The Microbial and Quality Properties of Poultry Carcasses Treated with Peracetic Acid as an Antimicrobial Treatment

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ABSTRACT *Salmonella* spp. and *Campylobacter* spp. continue to be prominent food safety concerns for the poultry industry and consumers alike. Peracetic acid (PAA) has been approved as an antimicrobial for use in poultry chillers. To validate its effectiveness, 100 poultry carcasses (per replication × 2) were inoculated with *Salmonella* (10^6 cfu) or *Campylobacter* (10^6 cfu) and were randomly allocated into chill water containing chlorine (0.003%) or PAA (0.0025%, 0.01%, or 0.02%). Results indicated that PAA concentrations as low as 0.0025% were effective in decreasing *Salmonella* spp., whereas PAA levels of 0.02% were effective in decreasing *Campylobacter* spp. when compared with the chlorine treatment. A sensory study was also conducted with another set of 500 carcasses (not inoculated). Birds were treated with water, chlorine (0.003%), or PAA (0.01%, 0.015%, or 0.02%). Sensory panels and microbial data were collected weekly on randomly sampled carcasses that were stored at 4°C for 21 d. The PAA-treated carcasses at 0.015% and 0.02% had an extended shelf-life compared with those treated with water or chlorine. Specifically, on d 15, the only treatments that could be served to sensory panelists were the carcasses treated with 0.015% or 0.02% PAA. The carcasses treated with water, chlorine, or 0.01% PAA had off-colors, off-odors, and high microbial counts. These results suggest that PAA may be an effective antimicrobial when used in poultry chiller applications and greater levels (≥0.015%) may extend product shelf-life.

Key words: peracetic acid, shelf-life, antimicrobial, *Salmonella*, *Campylobacter*

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INTRODUCTION

Salmonella and *Campylobacter* continue to be prominent food safety concerns for the poultry industry and consumers alike. The USDA-Food Safety and Inspection Service has proposed further reduction of the incidence of *Salmonella* on poultry carcasses to levels below 10%. Because poultry processing is highly automated, many points exist where cross-contamination may occur.

A critical step during processing where antimicrobials have been used is the poultry chiller. Traditionally, chlorine has been used as an antimicrobial in poultry chiller applications and is allowed up to 0.005% (USDA-FSIS, 2003). However, the efficacy of chlorine as an antimicrobial is greatly decreased by high organic loads and pH levels above 7.0 (Lillard, 1979). Additionally, Tamblyn and Conner (1997) reported that chlorine levels as high as 0.04% and 0.08% were needed to kill *Salmonella* attached to broiler skin, but these levels would not be allowable according to current regulations.

Alternative antimicrobial strategies for poultry that have been investigated include organic acids (Izat et al., 1990; Tamblyn and Conner, 1997; Bilgili et al., 1998), hydrogen peroxide (Lillard and Thomson, 1983), trisodium phosphate (Lillard, 1994), chlorine dioxide (Doyle and Waldroup, 1996), acidified sodium chlorite (Kemp et al., 2000, 2001), and cetylpyridium chloride (Yang et al., 1998). For antimicrobials to be effective and utilized by the industry, they have to be approved; their efficacy has to be documented; the level and contact time needed has to appropriate for the particular processing step; they have to be cost-effective; and finally, they must not have deleterious effects on product quality. Therefore, some antimicrobial products are more appropriate for rinses, dips, or sprays as opposed to a chiller application in which the volume used may be greater and the contact time would be longer, making cost-effectiveness and quality factors a consideration.

The most common antimicrobial product other than chlorine (generally in the form of sodium hypochlorite) used for carcass application during processing is acidified sodium chlorite in spray applications (21 CFR 173.370). However, this compound is not widely used in chiller applications. In chiller applications today, other

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than sodium hypochlorite (chlorine), chlorine dioxide is sometimes selected because it is more stable; however, its effectiveness is still decreased by organic matter, and results have not been consistent in decreasing *Salmonella* and *Listeria* at typical usage levels of 0.0001 to 0.0003% (Doyle and Waldroup, 1996).

