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Antimicrobial Efficacy of a Sulfuric Acid and Sodium Sulfate Blend, Peroxyacetic Acid, and Cetylpyridinium Chloride against *Salmonella* on Inoculated Chicken Wings

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ABSTRACT

Studies were conducted to evaluate the efficacy of a commercial blend of sulfuric acid and sodium sulfate (SSS) in reducing *Salmonella* on inoculated whole chilled chicken wings and to compare its efficacy to peroxyacetic acid (PAA) and cetylpyridinium chloride (CPC). Wings were spot inoculated (5 to 6 log CFU/ml of sample rinsate) with a five-strain mixture of novobiocin- and nalidixic acid–resistant *Salmonella* and then left untreated (control) or treated by immersing individual wings in 350 ml of antimicrobial solution. An initial study evaluated two treatment immersion times, 10 and 20 s, of SSS (pH 1.1) and compared cell recoveries following rinsing of treated samples with buffered peptone water or Dey/Engley neutralizing broth. In a second study, inoculated wings were treated with SSS (pH 1.1; 20 s), PAA (700 ppm, 20 s), or CPC (4,000 ppm, 10 s) and analyzed for survivors immediately after treatment (0 h) and after 24 h of aerobic storage at 4°C. Color and pH analyses were also conducted in the latter study. Recovery of *Salmonella* survivors following treatment with SSS (10 or 20 s) was not ($P \geq 0.05$) affected by the type of cell recovery rinse solution (buffered peptone water or Dey/Engley neutralizing broth), but there was an effect ($P < 0.05$) of SSS treatment time. Immersion of samples for 10 or 20 s in SSS resulted in pathogen reductions of 0.8 to 0.9 and 1.1 to 1.2 log CFU/ml, respectively. Results of the second study showed that there was an interaction ($P < 0.05$) between antimicrobial type and storage time. Efficacy against *Salmonella* at 0 h increased in the order CPC < SSS < PAA; however, after 24 h of aerobic storage, pathogen counts of SSS- and PAA-treated wings did not differ ($P \geq 0.05$). Overall, the results indicated that SSS applied at pH 1.1 for 20 s was an effective antimicrobial intervention to reduce *Salmonella* contamination on chicken wings.

Antimicrobial interventions are applied to poultry products to both physically and chemically reduce numbers of pathogens such as *Salmonella* spp. in U.S. processing plants and to prevent human foodborne infection *(2, 6, 9–11, 13)*. Further processed chicken products have been associated with numerous *Salmonella* outbreaks *(3–5)*. For example, *Salmonella* Heidelberg, a serotype of recent concern, was associated with a major outbreak in 2013 and 2014 that resulted in 634 cases of salmonellosis *(3, 4)*.

Preventing foodborne illness with the use of antimicrobial interventions for meat and poultry products is a priority for the industry and the U.S. Department of Agriculture, Food Safety and Inspection Service (USDA-FSIS *(15)*). To address the concern for meat safety, the USDA-FSIS developed a strategic plan for 2011 to 2016, including goals addressing strategies to improve control of foodborne pathogens for each fiscal year *(16)*. Some of the goals include maximizing compliance of food safety policies, improving public education in safe food handling, advancing employee training to maximize success in protecting public health, and effectively using scientific research to understand foodborne illness, pathogens of interest, and emerging trends *(16)*.

To move forward with both regulatory and industry goals, continued scientific investigation of antimicrobial intervention processes for poultry products is needed. Research, not only in the harvest process but also in final products that may be contaminated, such as poultry parts, is a key factor in improving safety of poultry products and in meeting performance standard goals for *Salmonella (7, 11, 16, 17)*. The antimicrobial interventions used for poultry products should be easy to implement into existing systems, inexpensive, environmentally friendly, have minimal negative residual effects on the product, and perform to regulatory standards *(14)*. A commercially available blend of sulfuric acid and sodium sulfate (SSS; Amplon, Zoetis, Florham Park, NJ) as an antimicrobial intervention may contribute to reducing bacterial contamination on poultry products and may provide financial and environmental benefits; however, few data have been published exploring the capabilities of this product. Therefore, the objectives of

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this study were to evaluate the efficacy of SSS against *Salmonella* on inoculated whole chilled chicken wings and to compare its efficacy to other chemicals commonly used by the poultry industry (i.e., peroxyacetic acid [PAA] and cetylpyridinium chloride [CPC]) immediately after treatment and after 24 h of aerobic storage at 4°C.

