Becton Dickinson, Sparks, Md.), and 1 ml of the diluent was spread onto duplicate plate count agar (Difco, Becton Dickinson) plates. Plates were incubated at 25°C for 48 h. Each isolate was assayed for Gram reaction, cytochrome oxidase activity, and production of catalase and was identified by one of the same rapid identification methods used to identify the pathogenic and indicator bacterial isolates discussed previously. *P. fluorescens* and *S. putrefaciens* isolates from these spoiled carcasses were obtained and used in this study.

Chiller water was collected from a commercial processing facility and was autoclaved to eliminate background microflora. The water was then compared with chiller water that had not been autoclaved by adding chlorine to the water and measuring the depletion from the reaction with organic material in the water. Both autoclaved and unautoclaved chiller water had the same characteristics with regard to depletion of chlorine. Thus, autoclaved chiller water was deemed acceptable as a chiller water substitute to provide background organic material.

To determine the effect of MON or SH on each isolate or on indicator populations of bacteria, *E. coli, L. monocytogenes, Salmonella* serovars, and *S. aureus* were individually placed into brain heart infusion broth (Difco, Becton Dickinson) at 35°C, and *P. fluorescens* and *S. putrefaciens* were individually placed into brain heart infusion broth at 25°C for 24 h. One 10-μl loopful of each of these actively growing cultures was placed into 10 ml of sterile chiller water as controls or into sterile chiller water containing MON or SH at concentrations of 50 ppm, and the suspen-

TABLE 1. *The effect of water, sodium hypochlorite (50 ppm), and monochloramine (50 ppm) on pathogenic, indicator, and spoilage bacteria associated with chicken carcasses*[a]

	Chiller water		Monochloramine		Sodium hypochlorite	
Bacterium[b]	DT	Log CFU/ml	DT	Log CFU/ml	DT	Log CFU/ml
Salmonella serovars	3.3 ± 0.1 B	6.8 ± 0.1	24.0 ± 0 A	0	22.6 ± 3.6 A	<10
Listeria monocytogenes	3.1 ± 0.2 B	7.5 ± 0.1	24.0 ± 0 A	0	24.0 ± 0 A	0
Staphylococcus aureus	3.0 ± 0.2 A	6.6 ± 0.2	2.7 ± 0.2 A	6.8 ± 0.2	3.1 ± 0.4 A	6.6 ± 0.3
Escherichia coli	3.1 ± 0.2 B	6.9 ± 0.2	24.0 ± 0 A	0	24.0 ± 0 A	0
Pseudomonas fluorescens	6.5 ± 0.7 B	7.5 ± 0.2	18.6 ± 8.4 A	3.3 ± 2.9	9.8 ± 5.0 B	6.3 ± 1.7
Shewanella putrefaciens	6.4 ± 0.5 B	—	22.0 ± 3.6 A	—	17.4 ± 8.0 A	—

[a] Means within a row with different letters are significantly different ($P \leq 0.05$). DT, time in hours required for bacterial growth to exceed the detection threshold of approximately 10^6; —, calibration curves have not been established for this bacterium.
[b] $n = 5$ for each of three repetitions for each bacterium. Estimates were calculated on the basis of preestablished calibration curves for each bacterium, in which detection times were regressed against log CFU per milliliter.

sions were allowed to remain for 1 h to mimic commercial chill times.

After the exposure period, 1 ml of the suspension was placed into 9 ml of sterile brain heart infusion broth containing 0.16 g of sodium thiosulfate per liter and vortexed. One milliliter of this mixture was placed into a bactometer module well in duplicate. Samples were monitored with the bactometer microbial monitoring system M128 (bioMérieux, Inc., Hazelwood, Mo.). The pathogens and *E. coli* were monitored at 35°C. Spoilage bacteria were monitored at 25°C. Impedance was measured on all samples for 24 h.

Study 2: Effect of SH versus MON on *E. coli, Salmonella,* and *Pseudomonas* on broiler carcasses during immersion chilling. Ninety-six broiler chicken carcasses were collected just after evisceration and just before the rinse cabinets at a commercial processing facility. The carcasses were transported to The University of Georgia Poultry Research Center pilot processing facility for inoculation, treatment, and testing.

