



Effects of Cetylpyridinium Chloride and Peroxyacetic Acid Treatment of Broiler Frames on *Salmonella* Incidence and Mechanically Separated Chicken Quality

Saxon M. Perez¹, Nitin Dhowlaghar¹, Taejo Kim², Lurdes Siberio¹, Vitor Heiti¹, Christine Leick Cord¹, M. Wes Schilling^{1*}

¹Department of Food Science, Nutrition and Health Promotion, Mississippi State University, Mississippi State, MS 39762, USA

²Department of Food and Nutrition, University of Wisconsin Stout, Menomonie, WI 54751, USA

*Corresponding author. E-mail: schilling@foodscience.msstate.edu (M. W. Schilling)

Abstract: Mechanically separated chicken (MSC) has a high incidence of *Salmonella* since it is separated and homogenized from multiple broiler frames. In addition, limited research has been reported on the reduction of naturally contaminated *Salmonella* on chicken carcasses or chicken frames. Therefore, broiler frames were treated with antimicrobial solutions of 0.1% peroxyacetic acid (PAA) or 0.5% cetylpyridinium chloride with Citrilow (CPC) for contact times of 30, 60, 90, or 120 s and evaluated for their effectiveness at reducing the incidence of naturally contaminated *Salmonella* spp. on broiler frames and decreasing *Salmonella* counts on inoculated frames that were ground and sieved into MSC. Treatment times for PAA and CPC did not affect ($P > 0.05$) % incidence of *Salmonella* on naturally contaminated broiler frames. While CPC30 showed a greater % reduction in incidence ($P < 0.05$) than PAA30, CPC90 and CPC120 did not differ ($P > 0.05$) from PAA90 and PAA120. However, the CPC treatments imparted a greater decrease in incidence of *Salmonella* on frames than PAA. For inoculated frames, both antimicrobial treatments at all treatment times had fewer ($P < 0.05$) *Salmonella* counts in MSC than their controls. Treated MSC samples were evaluated for pH, color, cook loss and protein bind. On average, CPC treatments were lighter (CIE L^* ; $P < 0.05$) than PAA treatments, and PAA treatments were more red (CIE a^*) and more yellow (CIE b^* ; $P < 0.05$) than CPC treatments. All treatments produced MSC with lesser hue values than their controls. Protein bind and cook loss results indicated that the PAA treatments had no significant impact on MSC quality. Frames that were treated with CPC for 60 s yielded less protein bind than the control, which indicates less protein functionality.

Keywords: cetylpyridinium chloride, mechanically separated chicken, peroxyacetic acid, *Salmonella* spp.

Meat and Muscle Biology 2(1):197–204 (2018)

doi:10.22175/mmb2017.11.0056

Submitted 30 Nov. 2017

Accepted 16 May 2018

Introduction

Mechanically separated chicken (MSC) is typically used as a cost-effective ingredient in products such as bologna, hot dogs, and non-whole muscle chicken nuggets and patties. Since MSC is traditionally used in emulsified products, the protein functionality of the product is important (Owens, 2010). During processing, broiler frames are stored, ground and sieved in large batches. Through this process, contamination on a single frame easily cross-contaminates other carcasses and the entire batch of MSC. In a 2012 Baseline Study conducted by the Food Safety and Inspection Service (FSIS) on raw

chicken parts, 24.0% of broiler parts were positive with *Salmonella* spp., including *S. Kentucky*, *S. Enteritidis* and *S. Typhimurium* (USDA-FSIS, 2012). *Salmonella* is thought to harbor in skin folds, crevices, and feather follicles and contaminate equipment and other carcasses via blades during the deboning process and in the case of MSC, during grinding (Kim et al., 1996).

In January 2015, the United States Department of Agriculture (USDA) set new performance standards for poultry processors for chicken parts, ground chicken, and ground turkey in an effort to reduce illnesses due to *Salmonella* by 30% (USDA-FSIS, 2016). Two common industrially available antimicrobial treatments in

the poultry industry include peracetic acid (PAA) and cetylpyridinium chloride (CPC). The maximum permissible limit for application of PAA on carcasses, parts, and organs is 2,000 ppm (USDA-FSIS, 2017). Post-chill PAA dips at 400 and 1,000 ppm were effective at reducing *Salmonella* on chicken carcasses with a 2-log reduction on broiler chicken carcasses (Nagel et al., 2013). Similarly, Chen et al. (2014) reported a 1.5-log reduction of *S. Typhimurium* on ground chicken after post chill dips of 700 and 1,000 ppm of PAA. The maximum permissible limit of CPC for surface treatment of raw poultry carcasses or giblets, or raw poultry parts as either a spray or immersion is 8,000 ppm (USDA-FSIS, 2017). Kim and Slavik (1996) reported an approximate 1.7-log reduction of *Salmonella* spp. on the surface of chicken skin, through immersion or a spray at 1,000 ppm of CPC. Additionally, Yang et al. (1998) reported that the application of 5,000 ppm of CPC using an inside-outside spray reduced *Salmonella* counts on inoculated chicken carcasses by 2.1-log CFU per carcass.