MATERIALS AND METHODS

Bacterial strains and inoculum preparation. Five *Salmonella* isolates of poultry origin, including *Salmonella* Montevideo, *Salmonella* Typhimurium, *Salmonella* Heidelberg, *Salmonella* Enteritidis, and *Salmonella* Newport, were used in these studies. All the isolates (kindly provided by Dr. Thomas Edrington, USDA, Agricultural Research Service, College Station, TX) were hydrogen sulfide producing, indicated by the formation of black colonies on xylose lysine deoxycholate agar (Acumedia, Neogen Corp., Lansing, MI) and were resistant to nalidixic acid (20 μg/ml) and novobiocin (25 μg/ml). Resistance to these two antibiotics was used as a selective marker for enumeration purposes. Working cultures of the five *Salmonella* serotype strains were maintained on xylose lysine deoxycholate agar supplemented with nalidixic acid (20 μg/ml; Sigma-Aldrich, St. Louis, MO) and novobiocin (25 μg/ml; Sigma-Aldrich) (XLDNN). Before the start of each experiment, a single isolated colony from each *Salmonella* serotype was individually inoculated into 10 ml of tryptic soy broth (TSB; Difco, BD, Sparks, MD) supplemented with 20 μg/ml nalidixic acid and 25 μg/ml novobiocin (TSBNN) and incubated for 22 to 24 h at 35°C. After incubation, broth cultures were subcultured by transferring 0.1 ml of the original culture into 10 ml of fresh TSBNN, and the cultures were incubated for 22 to 24 h at 35°C. Cultures of all five *Salmonella* serotypes were then combined, and the cells harvested by centrifugation (20 min, 4°C, 3,220 × *g*; Eppendorf model 5810 R, Brinkmann Instruments Inc., Hamburg, Germany). Cell pellets were washed with 10 ml of phosphate-buffered saline (PBS, pH 7.4; Sigma-Aldrich), centrifuged an additional time, and then the cell pellets were resuspended to the original volume (50 ml) with PBS. The concentration of the inoculum suspension was ~7 to 8 log CFU/ml.

Inoculation of chicken wings. Whole skin-on broiler chicken wings (including the humerus, radius, ulna, and phalanges [wing tip]) of similar weight were collected from a commercial poultry processing facility after postharvest chilling but before application of any postchilling antimicrobial treatment. The chicken wings were shipped fresh and refrigerated to the Center for Meat Safety & Quality at Colorado State University (Fort Collins), and upon arrival they were immediately refrigerated (4°C) and used within 24 to 36 h. On the day of the experiment, chicken wings were randomly assigned to a treatment group and inoculated. The two surfaces (medial and lateral surfaces) of the chicken wings were each spot inoculated with 100 μl (~15 drops) of the *Salmonella* inoculum mixture, with a 10-min cell attachment time at 4°C, for each side. The target inoculation level of the chicken wings was ~5 to 6 log CFU/ml of wing rinsate. After inoculation, half of the chicken wings were assigned to an antimicrobial treatment and the other half were left untreated to serve as control samples to obtain initial *Salmonella* and aerobic plate counts.