A marker strain of nalidixic acid–resistant *Salmonella* was obtained from the USDA-ARS Poultry Microbiological Safety Unit laboratory. These isolates were originally collected from commercial broiler carcasses and were selected for resistance to nalidixic acid. The *Pseudomonas* used in study 2 was collected, identified, and cultured as described in study 1. For the *E. coli* evaluation, broiler carcasses were subjected to temperature abuse to increase the populations of naturally occurring *E. coli* on their surfaces. These populations were enumerated for control and treated carcasses.

Actively multiplying (24-h-old) cultures of nalidixic acid–resistant *Salmonella* serovars or *P. fluorescens* were diluted, and 0.1 ml was placed onto the breast of each carcass and spread over the breast of each chicken with a sterile bent glass rod. The bacteria were allowed to attach for 15 min before treatment. Ten carcasses each were inoculated with *Salmonella* serovars or *P. fluorescens,* and 10 were temperature abused to increase *E. coli* populations. The *Salmonella* serovars and *E. coli* groups of the inoculated or temperature-abused carcasses were immersed separately in pilot-scale poultry chillers containing tap water, tap water with 20 ppm SH, or tap water with 20 ppm MON. The *P. fluorescens* group of inoculated carcasses was immersed in pilot-scale poultry chillers containing tap water, tap water with 50 ppm SH, or tap water with 50 ppm MON. The carcasses for all groups were exposed for 1 h at 5°C and sampled. Six additional carcasses per replicate were inoculated—two with each type of bacteria—and allowed to attach or temperature abused and tested immediately to determine how many of the bacteria could be recovered from inoculated or temperature-abused carcasses. Three replicate trials were conducted for treated and control carcasses.

In studies 1 and 2, carcasses were sampled by rinsing according to the procedure described by Cox et al. *(1),* except that 100 ml of Butterfield's phosphate buffer was used instead of deionized water. For the evaluation of nalidixic acid–resistant *Salmonella* serovars, 0.1 ml of carcass rinsate was placed onto the surface of brilliant green sulfa agar (Difco, Becton Dickinson) containing 200 ppm nalidixic acid. The plates were incubated at 35°C for 24 h. Nalidixic acid–resistant *Salmonella* serovars were then enumerated.

For the *E. coli* evaluation, 5 ml of carcass rinse was placed

TABLE 2. *The effect of tap water, sodium hypochlorite (50 ppm), and monochloramine (50 ppm) in a mock-scale immersion chiller on log* Escherichia coli *on broiler chicken carcasses*[a]

	E. coli count (log CFU/ml)			
Repetition[b]	Initial count	Tap water control	Sodium hypochlorite	Monochloramine
1	7.7 ± 0.2 A	7.2 ± 0.6 A	7.3 ± 0.4 A	5.8 ± 0.7 B
2	7.6 ± 0.1 A	7.8 ± 0.2 A	7.7 ± 0.3 A	7.0 ± 0.3 B
3	7.6 ± 0.0 A	7.6 ± 0.6 AB	8.1 ± 0.5 A	7.1 ± 0.4 B
Average	7.6	7.5	7.7	6.6
Change from tap water control	—	—	+0.2	−0.9

[a] Means within a row with different letters are significantly different ($P \leq 0.05$).
[b] $n = 10$ for each of the three repetitions.

TABLE 3. *The effect of tap water, sodium hypochlorite (50 ppm), and monochloramine (50 ppm) in a mock-scale immersion chiller on nalidixic acid–resistant* Salmonella *serovar counts on broiler chicken carcasses*

	Salmonella serovar count (CFU/ml)			
Repetition[a]	Initial count	Tap water control	Sodium hypochlorite	Mono-chloramine
1	1,100	25	148	19
2	550	21	1	3
3	800	76	16	1
Average	817	41	55	8

[a] $n = 10$ for each of the three repetitions.

into 5 ml of sterile double-strength CM medium (bioMérieux) supplemented with 2% dextrose, which acts as a selective growth medium, for *E. coli* conductance assays according to the procedure described by Russell *(3),* and the mixture was vortexed. One milliliter of this mixture was placed into a bactometer module well in duplicate. Samples were monitored with the bactometer microbial monitoring system M128. All of the bacterial isolates tested were monitored at 44°C. All samples were monitored for 48 h by conductance. *E. coli* conductance detection times were converted (log CFU per milliliter) with a previously developed calibration curve. For *Pseudomonas,* 1 ml of carcass rinse was placed into 9 ml of sterile brain heart infusion broth and vortexed. One milliliter of this mixture was placed into a bactometer module well in duplicate. Samples were monitored with the bactometer microbial monitoring system M128 at 25°C.