There are limited reports on the quality and sensory attributes of meat from chicken carcasses that have been treated with CPC or PAA. Treatment with either CPC (3,500 or 6,000 ppm), or PAA (700 or 1,000 ppm) did not affect the color and sensory attributes of ground chicken patties during 1, 4, and 7 d storage (Chen et al., 2014). Similarly, the pH and color of MSC was not affected when treated with either 1,000 ppm PAA or 5,000 ppm CPC (Moore et al., 2017).

Most antimicrobial studies pertaining to the reduction of *Salmonella* were conducted using artificial inoculation methods. Limited research has been reported on the reduction of naturally contaminated *Salmonella* on chicken carcasses or chicken frames. Therefore, the objectives of this study were: (1) to evaluate the effect of exposure time on the reduction of *Salmonella* spp. on naturally contaminated broiler frames that were dipped in solutions of CPC or PAA; (2) to determine the efficacy of CPC and PAA treatments at reducing *Salmonella* that was inoculated on broiler frames at 4-logs, treated with the antimicrobial and then ground and sieved to produce MSC; (3) to determine the instrumental quality of MSC that was produced from broiler frames treated with CPC or PAA.

Materials and Methods

Preparation of antimicrobials

For experiments 1 and 2, antimicrobials were prepared according to manufacturer instructions. Forty liters of 0.10% PAA (Microtox 5P, Zee Company,

Chattanooga, TN) solution was prepared for each replication with a pH of 2.89 ± 0.05 . Forty liters of 0.50% CPC (Cecure, Safe Foods Corporation, North Little Rock, AR) solution was prepared and Citrilow (Safe Foods Corporation) was used to adjust the pH to 1.50. Solution pH was monitored before and after each immersion dip. Average pH values ranged from 1.50 to 1.58 for CPC solutions, 3.17 to 3.35 for PAA solutions and 6.97 to 7.14 for distilled water. Control solutions for all samples consisted of 40 L of distilled water. All solutions were stored in food safe pails and chilled overnight at $2 \pm 2^\circ\text{C}$.

Experiment 1: Antimicrobial treatments of non-inoculated broiler frames

Quantification of *Salmonella* from broiler frames and antimicrobial treatments. Chicken frames were randomly selected from a commercial processing facility, transported on ice, and stored at $2 \pm 2^\circ\text{C}$ prior to treatment and analysis. Samples were randomly assigned to either 0.10% PAA or 0.50% CPC with Citrilow treatments. Within each treatment group, broiler frames were further assigned to exposure times of 30, 60, 90, or 120 s. Each solution and exposure time had its own control group consisting of a distilled water dip. Frames were divided into 8 groups of 20 frames for each antimicrobial/exposure time treatment. Of the 20 frames per antimicrobial/exposure time treatment, half were controls (treated with distilled water) and half were treated with the antimicrobial solution for the assigned treatment time. Therefore, the treatments consisted of: CPCC30, CPC30, CPCC60, CPC60, CPCC90, CPC90, CPCC120, CPC120, PAAC30, PAA30, PAAC60, PAA60, PAAC90, PAA90, PAAC120, and PAA120 where “C” at the end of a name (i.e., CPC“C”) indicates a control group. The total number of broiler frames that were sampled to evaluate the effect of PAA and CPC on naturally contaminated *Salmonella* included $n = 480$ total broiler frames, $n = 160$ broiler frames per replication, and 10 frames per treatment per replication.

Insulated coolers (142 L, Igloo, Kitchener, Ontario, Canada) were used to dip frames in each treatment solution. One cooler was utilized for controls and another cooler was used for each antimicrobial treatment. The control cooler was filled with distilled water and each treatment cooler was filled with the appropriate PAA or CPC treatment. Frames were added to the coolers and agitated by shaking. Among the same treatment group, the water in each cooler was not changed to simulate the build-up of organic matter which occurs in industrial settings. Temperature and pH of the solutions were monitored during processing. After antimicrobial treatment,

frames were placed into sterile sampling bags (Nasco Whirl-Pak, Fort Atkinson, WI) with 400 mL 2% buffered peptone water (BPW; Becton Dickinson, Sparks, MD) and shaken for 1 min by hand. Frames were aseptically removed and disposed. The sample bags were then incubated for 24 h at $35 \pm 2^\circ\text{C}$. A USDA-FSIS approved commercial PCR method was used to detect molecular markers that are characteristic of *Salmonella* from the rinsate, using the DuPont Qualicon BAX system (USDA-FSIS, 2014; DuPont, 2010). Nuclease free water (Promega Corporation, Madison, WI) was used as a negative control and *Salmonella enterica* ser. Typhimurium ATCC 14080 (Hardy Diagnostics, Santa Maria, CA) was used as a positive control. Results were reported as the percentage of frames that were positive for *Salmonella* after treatments.

Experiment 2: Inoculation of *Salmonella* on broiler frames and antimicrobial treatment

Bacterial culture. *S. enterica* ser. Typhimurium ATCC 14080, *S. enterica* ser. Enteritidis ATCC 4931, and *S. enterica* ser. Braenderup ATCC BAA-664 (Hardy Diagnostics, Santa Maria, CA) were individually cultured in trypticase soy broth (TSB; Beckton Dickinson and Company, Durham, NC) that was supplemented with 50 ppm nalidixic acid (Sigma-Aldrich, St. Louis, MO; Weissinger et al., 2000). After 3 successive adaptations of each individual *Salmonella* strain, cell suspensions were combined to give approximately equal populations of each strain. Serial 10-fold dilutions were performed with 0.1% peptone water to prepare a final working solution that contained approximately 10^6 CFU/ml.