Several of the organic acids investigated for application in poultry include acetic, formic, citric, lactic, and propionic acid (Mulder et al., 1987; Izat et al., 1990; Dickens et al., 1994). Although these acids can be effective antimicrobials, it has been reported that they could cause negative flavor and color changes (Blankenship et al., 1990). To avoid the negative quality changes associated with organic acids, the ideal approach is to combine antimicrobials. This will allow the use of lower levels of organic acids but maintain the antimicrobial efficacy of the compound. Peracetic acid (**PAA**) combined with hydrogen peroxide is an example of this approach. The PAA tested in this study was Spectrum (FMC, Philadelphia, PA), which consisted of 15% PAA. In water, PAA forms an equilibrium with acetic acid and hydrogen peroxide (Baldry and Fraser, 1988). As an antimicrobial application in poultry, the maximum allowable concentrations of the chemicals in the mixture are 0.022% peroxyacetic acid and 0.012% hydrogen peroxide. The combined acidic and oxidizing properties of PAA have been found to be effective against bacteria, bacterial spores, fungi, and yeast (Fatemi and Frank, 1999).

Bell et al. (1997) reported that combinations of 1% acetic acid and 3% hydrogen peroxide provide the greatest reduction in *Escherichia coli*, *Salmonella* Wentworth, and *Listeria innocua* when sprayed on beef carcasses that had been previously inoculated. Brinez et al. (2006) also reported that PAA resulted in a greater than 5-log reduction of *Staphylococcus* spp., *Listeria* spp., and generic *E. coli* regardless of the food matrix tested. These studies suggest that PAA has antimicrobial efficacy at relatively low levels, due to combined acidic and oxidizing properties. Although the PAA described above has been approved for use in poultry chillers, there is a lack of published data to indicate its antimicrobial efficacy and its effect on product quality. Therefore, the objectives of this study were to determine the effective levels needed to decrease *Salmonella* and *Campylobacter* when used in poultry chiller applications and to evaluate the quality of carcasses.

MATERIALS AND METHODS

Pilot Plant Study

Poultry chill water was collected in 18.93-L buckets from a commercial poultry processing facility and transported to Auburn University Poultry Processing Unit (<160.93 km). Buckets containing chill water were stored at 4°C overnight. Water samples were collected from each bucket, and chlorine levels and organic loads were measured. Chlorine was measured using Aquachek Water Quality Test Strips (Hach Company, Loveland, CO). To determine water quality, chemical oxygen demand (**COD**) and biological oxygen demand (**BOD**) were measured (Boyd, 1979). Using sterile containers, three 500-mL samples of chill water were collected for COD and BOD measurements. Water was collected from the end sections of the chill tank so that the water samples would be representative of the chill water collected for the study. Water samples were placed on ice, and COD and BOD measurements were carried out within 6 h of sampling.

Five treatments consisting of varying levels of PAA (Spectrum, FMC) were prepared in the chill water containers. The water was maintained at 4°C, and chlorine levels were tested to confirm that they were at minimum concentrations to prevent confounding of results. Five chill water treatments prepared were 0.0025%, 0.01%, 0.02% PAA, 0.003% chlorine, or a control in which carcasses were not inoculated. Noninoculated carcasses were used to sample for any background *Salmonella* spp. or *Campylobacter* spp. that may be present. The PAA levels were confirmed and tested using LaMotte Peracetic Acid Test Kit (LaMotte Company, Chestertown, MD), and chlorine was measured using Aquachek Water Quality Test Strips (HACH Company). The pH of the treatments was also recorded (model 720A, Thermo Orion pH Meter, Pittsburg, PA), and the average pH of the PAA treatments was 4.5 and the chlorine treatment was 6.0. The pH of the chlorine treatment was not adjusted, because this was actual chill water from a poultry facility and the normal pH of this water was approximately 6.0 and was not adjusted at the plant.