Three batch chillers were filled with 30 gal (114 liters) of tap water. Ice and 1 liter of fresh chicken blood were added to the chillers. No chemicals were added to the first chiller as a tap water control. SH was added to the second chiller to produce a final concentration of 50 ppm chlorine. MON was added to the third chiller to produce a final concentration of 50 ppm. Ten carcasses inoculated with *Salmonella* were added to each of the chillers and treated for 1 h. The carcasses were removed, and whole carcass rinses were conducted by the procedure described in Cox et al. *(1),* except that Butterfield's phosphate buffer was used instead of water.

Study 3: Effect of SH compared with MON on *Salmonella* prevalence and *E. coli* counts on broiler carcasses in a commercial processing facility. Data were collected during three phases. The first phase was termed historical (Hist). During this phase, SH was preseeded into the chillers and added to the fresh make-up water during processing. The concentration of chlorine used was 50 ppm. During the prepilot (Pre) phase, SH was injected directly into the red water chiller return lines and controlled to total chlorine levels of between 10 and 20 ppm in the chillers. During the pilot (Test) phase, MON was injected directly into the redwater chiller return lines and controlled to total chlorine levels between 10 and 20 ppm in the chillers.

Carcasses were sampled by rinsing with 400 ml of Butterfield's phosphate buffer as required by the USDA-FSIS. *E. coli* was assayed with *E. coli* plate counts according to the Official Methods of Analysis of AOAC International method 990.12 (CFU). *Salmonella* was assayed with The Official Methods of Analysis of AOAC International method 2000.07 and reported as either positive or negative.

RESULTS AND DISCUSSION

Study 1. With the exception of its performance against *S. aureus,* MON equaled or outperformed SH in reducing populations of pathogenic, indicator, and spoilage bacteria in chiller water. MON at 50 ppm reduced *Salmonella* to a level such that no growth in the bactometer was detected in any of the repetitions over a period of 24 h, which equates to the elimination of all viable organisms in the initial population (6.8 log CFU). The SH treatment eliminated all viable organisms in five of six samples evaluated. Both the SH and MON treatments at 50 ppm resulted in complete reductions of the initial populations of *Listeria* (7.5 log CFU) and *E. coli* (6.9 log CFU) in all of the repetitions such that no growth occurred in the bactometer. Neither SH nor MON significantly reduced initial *S. aureus* populations.

MON-treated *Pseudomonas* resulted in no growth in one of the repetitions and long detection times in the other two repetitions, which equated to an average reduction of the initial 7.5-log CFU populations of 4.2 log CFU. The SH treatment had no significant effect on *Pseudomonas* in two repetitions and reduced the initial 7.5-log CFU populations by an average of 1.2 log CFU. No calibration curves had been established for *S. putrefaciens* at the time of this experiment, so the recorded detection times could not be regressed to determine initial bacterial populations or reductions (log CFU). However, detection times revealed a pattern similar to that observed with the other bacteria, with the MON-treated *S. putrefaciens* producing longer average detection times and hence outperforming SH. The MON

TABLE 4. *The effect of tap water, sodium hypochlorite (50 ppm), and monochloramine (50 ppm) in a mock-scale immersion chiller on* Pseudomonas fluorescens *counts on broiler chicken carcasses*[a]

	P. fluorescens count (log CFU/ml)			
Repetition[b]	Initial count	Tap water control	Sodium hypochlorite	Monochloramine
1	7.7 ± 0.3 B	7.5 ± 0.2 B	6.7 ± 0.4 A	6.7 ± 0.4 A
2	7.9 ± 0.7 B	7.1 ± 0.4 B	6.7 ± 0.3 A	6.9 ± 0.3 A
3	7.1 ± 0.0 B	7.1 ± 0.2 AB	7.3 ± 0.3 AB	6.5 ± 0.5 A
Average	7.5	7.2	6.9	6.7
Change from initial count	—	−0.3	−0.6	−0.8

[a] Means within a row with different letters are significantly different ($P \leq 0.05$).
[b] $n = 10$ for each of the three repetitions.