Antimicrobial treatment of chicken wings. The objective of the first study was to determine the efficacy of SSS applied at two immersion times and to compare cell recoveries following rinsing of treated samples with one of two rinse solutions. Inoculated chicken wings were aseptically placed in a sterile Whirl-Pak bag (Nasco, Fort Atkinson, WI) containing 350 ml of SSS (pH 1.1; Zoetis) solution for one of two immersion times: 10 or 20 s. Each sample was immersed in a new Whirl-Pak bag containing fresh, unused SSS solution. Treated chicken wings were aseptically removed from the SSS solution after the designated treatment time and allowed to drip on sterile wire racks for 5 min. Following the 5-min drip time, treated wings were placed in a Whirl-Pak bag containing 150 ml of Dey/Engley neutralizing broth (D/E; Difco, BD) or buffered peptone water (BPW; Difco, BD). These two sample rinsing solutions were selected to determine whether there were effects on *Salmonella* population recovery based on the solution's ability to neutralize the SSS after treatment.

The objective of the second study was to compare the efficacy of SSS with that of PAA and CPC immediately after treatment (0 h) and after 24 h of aerobic storage at 4°C. Chicken wings, inoculated as previously described, were left untreated (control) or were immersed in SSS (pH 1.1, 20 s), PAA (700 ppm, 20 s; Enviro Tech Chemical Services, Inc., Modesto, CA), or CPC (4,000 ppm, 10 s; Safe Foods Corporation, Little Rock, AR). The antimicrobial solutions were prepared according to the manufacturers' recommendations and applied according to parameters outlined in USDA-FSIS Directive 7120.1 *(17)*. The CPC treatment was limited to a 10-s immersion time and was followed by a water rinse, in compliance with USDA-FSIS Directive 7120.1 *(17)*. In this study, CPC-treated wings were each rinsed with ~25 ml of water by using a spray bottle. Water rinsing of SSS- and PAA-treated samples is not required *(17)* and therefore was not performed in this study. All treated samples were allowed to drip for 5 min, as previously described, and then transferred to a Whirl-Pak bag containing 150 ml of D/E for 0 h of microbial analysis, or placed in a Whirl-Pak bag and stored at 4°C for 24 h; after 24 h of storage, samples were microbially analyzed.

Microbiological, pH, and color analyses of chicken wings. The untreated and treated chicken wing samples were analyzed for aerobic plate counts and inoculated *Salmonella* populations. Untreated and treated samples from the first study were rinsed in a bag with 150 ml of BPW or D/E, whereas samples from the second study were rinsed with 150 ml of D/E only. Rinsing was performed by vigorously shaking the samples by hand with a strong downward force for 1 min to recover cells from the chicken wings. Rinsates were 10-fold serially diluted in 0.1% BPW. Appropriate dilutions (0.1 or 1 ml) were then surface plated onto two selective media: XLDNN and tryptic soy agar (Acumedia, Neogen Corp.) supplemented with nalidixic acid (20 μg/ml) and novobiocin (25 μg/ml) (TSANN; used to compare with the harsh selective medium XLDNN in the first study) for enumeration of inoculated *Salmonella* populations, and TSA for enumeration of aerobic microbial populations. Colonies were manually counted after incubation of XLDNN and TSANN plates at 35°C for 24 h and after incubation of TSA plates at 25°C for 72 h. Uninoculated chicken wings were also analyzed (five wings per replication in each of the two studies) for any naturally present hydrogen sulfide–producing and nalidixic acid- and novobiocin-resistant (on XLDNN and TSANN) microflora. The detection limit of the microbiological analysis was 1 CFU/ml of wing rinsate.

In both studies, uninoculated chicken wings that were left untreated, to serve as controls, and treated chicken wings were analyzed for pH. Control and treated samples were diluted (1:5 dilution) with deionized water and vigorously shaken by hand with a strong downward force (1 min). The pH of the rinsate was measured with a calibrated pH meter fitted with a glass electrode (Denver Instruments, Arvada, CO).