For each replication, 100 carcasses were obtained from a commercial processing facility before entering the chiller. The carcasses were placed on ice and transported to Auburn University (<160 km). Carcasses were stored on ice at 4°C before being used in the study. Fifty carcasses per replication were inoculated on the skin of the carcass with *Salmonell*a enterica Typhimurium (10^6 cfu/mL) or *Campylobacter jejuni* (10^6 cfu/mL). Inoculum preparation is described below. Once the inoculum had dried (10 min), the birds were placed in the assigned treatment for 1 h (5 treatments × five 8.93-L buckets × 2 carcasses per bucket × 2 replications, n = 100 birds total). Afterward, the birds were sampled using the carcass rinse method described below.

Salmonella Inoculum Preparation

Test tubes containing 10 mL of tryptic soy broth were inoculated with a frozen culture of a nalidixic acid-resistant strain of *Salmonella* Typhimurium (isolated from the Auburn University Poultry Research Farm and selected for resistance to nalidixic acid). After incubating at 37°C for 24 h, 1 loop full of the *Salmonella* culture was streaked onto xylose-lysine-tergitol 4 agar (**XLT4**; Acumedia Manufactures Inc., Baltimore, MD) containing 50 μL/mL of nalidixic acid. The plates were

incubated at 37°C for 48 h. Black, isolated colonies were picked from the XLT4 plates, and fresh tryptic soy broth tubes were inoculated with 1 colony per test tube. The tubes were incubated 20 to 24 h at 37°C. A stock culture of 10^8 cells/mL of *Salmonella* Typhimurium was prepared.

Campylobacter Inoculum Preparation

One milliliter of the frozen *C. jejuni* (isolated from the Auburn University Poultry Research Farm) culture was added to 10 mL of Brucella-FBP broth (Acumedia Manufactures Inc.) in a test tube and incubated for 42 h at 42°C in a AnaeroJar (Oxoid, Ogdensburg, NY) containing a CampyGen sachet (Oxoid) to generate a microaerophilic mixture of 5% O_2, 10% CO_2, and 85% N_2. The culture was streaked onto Campy-Cefex agar (Stern et al., 1992) and incubated at 42°C for 42 h in microaerophilic conditions as described above to form a lawn of bacteria. *Campylobacter jejuni* was removed from the agar and added to 0.1% phosphate-buffered saline (Fisher BioReagents, Fair Lawn, NJ). A stock culture of 10^6 cells/mL was prepared.

Carcass Sampling

A whole-carcass rinse method described by the USDA in the Microbiology Laboratory Guidebook was used for the microbiological sampling, detection, and enumeration with the following modifications (USDA-FSIS, 2004). Carcasses were placed into sterile stomacher bags and rinsed with 200 mL of Neutralizing Buffer (Difco, Sparks, MD) for 1 min with a rocking motion to assure that all interior and exterior surfaces were rinsed. Decreasing the volume of rinsate has no affect on the recovery of *Salmonella* (Cox et al., 1980) and has been shown to increase the recovery of *Campylobacter* (Bailey and Berrang, 2007) in carcass rinse methods. The rinsate was transferred to a sterile bottle and placed on ice until analysis.

Direct-Plating of Salmonella and Campylobacter

Direct-plating was generally used for enumerating inoculated samples. After carcasses were sampled, serial dilutions were prepared using buffered peptone water. Samples were plated in duplicate. For *Salmonella*, the rinsate was direct-plated using the pour-plate method onto XLT4 agar (Acumedia) containing nalidixic acid (50 μg/mL; Sigma, St. Louis, MO). Briefly, the pour-plate method involved adding 1 mL of sample from the appropriate dilution to a sterile Petri dish, and then 20 mL of XLT4 agar that was <50°C was added to the sample and immediately swirled 8 times counterclockwise and 8 times clockwise. After the plates solidified, they were inverted and incubated at 37°C for 24 to 48 h. Populations were converted to log values with the 200 mL of carcass rinsate representing the sample. Therefore, results are reported as log colony-forming units per sample.

For *Campylobacter*, serial dilutions were plated using the spread-plate method on Campy-Cefex agar (Stern et al., 1992) in duplicate. Spread-plating indicates that 0.1 mL of the appropriate dilution was placed on top of the agar and spread with a spreader. Plates were incubated for 36 h at 42°C in AnaeroPack rectangular jars (Mitsubishi Gas Chemical America, Tokyo, Japan) with a microaerophilic environment of 5% O_2, 10% CO_2, and 75% N_2, generated by CampyGen sachets (Oxoid). Again, populations were converted to log values with the 200 mL of carcass rinsate representing the sample, and results were reported as log colony-forming units per sample.