Inoculation of chicken frames with *Salmonella* and production of MSC. Chicken frames were obtained from a commercial processing facility, transported on ice, and stored at $2 \pm 2^\circ\text{C}$ prior to treatment. Chicken frames were inoculated with the prepared *Salmonella* cocktail suspension by submersion and agitation in sterile Whirl-Pak bags (Nasco, Fort Atkinson, WI) for 30 s. Frames were removed and allowed to drain on sheet trays with racks, and the frames were stored undisturbed in a biological safety cabinet for 30 min to allow proper attachment of bacterial cells to the frames. Initial *Salmonella* counts were 4.5-log. After attachment, frames were dipped in either a control (distilled water dip) or antimicrobial solution of 0.50% CPC with Citrilow for 30 or 60 s or 0.10% PAA for 60 or 90 s. Frames were then removed and allowed to drain on clean racks for 30 min at room temperature ($22 \pm 2^\circ\text{C}$). Chicken frames were then blended using a sterile meat grinder (STX Magnum 1800W, The Mercantile Station 2, Lincoln, NE) with a #12 grinding head that was fitted

with a 3.96 mm plate to obtain a ground product similar to MSC. The blended product was aseptically transferred to sterile Whirl-Pak bags and hand massaged to ensure proper distribution of inoculum throughout the sample. A total of 216 chicken frames ($n = 216$ frames total, 3 replications of 72 frames each, $n = 9$ frames per treatment for each replication) were used for the inoculation study. Nine frames were used for each treatment per replication, where a set of 3 frames was used as a subsample within each replication to obtain enough MSC from the frames for analysis.

Sampling and enumeration of *Salmonella*.

Twenty-five grams of each sample (ground frame) were placed into sterile whirl-Pak bags and stomached (Stomacher 400 Circulator, Seward, Cincinnati, OH) in 225 mL of 0.1% peptone water (Oxoid, Thermo Fisher Scientific, Waltham, MA) to make a 10^{-1} dilution. Serial dilutions of 10^{-2} and 10^{-3} were made by transferring 1 mL of the 10^{-1} dilution into test tubes containing 9 mL of 0.1% peptone water and plated onto XLD agar plates (Oxoid, Thermo Fisher Scientific, Waltham, MA) that contained 50 ppm of nalidixic acid sodium salt solution and sterilely spread on the plates (L-shaped cell spreaders, Fisherbrand, Thermo Fisher Scientific, Waltham, MA). Samples were then incubated at $35 \pm 2^\circ\text{C}$ for 48 h and black colonies were hand counted after incubation.

Experiment 3: Instrumental quality of mechanically deboned meat from antimicrobial treated frames

Preparation of samples. Samples for instrumental pH, color, cook loss, and protein bind analysis were prepared from broiler frames ($n = 144$; 48 per rep; 3 replications) using the treatments and methods described for Experiment 2; however, frames were not inoculated.

Instrumental pH and color. For pH evaluation of MSC from control and treated frames, duplicate 10 gram samples of each treatment were homogenized (Model PowerGen 500, Fisher Scientific) in 90 mL of distilled water to form a slurry. The pH of MSC was measured (Model AP61, Fisher Scientific, Hampton, NH) using a pH probe (Cole-Parmer, Vernon Hills, IL). For color, cook loss, and protein bind, the same set of samples was used. Each MSC treatment was weighed and preblended with 1% NaCl. For each treatment, six $11.5 \text{ cm} \times 11.5 \text{ cm}$ patties weighing $180 \pm 0.1 \text{ g}$ were formed and used for instrumental color analysis, protein bind, and cooking loss. Values for CIE L^* (lightness), a^* (redness), and b^* (yellowness) were determined using a Mini Scan EZ spectrophotometer (Model 4500L, Hunter Associates Laboratory, Reston, VA) with a 10° observer angle and a D65 light source. The

spectrophotometer was calibrated using white and black instrument standards that were provided by the manufacturer. Instrumental color analysis was performed by taking 3 measurements on the surface of each patty and reported as CIE $L^*a^*b^*$, hue, and chroma.

Cooking loss. Patties were pre-weighed prior to color analysis. After color analysis, patties were baked in a 204°C oven to an internal temperature of 74°C on a broiler pan with a rack (Viking Professional, Greenwood, MS). The internal temperature was checked by a hand held digital thermometer (TruTemp 3519N, Taylor Precision Products, Oak Brook, IL). After reaching an internal temperature of 74°C, samples were removed from the oven and cooled to room temperature (22 ± 2°C). Samples were then re-weighed for a final weight. Cooking loss was determined using the following equation

$$\% \text{ Cooking Loss} = \frac{[(\text{raw wt} - \text{cooked wt}) / (\text{raw wt})] \times 100}$$

Protein bind. After cooked weights were determined, patties were then used for instrumental protein bind. Protein bind was determined using the method described in Schilling et al. (2004). An Instron Universal Testing Center (Model 3300, Instron, Norwood, MA) that was equipped with a 500 N load cell and a 25mm diameter steel ball (chrome alloy grade 25) was used. For each test, a patty was centered on the plexiglass stand and the steel ball penetrated the center of each patty. The compressive load at maximum peak force (N) was recorded as the protein bind value.