TABLE 1. *Least-squares mean plate counts recovered with XLDNN, TSANN, and TSA*[a]

Treatment time (s)	LSMean (SE) plate counts (log CFU/ml)								
	XLDNN			TSANN			TSA		
	Untreated	Treated	*P* value[b]	Untreated	Treated	*P* value	Untreated	Treated	*P* value
10	5.5 (0.1)	4.6 (0.1)	<0.0001	5.7 (0.0)	4.9 (0.0)	<0.0001	5.6 (0.1)	4.8 (0.1)	<0.0001
20	5.5 (0.0)	4.3 (0.0)	<0.0001	5.7 (0.1)	4.6 (0.1)	<0.0001	5.6 (0.1)	4.5 (0.1)	<0.0001

[a] Counts were obtained from *Salmonella*-inoculated (5 to 6 log CFU/ml of sample rinsate) chicken wing samples that were left untreated or were treated with a blend of sulfuric acid and sodium sulfate (SSS; pH 1.1) for 10 or 20 s. XLDNN, xylose lysine deoxycholate agar supplemented with novobiocin and nalidixic acid; TSANN, tryptic soy agar supplemented with novobiocin and nalidixic acid; TSA, tryptic soy agar.

[b] *P* values < 0.05 are significant.

In the second study, surface color measurements were collected on untreated and treated chicken wings to determine effects of treatment on integrity and stability of chicken wing color. Color was measured using a HunterLab MiniScan handheld spectrophotometer (45/0-S; Hunter Associates Laboratory Inc., Reston, VA) to obtain color measurements from the exterior tissue surface of the chicken wings. Measurements were obtained from uninoculated chicken wings that were untreated and treated at 0- and 24-h storage times. Three measurements were obtained from each wing sample to obtain an average color measurement for CIE L* (white versus black), a* (red versus green), and b* (yellow versus blue).

Statistical analysis. Both studies were designed as randomized complete blocks (study 1 was a 2×2 factorial, study 2 was a 2×3 factorial) by using treatment days as blocks. Study 1 was repeated on three separate days, with $n = 15$ per treatment; study 2 was replicated on two separate days, with $n = 10$ per treatment. Separate analyses were performed for each treatment to analyze the effect of each treatment against aerobic plate counts and inoculated *Salmonella* populations compared with those of untreated (control) samples. Then, log CFU per milliliter plate counts obtained from treated chicken wings were analyzed by treatment to determine interactions and main effects of treatment parameters. Data were analyzed using the Mixed Procedure of SAS version 9.3 (SAS Institute Inc., Cary, NC), with independent variables in study 1 including SSS immersion time (10 or 20 s), sample rinsing solution type (D/E or BPW), and the respective interactions and in study 2, antimicrobial treatment (SSS, PAA, or CPC), storage time (0 or 24 h), and the respective interactions. Bacterial populations were expressed as least-squares means for log CFU per milliliter of wing rinsate calculated under an assumption of a log-normal distribution of plate counts. Color and pH results were compared within treatment with their respective controls to determine treatment effect by using the Mixed Procedure of SAS, and results were expressed as least-squares means. All differences were reported using a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Antimicrobial effect of treatments. Microbial analysis of uninoculated chicken wings indicated absence (<1 CFU/ml of wing rinsate) of any naturally occurring hydrogen sulfide–producing and nalidixic acid- and novobiocin-resistant (on XLDNN and TSANN) microbial populations. Therefore, plate counts recovered with XLDNN and TSANN from inoculated untreated and treated samples were those of the *Salmonella* inoculum used in this study.

For the first study, microbial population counts for untreated and treated inoculated chicken wings were obtained with XLDNN, TSANN, and TSA (Table 1). Initial levels of inoculated *Salmonella* on untreated chicken wings were 5.5 to 5.7 log CFU/ml of wing rinsate (Table 1). When comparing SSS-treated chicken wing counts between treatments (immersion time, 10 versus 20 s; sample rinsing solution type, D/E versus BPW), no interactions ($P \geq 0.05$) were observed. There were also no differences ($P \geq 0.05$) in mean *Salmonella* plate counts observed between D/E- and BPW-rinsed chicken wing samples (data not shown); therefore, all results were expressed as the main effect ($P < 0.05$) of immersion time (Table 1). Compared with the least-squares mean *Salmonella* and aerobic plate counts for inoculated untreated controls, all of the plate counts obtained from treated chicken wings were reduced ($P = 0.0001$) after treatment with SSS.