Shelf-Life and Quality Determination

Broilers were conventionally processed (n = 250 × 2 replications) at the Poultry Science Research Unit at Auburn University. Specifically, the broilers were hung on shackles and electrically stunned (50 V, 20 mA, 400 Hz) via 1% saline stunner bath (custom built, 1.52 m) with a metal plate running along the bottom attached to an electrical stun control box (model 901-1001IA, Georator Corp., Manassas, VA). After stunning, birds were killed by exsanguination through a unilateral neck cut followed by a 95-s bleed-out. After bleed-out, the birds were scalded in a 2.44-m-long single-pass steam-injected scalder (custom built, Cantrell, Gainesville, GA). The birds were defeathered in a 1.22-m-long disk-picker (custom built, Meyn, Oostzaan, the Netherlands), eviscerated (Meyn) and rinsed, and then broiler carcasses were randomly divided among the 5 chill water treatments. Chill water (static) treatments were stored at 4°C overnight, and the day of processing, the following treatments were added to each separate tank: 0.01% PAA, 0.015% PAA, 0.02% PAA, 0.003% chlorine, and water (control). Carcasses were allowed to chill at 4°C for 2 h. The birds were packaged in polystyrene foam tray packs with a soaker pad and polyvinyl chloride film overwrap and stored at 4°C. In each replication, 5 carcasses from each treatment were taken for microbial analysis of total aerobic plate count (**APC**) and psychrotroph (**PSY**) enumeration at 1, 7, 10, and 15 d. Briefly, carcasses were rinsed using the carcass rinse method described previously using 200 mL of buffered peptone water as the rinsate. To enumerate APC and PSY, serial dilutions of the rinsate were plated in duplicate on Standard Methods Agar (Acumedia) using the pour-plate method. The APC were incubated at 37°C for 24 h, and PSY were incubated at 4°C for 10 d. Serial dilutions were plated on petrifilm plates (3M Petrifilm, 3M Microbiology Products, St. Paul, MN) in duplicate to enumerate *E. coli* and coliforms, and plates were incubated at 37°C for 24 h to determine coliforms and at 48 h to determine *E. coli*.