Statistical analysis

In Experiment 1, a 2 × 4 factorial structure with 3 replications was utilized to determine if significant differences ($P < 0.05$) existed in terms of the presence or absence of naturally occurring *Salmonella* spp. on broiler frames following treatment with solutions of 0.50% CPC with Citrilow or 0.10% PAA at 30, 60, 90, or 120 s. In Experiment 2, a randomized complete block design with 3 replications ($n = 72$ per replication) was utilized to determine if differences ($P < 0.05$) existed in terms of *Salmonella* counts in MSC produced from broiler frames to which solutions of 0.50% CPC with Citrilow or 0.10% PAA at 30, 60, 90, or 120 s were applied. In Experiment 3, a randomized complete block design with 3 replications ($n = 48$ per replication) was used to evaluate the impact of applying solutions of 0.50% CPC with Citrilow or 0.10% PAA at 30, 60, 90, or 120 s to chicken frames on the color, cooking loss and protein bind of sausage patties made from MSC.

For all experiments, Tukey's HSD tests were used to separate means when significant differences occurred among treatments. Microsoft Excel 2013 XLStat 2013 (Addinsoft, Inc., Brooklyn, NY) was used to conduct all statistical analyses.

Results and Discussion

Experiment 1: antimicrobial treatments of non-inoculated broiler frames

Results indicate that naturally-occurring *Salmonella* contamination was highly variable among samples (Table 1). The CPC90, CPC120, and PAA120 treatments led to decreased incidence ($P < 0.05$) of *Salmonella* in comparison to their controls. CPC60 did not differ ($P > 0.05$) from its control but had 0% incidence of *Salmonella*. This lack of difference was due to a relatively low incidence of *Salmonella* (33.3%) in the control sample for CPCC60. When CPC and PAA treatments were compared to each other, all CPC treatments had a greater reduction in percentage of *Salmonella* ($P < 0.05$)

Table 1. Mean percent positive and reduction of the incidence of *Salmonella* spp. for naturally contaminated broiler frames dip treated with either a water dip (control), 0.50% CPC (adjusted to pH = 1.5 with Citrilow), or 0.10% PAA (pH = 2.89 ± 0.05) solution for 30, 60, 90, or 120 s

Treatment	% Positive	% Reduction in incidence
CPCC30	47 ^{BCDEF}	
CPC30	6.7 ^{EFG}	86 ^{AB}
CPCC60	33 ^{DEFG}	
CPC60	0.0 ^G	100 ^A
CPCC90	77 ^{ABCD}	
CPC90	3.3 ^{FG}	96 ^A
CPCC120	77 ^{ABCD}	
CPC120	3.3 ^{FG}	96 ^A
PAAC30	90.0 ^{AB}	
PAA30	77 ^{ABCD}	14 ^C
PAAC60	87 ^{ABC}	
PAA60	60 ^{ABCD}	31 ^{BC}
PAAC90	93 ^A	
PAA90	50 ^{ABCDE}	46 ^{ABC}
PAAC120	93 ^A	
PAA120	43 ^{CDEFG}	54 ^{ABC}
SEM ¹	8.4	16

A-G Different superscripts within each column indicate a significant difference ($P < 0.05$).

¹SEM: standard error of the mean.

incidence than PAA30 and PAA60 but did not differ ($P > 0.05$) from PAA90 and PAA120. Results suggest that CPC could be employed for any length of time between 30 and 120 s, but there was no additional benefit after 60 s of contact time. Meanwhile, PAA's efficacy was time dependent and showed its best reduction potential at 90 and 120 sec. Beers et al. (2006) reported that the application of 0.5 to 0.7% CPC (Cecure) to pre-chill carcasses, reduced the incidence of *Salmonella*, as determined using BAX-PCR, from 35 to 9%.

Experiment 2: Antimicrobial treatments with inoculated *Salmonella* on broiler frames

Broiler frames were inoculated on average with 4.6 log CFU/g of the 3-strain *Salmonella* cocktail. This value was determined after attachment, but prior to treatments. Post-treatment log counts indicated that PAA and CPC treatments led to 0.6–1.2 log reductions in counts but were not different from each other ($P > 0.05$). Both the PAA60 and PAA90 treatments had average log reductions of 1.1 CFU/g as compared to the 0.80 CFU/g log reduction for CPC30 and CPC60 treatments (Table 2).