Salmonella plate counts obtained from chicken wings treated with SSS for 10 s were greater ($P < 0.05$) than corresponding counts obtained from wings that were treated for 20 s (Table 1). Pathogen counts obtained from chicken wings treated with SSS for 10 or 20 s were reduced by 0.8 to 0.9 log CFU/ml and 1.1 to 1.2 log CFU/ml, respectively, based on counts recovered with XLDNN and TSANN. In a previous study *(12),* beef cheek meat inoculated with 4.1 log CFU/cm^2 *Salmonella* was immersed in SSS (pH 1.8) for 1, 2.5, or 5 min. The investigators reported reductions of 1.0 to 1.5 log CFU/cm^2 depending on duration of immersion *(12)*. In another study *(9),* researchers immersed *Salmonella*-inoculated beef trimmings in SSS (pH 1.2) for 30 s and reported reductions of 0.5 to 0.7 log CFU/cm^2 for *Salmonella* Typhimurium and *Salmonella* Newport. Overall, findings of the present study indicated that SSS at a pH of 1.1 applied for 10 or 20 s may be an effective antimicrobial intervention for chicken wings.

In the second study, plate counts were obtained from XLDNN and TSA, and the results of this study are shown in Table 2. There was an interaction ($P < 0.05$) between antimicrobial type and storage time. The initial *Salmonella* inoculation level of chicken wings was 5.5 log CFU/ml as obtained from XLDNN (Table 2). All least-squares mean plate counts obtained from treated and stored (0 or 24 h) chicken wings were lower ($P < 0.05$) than those of

TABLE 2. *Least-squares mean plate counts recovered with TSA and XLDNN*[a]

Storage time (h)	LSMean (SE) plate counts (log CFU/ml)							
	TSA				XLDNN			
	Untreated	SSS[b]	PAA[b]	CPC[c]	Untreated	SSS[b]	PAA[b]	CPC[c]
0	5.7 (0.1) A	4.6 (0.1) C	4.2 (0.1) D	5.0 (0.1) B	5.5 (0.1) A	4.3 (0.1) C	4.0 (0.1) D	4.7 (0.1) B
24	5.7 (0.1) A	4.1 (0.1) DE	4.0 (0.1) E	4.9 (0.1) B	5.5 (0.1) A	3.7 (0.1) E	3.8 (0.1) DE	4.8 (0.1) B

[a] Counts were obtained from *Salmonella*-inoculated (5 to 6 log CFU/ml of sample rinsate) chicken wings that were left untreated or were treated with different antimicrobial chemicals and stored at 4°C (0 or 24 h). TSA, tryptic soy agar; XLDNN, xylose lysine deoxycholate agar supplemented with novobiocin and nalidixic acid. Within each culture medium (TSA and XLDNN), LSMeans with different letters are different ($P < 0.05$).

[b] Chicken wings were immersed (20 s) in a blend of sulfuric acid and sodium sulfate (SSS; pH 1.1) or peroxyacetic acid (PAA; 700 ppm).

[c] Chicken wings were immersed (10 s) in cetylpyridinium chloride (CPC; 4,000 ppm) followed by a 25-ml water rinse.

untreated samples, irrespective of plating medium (XLDNN or TSA) (Table 2).

All tested antimicrobial treatments reduced ($P = 0.0001$) *Salmonella* and aerobic plate counts obtained from the chicken wings compared with corresponding counts of untreated samples (Table 2). At 0 h, SSS reduced aerobic plate counts on chicken wings by 1.1 log CFU/ml (TSA) and pathogen counts by 1.2 log CFU/ml (XLDNN) (Table 2). Wings stored for 24 h after treatment with SSS or PAA resulted in additional reductions ($P < 0.05$) of aerobic microbial populations (Table 2). However, counts of CPC-treated samples stored for 24 h did not differ ($P \geq 0.05$) from those of corresponding 0-h samples, irrespective of agar type (Table 2). Pathogen counts of SSS-treated chicken wings had the greatest reduction ($P = 0.0001$) after 24 h of storage. More specifically, a 0.6-log CFU/ml reduction was observed from 0 to 24 h (Table 2).