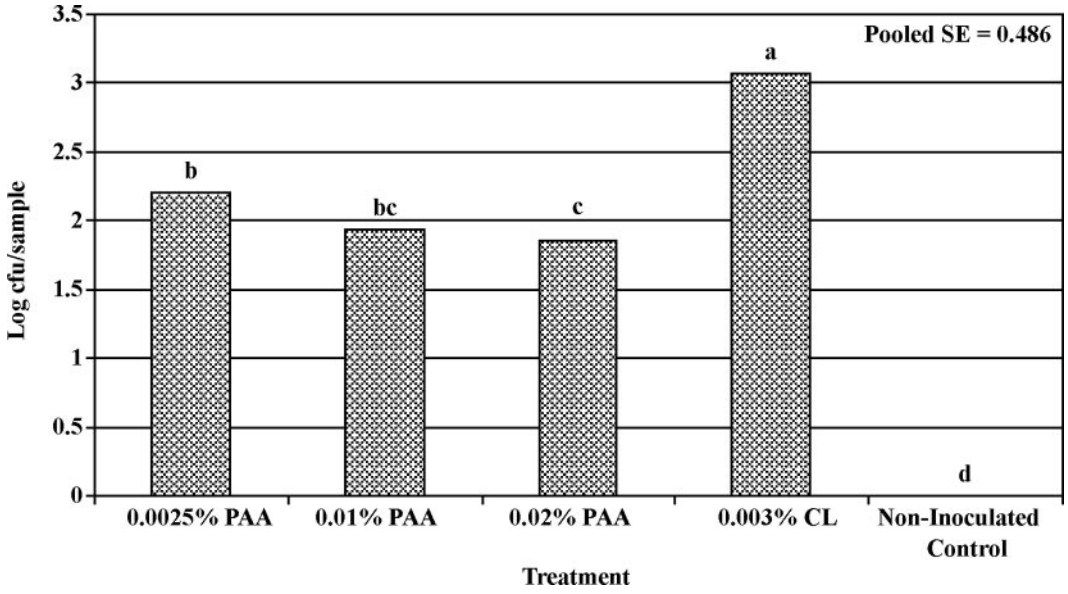

Figure 1. *Salmonella* Typhimurium recovered from inoculated carcasses (n = 100) treated with varying levels of peracetic acid (PAA; 0.0025%, 0.01%, 0.02%) and Cl (0.003%) reported as mean log colony-forming units of *Salmonella* Typhimurium per sample for each treatment group. [a–d]Means with no common letter differ significantly ($P \leq 0.05$).

At each storage period (1, 7, 15 d), 5 carcasses from each group were used for the sensory analysis and color evaluation. An average of 3 color measurements were recorded from each carcass using a Minolta Colorimeter (model DP-301, Minolta Corp., Ramsey, NJ) before they were deboned. Measurements were taken on the breast skin portion of the carcass avoiding feather follicles. Values were recorded using the Hunter L*a*b* color system in which greater L* values indicate a lighter-colored sample.

For the sensory analysis, breast fillets were deboned the morning of the sensory panels. Sensory evaluation was conducted in duplicate (1 panel in the morning and 1 panel in the evening) with untrained panelists in the Department of Poultry Science with 58, 57, and 52 panelists participating on d 1, 7, and 15, respectively. On each day of sensory testing, fillets were baked on covered aluminum trays in a convection oven (Viking Professional Series, VESC Series, Greenwood, MS) set at 177°C to an internal temperature of 76°C. The samples were held in a warm oven at 93°C (<1 h) until they were served to panelists. The cooked fillets were cut into 2- × 2-cm cubes and placed in plastic containers that were preassigned random 3-digit numbers. The panelists were served 1 sample at a time and asked to rate each sample using a modified 8-point hedonic scale. The hedonic scale included the attributes of appearance (like to dislike), texture (tender to tough), flavor (like to dislike), juiciness (moist to dry), and overall acceptability (like to dislike).

Statistical Analysis

Experiments were all performed in duplicate. All data (bacterial counts were converted to log colony-forming units per sample) were reported as least squares means. Data were analyzed using ANOVA in the GLM of SAS (SAS Institute, 2003). Because 0 cannot be directly analyzed with the statistical model, we used a value equivalent to 0.9. Significance was reported using a level of $P \leq 0.05$.

RESULTS AND DISCUSSION

The first objective of this research was to determine the most effective levels of PAA against *Salmonella* spp. and *Campylobacter* spp. *Salmonella* Typhimurium and *C. jejuni* were selected because they are commonly found on chicken carcasses. When the PAA was added to the poultry chill water, all PAA levels tested (0.0025%, 0.01%, 0.02%) decreased *Salmonella* Typhimurium compared with the carcasses treated with 0.003% chlorine (Figure 1). Although all levels of PAA decreased *Salmonella* Typhimurium on broiler carcasses, the 0.02% PAA treatment level was more effective than the 0.0025% PAA treatment level (Figure 1). The noninoculated control was negative, indicating there was no background *Salmonella* spp. on the carcasses before initiation of the study.

Although PAA was effective against *Salmonella* spp. at concentrations as low as 0.0025% PAA, greater levels were required to decrease *Campylobacter* spp. Specifically, PAA at 0.02% PAA resulted in a 1.5-log reduction against *Campylobacter* spp.; however, lower levels of PAA were not found to be different from the chlorine treatment in decreasing *Campylobacter* levels (Figure 2). Moreover, *Campylobacter* spp. was found on noninoculated control, indicating birds had background *Campylobacter*. *Campylobacter* is more com-