A past study compared the efficacy of CPC residuals on the reduction of *Escherichia coli* O157:H7 and *Salmonella* Typhimurium on whole beef muscle versus a ground blend consisting of meat that was processed from previously treated whole muscle that were blended with untreated meat (Cutter et al., 2000). Results indicated that CPC was more effective on whole muscle than ground meat. This could explain the relatively low log

reductions achieved in this study. Results indicated that longer exposure time may be necessary for CPC treatments to increase effectiveness, whereas PAA treatments were more effective at shorter exposure times. This was in accordance with previous studies which reported that CPC was more effective when applied for longer exposure times (Kim and Slavik, 1996). The reductions in the present study are lower than those previously reported when PAA was used as an antimicrobial and may be attributed to the buildup of organic matter in the rinse system. Bilgili et al. (2002) sampled 1080 broiler carcasses at seven facilities and found 0.75 to 3.25 log CFU/mL to be the average total microbial counts at post-chill sampling sites. The log count included enteric bacteria as well as aerobic bacteria, so it is understood that inoculating with 4.5-log CFU/g of *Salmonella* spp. is much higher than natural contamination that exists on broiler frames post-chill in the industry. Buildup of organic matter, such as fat and protein in the rinse water would reduce the effectiveness of PAA, since the antimicrobial would have oxidized both microbial cells and any organic particles that were present. King et al. (2005) inoculated hot beef carcass pieces with 6 log CFU/cm² each of antibiotic resistant *S. Typhimurium* and *E. coli* O157:H7, but only achieved a 0.7-log₁₀ CFU/cm² reduction respectively, even with a dwell time of 10 min in a 200 ppm PAA solution. Because of its many crevices, poultry skin is difficult to decontaminate (Kim and Slavik, 1996; Kim et al., 1996). This could explain the difference between log reductions achieved in other studies and the present study where skin and muscle tissue were ground into the final product. Additionally, pH and concentration have an impact on the antimicrobial efficacy of organic acids (Mani-López et al., 2012). It is possible that neither antimicrobial was able to fully penetrate the multitude of crevices in the poultry skin and reduce the attached *Salmonella* spp. Therefore, when the skin was processed into MSC, the cells were released.

Table 2. Mean log CFU/g of *Salmonella* spp. present in mechanically separated chicken (MSC) produced from broiler frames ($n = 216$, 3 replications) that were inoculated with 4.5-log CFU *Salmonella* and then treated with either a 0.50% cetylpyridinium chloride (CPC) with Citrilow solution for 30 or 60 s or 0.10% peracetic acid (PAA) solution for 60 or 90 s

Treatments	Log CFU/g
CPCC30	4.5 ^A
CPC30	3.7 ^B
CPCC60	4.6 ^A
CPC60	3.7 ^B
PAAC60	4.7 ^A
PAA60	3.6 ^B
PAAC90	4.5 ^A
PAA90	3.5 ^B
SEM ¹	0.15

^{A-B}Means with different superscripts are significantly different ($P < 0.05$).

¹SEM: standard error of the mean.

Experiment 3: Instrumental quality of mechanically deboned meat from antimicrobial treated frames

When controls and treatments were compared, there were differences ($P < 0.05$) between CPCC's and their CPC's but not ($P > 0.05$) between PAAC's and PAA treatments (Table 3). All CPC controls exhibited higher mean pH values than their respective treatments, indicating that the use of this acidic antimicrobial solution on broiler frames subsequently lowered the pH of the MSC that was produced. Within the treatment category, CPC30 and CPC60 were not different ($P > 0.05$) from

Table 3. Instrumental Analysis of pH, Color, Cook Loss, and Protein Bind of mechanically separated chicken (MSC) produced from broiler frames ($n = 144$, 3 replications) treated with either a 0.50% cetylpyridinium chloride (CPC) with Citrilow solution for 30 or 60 s or 0.10% peracetic acid (PAA) solution for 60 or 90 s

Treatment	pH	L^*	a^*	b^*	Hue	Chroma	Protein Bind (N)	% Cook Loss
CPCC30	6.5 ^A	69.2 ^{AB}	10.3 ^{BC}	21.3 ^{AB}	23.7 ^B	1.1 ^{AB}	24.1 ^A	51.4 ^{BC}
CPC30	6.1 ^{BC}	70.1 ^A	8.9 ^{CD}	19.3 ^C	21.3 ^C	1.1 ^{AB}	17.1 ^B	55.9 ^{AB}
CPCC60	6.6 ^A	65.9 ^{BC}	12.8 ^A	22.0 ^A	25.5 ^A	1.0 ^C	23.1 ^A	49.1 ^C
CPC60	5.9 ^C	69.9 ^A	8.1 ^D	19.4 ^C	21.0 ^C	1.2 ^A	12.4 ^B	51.6 ^{BC}
PAAC60	6.6 ^A	65.0 ^C	13.0 ^A	22.2 ^A	25.8 ^A	1.0 ^C	16.4 ^B	54.1 ^{ABC}
PAA60	6.4 ^{AB}	66.9 ^{ABC}	10.1 ^{BCD}	20.8 ^B	23.3 ^B	1.1 ^{AB}	15.7 ^B	53.8 ^{ABC}
PAAC90	6.6 ^A	65.9 ^{BC}	11.4 ^{AB}	21.4 ^{AB}	24.3 ^{AB}	1.1 ^{BC}	14.0 ^B	59.6 ^A
PAA90	6.4 ^{AB}	61.2 ^D	13.0 ^A	21.9 ^A	25.5 ^A	1.0 ^C	15.7 ^B	53.5 ^{ABC}
SEM ¹	0.11	1.19	0.678	0.318	0.516	0.022	1.23	1.46

^{A-D}Means within the same column with different superscripts are significantly different ($P < 0.05$).