In the present study, PAA (700 ppm) reduced aerobic plate counts and *Salmonella* populations by 1.5 log CFU/ml on chicken wings immediately after treatment (0 h of storage) (Table 2). Geornaras et al. *(8)* used PAA as an immersion treatment for decontamination of beef trimmings inoculated (3.2 log CFU/cm^2) with *Escherichia coli* O157:H7 or non-O157 Shiga toxin–producing *E. coli*. In their study, PAA was applied at a concentration of 200 ppm, and inoculated beef trimmings were immersed in the antimicrobial solution for 30 s; they reported reductions of 0.6 to 0.8 log CFU/cm^2 *(8)*.

In the present study, chicken wings were immersed in CPC (4,000 ppm) for 10 s, followed by a spray rinse with water to comply with parameters outlined in USDA-FSIS Directive 7120.1 *(17)*. Treatment of chicken samples with CPC reduced aerobic plate counts and *Salmonella* populations by 0.7 and 0.8 log CFU/ml, respectively, immediately after treatment (0 h of storage). Li et al. *(11)* also evaluated the antimicrobial efficacy of CPC, but as a prechill antimicrobial spray applied to *Salmonella*-inoculated chicken carcasses. In the present study, CPC was used as an immersion treatment that requires different concentration parameters than a spray treatment. Li et al. *(11)* applied the CPC spray treatment at 1,000 ppm for 90 s at ~119 lb/in^2, which resulted in a 1.6-log CFU per carcass reduction of *Salmonella*. With the differences in treatment application parameters, Li et al. *(11)* were able to achieve greater reductions (1.6-log reduction) of *Salmonella*. Li et al. *(11)* used a lower concentration of CPC, but applied it as a spray and did not have to rinse with water posttreatment, which may explain the greater reductions of *Salmonella* counts obtained. In a different study, Yang et al. *(18)* applied CPC by using an inside-outside birdwasher on *Salmonella* Typhimurium–inoculated chicken carcasses, at a concentration of 5,000 ppm for 17 s; after a 60-s dwell time, the treated carcasses were rinsed with water to remove chemical residue. This process was very similar to that of the present study because a similar CPC concentration was used and samples were rinsed with water after treatment. Yang et al. *(18)* found that CPC reduced *Salmonella* Typhimurium and total aerobes by ~2.0 log CFU per carcass when applied using the inside-outside birdwasher. The differences in application method, the slightly higher CPC concentration, and the 60-s dwell time before rinsing the treated carcasses with water may explain the differences in *Salmonella* reductions obtained by Yang et al. *(18)* and those of the present study.

Antimicrobial solution effects on pH of chicken wings. Measurements of pH were obtained for the first study from uninoculated untreated chicken wings and SSS-treated (10 or 20 s) chicken wings. The mean pH of the untreated wings was 6.30, whereas treatment with SSS lowered ($P < 0.05$) the pH of samples to 4.24 to 4.31 pH units (data not shown). No differences ($P \geq 0.05$) in pH were obtained between samples treated for 10 s and those treated for 20 s. In addition to the true pH of the untreated and treated chicken wings, the pH of the buffered wing rinsates (BPW and D/E) was measured. As previously described, two different rinsing solution types were evaluated for buffering the treated chicken wing samples before microbiological testing. The pH of the BPW and D/E wing rinsates did not differ ($P \geq 0.05$), indicating no difference in neutralization of SSS (data not shown).