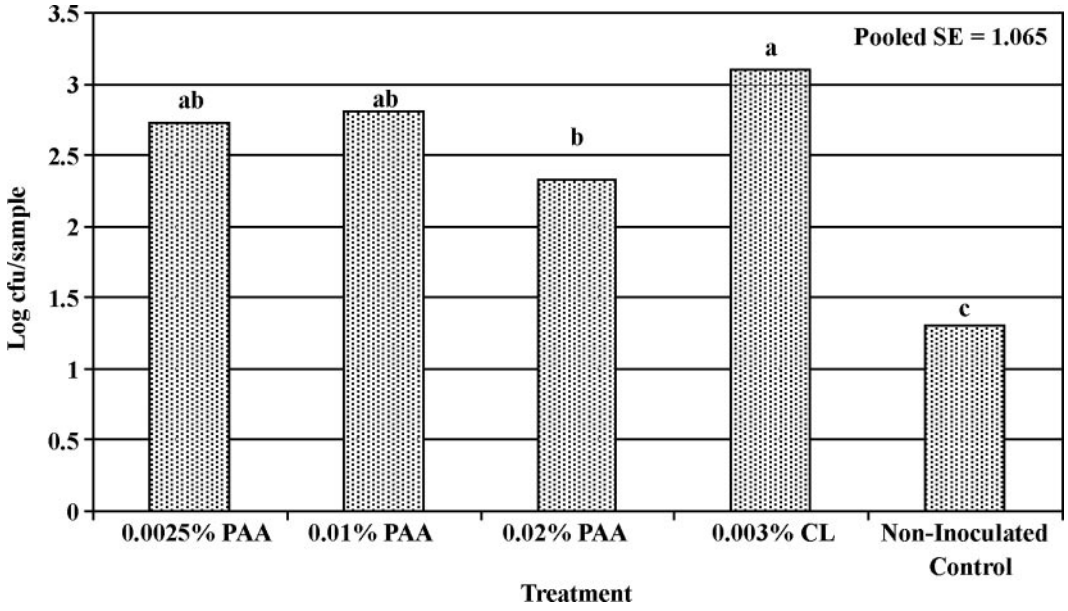

Figure 2. *Campylobacter jejuni* recovered from inoculated carcasses (n = 100) treated with varying levels of PAA (0.0025%, 0.01%, 0.02%) and Cl (0.003%) reported as mean log colony-forming units of *C. jejuni* per sample for each treatment group. [a–c]Means with no common letter differ significantly ($P \leq 0.05$).

monly found on poultry carcasses than *Salmonella*, and researchers have reported *Campylobacter* levels of approximately 4,000 cfu/carcass as typical (Oyarzabal, 2005). Another factor that could affect the efficacy of antimicrobials is the level of bacterial attachment to broiler skin. Organic acids at low concentrations have been found to be less effective when bacteria were attached to broiler skin (Tamblyn and Conner, 1997). However, when organic acids and hydrogen peroxide are combined, studies have shown greater antimicrobial efficacy (Brinez et al., 2006). In addition, Bell et al. (1997) reported that combinations of 1% acetic acid and 3% hydrogen peroxide gave a greater than 3-log reduction in *E. coli*, *Salmonella* Wentworth, and *L. innocua* when sprayed on beef carcasses that had been previously inoculated. These researchers found that this combination was more effective than each antimicrobial used individually.

Although chlorine can be effective against *Salmonella* and *Campylobacter*, it was found to be less effective than PAA in decreasing *Salmonella* and *Campylobacter* in the current study (Figures 1 and 2). Generally, chlorine is the industry standard for chiller applications and was used as the point of comparison for antimicrobial effectiveness. For the current study, chlorine may have been less effective due to the pH and presence of organic material in the chill water collected from the processing facility. Because chill water for the treatments in the current study was obtained from a commercial facility, it contained a certain level of organic load (BOD = 144.7 mg/L) and the pH was 6.0 compared with 4.5 when the PAA was added. It is important to note that high pH (>7) and high organic load are known to decrease the efficacy of chlorine as an antimicrobial (Lillard, 1979). Although the pH of the chill water treatment was not alkaline, it is likely that pH and the organic load were factors in the decreased effectiveness of the 0.003% chlorine treatment compared with the PAA treatments. In addition, treatments of 0.02% PAA were effective in decreasing both *Salmonella* and *Campylobacter* despite the presence of organic material (Figures 1 and 2).