¹SEM: standard error of the mean.

each other nor was there a difference between PAA60 and PAA90 ($P > 0.05$). PAA60 and PAA90 both yielded MSC meat with a higher pH than CPC30 and CPC60 (Table 3). Decreased muscle pH can lead to decreased water holding capacity and lighter color, since the meat pH is closer to the myofibrillar protein's isoelectric point (Qiao et al., 2001). In addition, the color could be lighter due to decreased moisture content and potential myoglobin denaturation (Hughes et al., 2014).

The L^* value of patties from the CPC60 was greater ($P < 0.05$) than patties from its control (CPCC60), but did not differ from the other 60 s control (PAAC60), so it is possible the difference between the two 60 s control L^* values can be attributed to differences between the frames prior to treatment or variation during processing. No differences existed ($P > 0.05$) between the L^* value of antimicrobial treatments and their controls. Froning and McKee (2010) indicated greater L^* values and lesser a^* values with an elevated level of skin in MSC (Owens, 2010). This could explain why the results differed from previous research, which reported no differences in the color of poultry skin or poultry meat treated with CPC (Bai et al., 2007; Bauermeister et al., 2008; Kim and Slavik, 1996). Data from the referenced study were based on visual and not instrumental analysis. Similarly, Chen et al. (2014) reported no difference in appearance after 1 d storage of ground chicken samples based on sensory evaluation of treated samples with CPC (0.35 and 0.6%) and PAA (0.07 and 0.1%). CIE a^* values for CPC treatments (CPC30 and CPC60) ranged from 8.1 to 8.9 and were not different ($P > 0.05$) from each other. However, CPC60 was less red ($P < 0.05$) than its control. In addition, CPC30 did not differ ($P > 0.05$) from its control, but was less red ($P < 0.05$) than other CPC controls. For PAA treatments, PAA60 was less red than its control

and PAA90 was more red ($P < 0.05$) than its control. The PAA 90 treatment was more red ($P < 0.05$) than PAA60, CPC30, and CPC60.

On average, PAA60 and PAA90 had greater ($P < 0.05$) b^* values than CPC30 and CPC60 (Table 3). Chen et al. (2014) previously reported no differences in yellowness between 0.1% PAA and 0.6% CPC treated ground chicken patties after 1 d of storage. Factors that may have contributed to differences between PAA and CPC treatments include utilization of poultry frames rather than parts, shorter contact time (23 s) and greater solution pH in the referenced study.

Hue is one of the 3 dimensions in the color space and is the most critical dimension to humans with normal color vision for acceptability of food (Wrolstad and Smith, 2017). The CPCC30 treatment produced MSC with lower hue values ($P < 0.05$) than the CPCC60 and PAAC60 controls (Table 3). This indicates natural color variability of frames. The PAA60 treatment had a greater hue value ($P < 0.05$) at 23.3 than CPC60 with a hue value of 21.0. When compared to the controls, each treatment had a lower hue ($P < 0.05$) than its control with the exception of PAA90 (Table 3). In addition, PAA treatments had greater hue values ($P < 0.05$) than CPC treatments. The lower hue values for MSC that was exposed to the CPC treatments was likely caused by the acidic pH of the CPC solution. When compared to their controls, PAA60 and CPC60 were the only treatments that differed ($P < 0.05$) from their control with respect to chroma (Table 3). Both of the treatments had slightly more intense chroma values ($P < 0.05$) in comparison to their control. Chroma measures color intensity or saturation, with a lower chroma value indicating less color saturation (Wrolstad and Smith, 2017). Chroma values ranging from 1.0 to 1.2, which indicates that these significant differences would not likely have a practical impact on appearance.

Protein bind is an indicator of how strong the association is between myofibrillar proteins in processed meat products (Schilling et al., 2004). Average protein bind values ranged from 14.0 to 24.1 N for the control treatments. The CPC controls had greater protein bind values ($P < 0.05$) than any of the other treatments or the PAA controls ($P < 0.05$; Table 3). The higher protein bind values for the CPC controls (23.6 N) in comparison to the PAA controls (15.2 N) may be due to variability in grinding where sample textures may have been more like traditional ground chicken than MSC. The CPC control groups had greater protein bind values ($P < 0.05$) than their respective CPC treatments. CPC30 had a mean protein bind value of 17.1 N, which was less ($P < 0.05$) than its control at 24.1 N. The MSC from the CPC60 treated frames had a decreased ($P < 0.05$) protein bind value (12.4 N) compared to that of CPCC60 (23.1 N). Among the PAA treatments, there was no difference ($P > 0.05$) between any of the treatments in terms of protein bind (Table 3). This is in agreement with previous research that reported no differences among texture scores for chicken breast fillets treated with PAA treatments of 0.0025, 0.01, or 0.02% (Bauermeister et al., 2008). Chen et al. (2014) conducted sensory testing on ground chicken patties that were produced from chicken parts that were dip treated for 23 s with CPC treatments (0.35 and 0.60%) and PAA treatments (0.07 and 0.10%). These researchers reported no differences in terms of texture. Based on previous analyses from our laboratory on samples that were submitted by industrial poultry companies, MSC with protein bind values less than 15.0 N generally do not have enough binding strength to make further processed products due to protein denaturation. This indicates that on average, MSC from frames treated with CPC60 may not be desirable for use in the poultry industry. No difference existed ($P > 0.05$) between each treatment or their control with respect to cooking loss.