The pH of uninoculated treated and untreated chicken wings was also measured in the second study. The pH values of untreated chicken wings at 0 h (pH 6.92) and 24 h (pH 6.96) of storage at 4°C were similar ($P \geq 0.05$) (Table 3). Initial (0-h) pH values of all treated chicken wings, except

TABLE 3. *Least-squares mean pH values of uninoculated chicken wings that were left untreated or were treated with different antimicrobial chemicals and stored at 4°C (0 or 24 h)*[a]

Storage time (h)	LSMean (SE) pH values			
	Untreated	SSS[b]	PAA[b]	CPC[c]
0	6.92 (0.05) A	4.41 (0.07) D	6.29 (0.07) B	6.98 (0.07) A
24	6.96 (0.05) A	5.57 (0.07) C	6.65 (0.07) AB	6.65 (0.07) AB

[a] LSMeans bearing different letters are different ($P < 0.05$).
[b] Chicken wings were immersed (20 s) in a blend of sulfuric acid and sodium sulfate (SSS; pH 1.1) or peroxyacetic acid (PAA; 700 ppm).
[c] Chicken wings were immersed (10 s) in cetylpyridinium chloride (CPC; 4,000 ppm) followed by a 25-ml water rinse.

those treated with CPC, were lower ($P < 0.05$) than the corresponding pH values of the control chicken wings. Following 24 h of storage, the pH of SSS-treated wings increased ($P < 0.05$) by 1.16 pH units, but was still lower (by 1.39 pH units; $P < 0.05$) than the pH of the corresponding untreated samples. The 24-h storage period did not ($P \geq 0.05$) affect the pH of PAA- and CPC-treated samples. Furthermore, after storage, the pH values of untreated and PAA- or CPC-treated wings were not different ($P \geq 0.05$). Geornaras et al. *(8)* also reported on the effect of SSS treatment on product pH. In their study, beef trimmings were immersed for 30 s in a solution of SSS at a pH of 1.2, and pH measurements were obtained after a dwell time of 1 h. Untreated and SSS-treated pH values of the trimmings were 5.47 and 4.68, respectively *(8)*.

Effects of antimicrobial solutions on color of chicken wings. In the second study, color measurements were obtained at 0 and 24 h for treated and untreated chicken wings. An effect ($P < 0.05$) of storage time was observed for L* and a* measurements of the treated chicken wings (Table 4). Except for a main effect ($P < 0.05$) of antimicrobial for b* color measurements, no differences ($P \geq 0.05$) were detected between untreated and treated samples (data not shown). The only antimicrobially treated samples that differed ($P < 0.05$) from the untreated wings for b* measurement were the SSS-treated wings. The SSS-treated chicken wings were more yellow after treatment and less blue due to the increase in b* values (data not shown). In a study conducted by Bauermeister et al. *(1),* chicken carcasses treated with varying levels of PAA (100 to 200 ppm) resulted in L* values that were the same ($P \geq 0.05$) as those of untreated samples after 24 h of storage at 4°C; however, on days 7 and 15 of storage, carcasses treated with 200 ppm of PAA had lower ($P < 0.05$) L* values than those of the untreated carcasses. Small differences ($P \geq 0.05$) in b* and a* values were detected among the different PAA treatments at 24 h and 15 d of storage *(1)*.

TABLE 4. *Least-squares means for L*, a*, and b* measurements of chicken wings stored at 4°C (0 or 24 h)*[a]

Storage time (h)	LSMean (SE)		
	L*	a*	b*
0	68.92 (1.78) B	−1.8 (0.17) A	4.48 (0.39) A
24	74.79 (1.78) A	−2.4 (0.17) B	5.05 (0.39) A

[a] Within each column, LSMeans bearing different letters are different ($P < 0.05$). L*, white versus black; a*, red versus green; b*, yellow versus blue.

Under the conditions of the described studies, the data demonstrated that SSS used as an immersion treatment at pH 1.1 for 20 s may be an effective antimicrobial intervention for chicken wings. Both BPW and D/E are viable rinsing solutions with similar neutralizing capabilities for samples treated with SSS. Overall, antimicrobially treated chicken wings had little color change compared with untreated chicken wings that would alter the visual quality of the product. The SSS, PAA, and CPC solutions were effective antimicrobial interventions for reducing levels of inoculated *Salmonella*. When effects of SSS treatment were compared with commonly used poultry industry antimicrobials, SSS performed at least equally and could be used by the poultry industry to treat parts to reduce *Salmonella* contamination as part of a multiple hurdle system.

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