TABLE 5. Escherichia coli *counts from postchill carcasses treated with sodium hypochlorite or monochloramine in a commercial poultry processing plant*[a]

	Saddle chiller		Front-half chiller	
	n	CFU/ml	*n*	CFU/ml
Sodium hypochlorite (historical)	651	25.7 ± 65.6 A	421	6.7 ± 14.2 A
Sodium hypochlorite (prepilot)	60	25.2 ± 21.9 A	39	6.9 ± 8.0 A
Monochloramine (pilot)	216	8.6 ± 13.0 B	110	2.5 ± 6.3 B

[a] Means within a column with different letters are significantly different ($P \leq 0.05$) when CFU data were transformed by the log-transformation NCFU = ln(CFU + 0.1).

treatment resulted in no *S. putrefaciens* growth in one repetition and significant reductions in initial populations in the other two repetitions. The SH treatment resulted in no *S. putrefaciens* growth in one repetition, a significant reduction in initial populations in one repetition, and no significant reduction in initial populations in the third repetition. Overall, MON was statistically equal or superior to SH in reducing populations of pathogenic, indicator, and spoilage bacteria in the model chiller water system (Table 1).

Study 2. When used as an antimicrobial agent in immersion chillers, MON outperformed SH in reducing the counts of *E. coli, Salmonella* serovars, and *P. fluorescens* on broiler carcasses. MON significantly reduced *E. coli* populations on broiler chicken carcasses, whereas SH had no effect in this study (Table 2). The authors hypothesize that this result occurred because, within several minutes of adding SH to the chiller water, the organic material in the water bound the disinfectant, rendering it inactive; with MON, only approximately 10 ppm was lost to organic binding, leaving 40 ppm available for disinfection.

MON nominally reduced *Salmonella* populations by 80%, whereas populations nominally increased by 34% on carcasses treated with SH (Table 3). MON likewise outperformed SH in reducing *Pseudomonas* populations (Table 4).

It is believed that because of the high concentration of organic material often encountered in poultry chiller water, MON would be advantageous to use as opposed to sodium or calcium hypochlorite. These differences would be emphasized in industrial situations because of the higher level of organic material in industrial chillers compared with the level used in this study (1,500 versus 90 ppm biological oxygen demand as tested, respectively).

Study 3. *E. coli* counts and *Salmonella* prevalence data were collected over a period of 84 days (historical data for SH), 9 days (prepilot data for SH), and 27 days (pilot for MON). *E. coli* counts were significantly reduced ($P < 0.0001$) on both the back halves (saddles) and the front halves (fronts) of carcasses when using MON compared with historical and prepilot data obtained when SH was used as the chiller antimicrobial. In addition, the variability of *E. coli* counts showed a marked reduction with MON compared with SH. Although the decrease in standard deviation on the fronts was substantial, it did not achieve statistical significance ($P = 0.1433$). On the saddles, however, after converting the data to a log scale, the decrease in standard deviation was highly statistically significant ($P < 0.0001$; Table 5).

Salmonella prevalence was also lower with MON (3 of 75, 4.0%) compared with the historical data for SH (11 of 127, 8.7%). Thus, MON appears to have a beneficial effect on reducing *Salmonella* prevalence over and above that observed for SH. Again, this is hypothesized to be because most SH is bound by organic material in the chiller and rendered inactive.

The data from these studies indicate that MON is an excellent alternative to SH for disinfecting chiller systems in poultry processing plants. Variance in process control as determined by oscillating bacterial prevalence and counts and resulting from increasing or decreasing organic loads can be mitigated with the use of MON because it is not affected nearly as much by organic material. Although an extensive literature search did not produce references that specifically address the efficacy of MON in a poultry chiller application, the conclusions reached in this study are strongly supported by the experience of a number of potable water treatment plants that found that MON both remained more persistent in distribution systems than free chlorine and maintained or improved the antimicrobial efficacy achieved under a chlorination regime *(2, 11).* The naturally occurring organic material found in all potable water distribution systems reacts with and therefore depletes residual free chlorine far more quickly than it can react with and deplete MON. This same principle explains the difference in efficacy between SH and MON treatments experienced in these studies and supports the conclusion that the controlled use of MON is a safe and more efficacious approach to disinfection during chilling.

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