Conclusions

Results from this study indicate that certain antimicrobials may be effective at reducing *Salmonella* spp. on broiler frames. An antimicrobial dip solution of 0.50% CPC with Citrilow at pH of 1.50 yielded a 100% reduction of naturally-occurring *Salmonella* by reducing *Salmonella* incidence from 33.3 to 0% when applied to broiler frames for 60 s. The reduction of *Salmonella* spp. on broiler frames using 0.10% PAA as a dip treatment at a pH of 2.89 was time dependent with a 54% reduction of incidence at 120 sec. PAA, when utilized at 0.10% for 60 to 90 s reduced *Salmonella* spp. by > 1 log cfu/g in MSC from frames that were inoculated with 4.5-log

CFU *Salmonella*. The acidic pH of each of the solutions likely contributed to differences in appearance, including increased lightness in some CPC treatments and decreased redness and yellowness in PAA and CPC treatments when compared to their controls. Furthermore, it is likely that once incorporated into a meat mixture and cooked, the differences would prove to be negligible. In terms of hue and chroma, nearly all treatments produced MSC with lower hue values than their controls. The CPC treatment at 60 s decreased protein bind, which indicates protein denaturation. This indicates that MSC from the CPC60 treatment may not bind, protein, water, and fat well enough to effectively make an emulsion meat product. However, PAA treatments and CPC30 did not have a significant impact on MSC quality. It is evident that the use of PAA and CPC dips can reduce the incidence of *Salmonella* on poultry frames but not completely control *Salmonella* at the concentrations evaluated. Therefore, though use of PAA and CPC can decrease food safety risks with minimal effects on quality, it cannot be used as a sole means to control *Salmonella* contamination.

Literature Cited

- Bai, Y., K. R. Coleman, C. W. Coleman, and A. L. Waldroup. 2007. Effect of cetylpyridinium chloride (ceceure CPC antimicrobial) on the refrigerated shelf life of fresh boneless, skinless broiler thigh meat. *Int. J. Poultry Sci.* 6(2):91–94. doi:10.3923/ijps.2007.91.94
- Bauermeister, L. J., J. W. J. Bowers, J. C. Townsend, and S. R. McKee. 2008. The microbial and quality properties of poultry carcasses treated with peracetic acid as an antimicrobial treatment. *Poult. Sci.* 87:2390–2398. doi:10.3382/ps.2008-00087
- Beers, K., J. Rheingans, K. Chinault, P. Cook, B. Smith, and A. Waldroup. 2006. Microbial efficacy of commercial application of Ceceure® CPC antimicrobial to ingesta-contaminated pre-chill broiler carcasses. *Int. J. Poultry Sci.* 5:698–703. doi:10.3923/ijps.2006.698.703
- Bilgili, S. F., A. L. Waldroup, D. Zelenka, and J. E. Marion. 2002. Visible ingesta on prechill carcasses does not affect the microbiological quality of broiler carcasses after immersion chilling. *J. Appl. Poultry Res.* 11(3):233–238. doi:10.1093/japr/11.3.233
- Chen, X., L. J. Bauermeister, G. N. Hill, M. Singh, S. F. Bilgili, and S. R. McKee. 2014. Efficacy of various antimicrobials on reduction of *Salmonella* and *Campylobacter* and quality attributes of ground chicken obtained from poultry parts treated in a postchill decontamination Tank. *J. Food Prot.* 77(11):1882–1888. doi:10.4315/0362-028X.JFP-14-114
- Cutter, C. N., W. J. Dorsa, A. Handie, S. Rodriguez-Morales, X. Zhou, P. J. Breen, and C. M. Compadre. 2000. Antimicrobial activity of cetylpyridinium chloride washes against pathogenic bacteria on beef surfaces. *J. Food Prot.* 63(5):593–600. doi:10.4315/0362-028X-63.5.593
- DuPont. 2010. Conforming to the USDA-FSIS *Campylobacter* and *Salmonella* performance standards with the BAX system. p. 6. Wilmington, DE: DuPont Qualicon.

- Froning, G. W., and S. R. McKee. 2010. Mechanical separation of poultry meat and its use in products. In: C. M. Owens, C. Z. Alvarado, and A. R. Sams, editors, *Poult. Meat. Proc.* 2nd ed. CRC Press, Boca Raton, FL. p. 295-307.
- Hughes, J., S. Oiseth, P. Purslow, and R. Warner. 2014. A structural approach to understanding the interactions between colour, water-holding capacity and tenderness. *Meat Sci.* 98:520–532. doi:10.1016/j.meatsci.2014.05.022
- Kim, J. W., and M. F. Slavik. 1996. Cetylpyridinium chloride (CPC) treatment on poultry skin to reduce attached *Salmonella*. *J. Food Prot.* 59(3):322–326. doi:10.4315/0362-028X-59.3.322
- Kim, K. Y., J. F. Frank, and S. E. Craven. 1996. Three-dimensional visualization of *Salmonella* attachment to poultry skin using confocal scanning laser microscopy. *Lett. Appl. Microbiol.* 22(4):280–282. doi:10.1111/j.1472-765X.1996.tb01161.x
- King, D. A., L. M. Lucia, A. Castillo, G. R. Acuff, K. B. Harris, and J. W. Savell. 2005. Evaluation of peroxyacetic acid as a post-chilling intervention for control of *Escherichia coli* O157: H7 and *Salmonella* Typhimurium on beef carcass surfaces. *Meat Sci.* 69(3):401–407. doi:10.1016/j.meatsci.2004.08.010
- Mani-López, E., H. S. García, and A. López-Malo. 2012. Organic acids as antimicrobials to control *Salmonella* in meat and poultry products. *Food Res. Int.* 45(2):713–721. doi:10.1016/j.foodres.2011.04.043
- Moore, A., R. Nannapaneni, A. Kiess, and C. S. Sharma. 2017. Evaluation of USDA approved antimicrobials on the reduction of *Salmonella* and *Campylobacter* in ground chicken frames and their effect on meat quality. *Poult. Sci.* 96:2385–2392. doi:10.3382/ps/pew497
- Nagel, G. M., L. J. Bauermeister, C. L. Bratcher, M. Singh, and S. R. McKee. 2013. *Salmonella* and *Campylobacter* reduction and quality characteristics of poultry carcasses treated with various antimicrobials in a post-chill immersion tank. *Int. J. Food Microbiol.* 165:281–286. doi:10.1016/j.ijfoodmicro.2013.05.016
- Owens, C. M. 2010. Coated poultry products. In: C. M. Owens, C. Z. Alvarado, and A. R. Sams, editors, *Poult. Meat. Proc.* 2nd ed. CRC Press, Boca Raton, FL. p. 279-294.
- Qiao, M., D. Fletcher, D. Smith, and J. Northcutt. 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. *Poult. Sci.* 80:676–680. doi:10.1093/ps/80.5.676
- Schilling, M. W., N. G. Marriott, J. C. Acton, C. Anderson-Cook, S. E. Duncan, and C. Z. Alvarado. 2004. Utilization of response surface modeling to evaluate the effects of non-meat adjuncts and combinations of PSE and RFN pork on the texture of boneless cured pork. *J. Muscle Foods* 14:143–161. doi:10.1111/j.1745-4573.2003.tb00696.x
- USDA-FSIS. 2014. Isolation and identification of *Salmonella* from meat, poultry, pasteurized egg, and catfish products and carcass and environmental sponges. *United States Department of Agriculture, Agricultural Marketing Service. Athens, GA. MLG 4.08.* Available at: <https://www.fsis.usda.gov/wps/wcm/connect/700c05fe-06a2-492a-a6e1-3357f7701f52/MLG-4.pdf?MOD=AJPERES> (accessed on 4 March 2018).
- USDA-FSIS. 2012. The Nationwide Microbiological Baseline Data Collection Program: Raw Chicken Parts Survey. Available at: https://www.fsis.usda.gov/shared/PDF/Baseline_Data_Raw_Chicken_Parts.pdf (accessed on 4 March 2018).
- USDA-FSIS. 2016. USDA Finalizes new food safety measures to reduce *Salmonella* and *Campylobacter* in poultry. *United States Department of Agriculture Food Safety and Inspection Service. Release No. 0032.16. Washington, DC.* Available at: <https://www.usda.gov/media/press-releases/2016/02/04/usda-finalizes-new-food-safety-measures-reduce-salmonella-and> (accessed on 4 March 2018).
- USDA-FSIS. 2017. Safe and suitable ingredients used in the production of meat, poultry, and egg products. United States Department of Agriculture Food Safety and Inspection Service. FSIS directive. 7120.1 Rev.43. Pg. 1-123. Available at: <https://www.fsis.usda.gov/wps/wcm/connect/bab10e09-ae6a-483b-8be8-809a1f051d4c/7120.1.pdf?MOD=AJPERES> (accessed on 4 March 2018).
- Weissinger, W. R., W. Chantarapanont, and L. R. Beuchat. 2000. Survival and growth of *Salmonella* baillon in shredded lettuce and diced tomatoes, and effectiveness of chlorinated water as a sanitizer. *Int. J. Food Microbiol.* 62(1):123–131. doi:10.1016/S0168-1605(00)00415-3
- Wrolstad, R. E., and D. E. Smith. 2017. Color analysis. In: S. S. Nielsen, editor, *Food Analysis.* 5th ed. Springer, Cham, Switzerland. p. 545–555. doi:10.1007/978-3-319-45776-5_31
- Yang, Z., Y. Li, and M. Slavik. 1998. Use of antimicrobial spray applied with an inside-outside birdwasher to reduce bacterial contamination on prechilled chicken carcasses. *J. Food Prot.* 61:829–832. doi:10.4315/0362-028X-61.7.829