Brinez et al. (2006) also reported that PAA and hydrogen peroxide were effective antimicrobials in the presence of organic material. Results from that study indicated that as little as a 0.1% concentration of the mixture with a 10-min contact time decreased *Staphylococcus* spp., *Listeria* spp., and *E. coli* greater than 5 log regardless of the organic matrix tested. Moreover, Bell et al. (1997) used spray washes containing acetic acid, sodium bicarbonate, or hydrogen peroxide, or all three ingredients, on beef carcasses. They reported that using organic acids, specifically acetic acid, in combination with hydrogen peroxide provided the greatest log reductions in the study. However, King et al. (2005) found that when peroxyacetic acid was applied as a spray to beef carcasses, there was not a significant reduction in *E. coli* O157:H7 and *Salmonella* Typhimurium. They suggested that some organisms may be more susceptible to peroxyacetic acid than others and the degree of the attachment of the organism to the surface of the product could affect the effectiveness of the peroxyacetic acid.

Many studies have demonstrated the effect of initial levels of microorganisms on products treated with organic acids and hydrogen peroxides (Lillard and Thomson, 1983; Dickens et al., 1994; Dickens and Whittemore, 1995, 1997; Tamblyn and Conner, 1997), but some studies have noted considerable quality changes in products when organic acids are used (Mulder et al.,

Table 1. Microbial analysis of broiler carcasses treated with various levels of peracetic acid (PAA) and Cl during storage[1]

Storage period	Treatment	*Escherichia coli* (log cfu/sample)	Coliforms (log cfu/sample)	Aerobic plate count (log cfu/sample)	Psychrotroph (log cfu/sample)
Day 1	0.01% PAA	3.17 ± 0.507^{c}	3.44 ± 0.408^{c}	4.23 ± 0.352^{ab}	1.57 ± 0.346^{bc}
	0.015% PAA	2.40 ± 0.815^{ab}	2.64 ± 0.798^{b}	3.37 ± 0.396^{ab}	0.26 ± 0.253^{a}
	0.02% PAA	1.86 ± 0.211^{a}	1.96 ± 0.243^{a}	2.85 ± 0.489^{a}	1.24 ± 0.883^{b}
	0.003% Cl	3.15 ± 0.385^{c}	3.54 ± 0.324^{c}	4.58 ± 0.389^{b}	2.14 ± 0.129^{bc}
	Control	2.97 ± 0.332^{bc}	3.10 ± 0.279^{bc}	4.24 ± 0.731^{ab}	2.37 ± 1.159^{c}
Day 7	0.01% PAA	3.14 ± 0.308^{a}	2.90 ± 0.328^{a}	4.30 ± 0.128^{a}	6.05 ± 0.367^{b}
	0.015% PAA	3.64 ± 0.958^{ab}	3.43 ± 1.048^{ab}	4.25 ± 0.579^{a}	3.77 ± 1.129^{a}
	0.02% PAA	3.08 ± 0.802^{a}	3.03 ± 0.802^{a}	3.66 ± 0.727^{a}	4.12 ± 1.297^{a}
	0.003% Cl	3.68 ± 0.612^{ab}	3.33 ± 0.621^{ab}	4.14 ± 0.543^{a}	6.50 ± 0.751^{b}
	Control	3.46 ± 0.664^{a}	3.21 ± 0.725^{ab}	4.24 ± 0.625^{a}	5.85 ± 1.034^{b}
Day 10	0.01% PAA	2.31 ± 0.370^{a}	2.56 ± 0.513^{a}	6.36 ± 0.742^{bc}	6.24 ± 2.959^{a}
	0.015% PAA	2.50 ± 1.262^{a}	2.75 ± 1.297^{a}	4.73 ± 0.483^{a}	5.37 ± 1.163^{a}
	0.02% PAA	2.05 ± 1.072^{a}	2.15 ± 1.100^{a}	4.88 ± 1.504^{a}	5.81 ± 0.568^{a}
	0.003% Cl	2.92 ± 0.927^{a}	2.87 ± 0.896^{ab}	6.54 ± 0.534^{c}	6.26 ± 2.970^{a}
	Control	2.89 ± 1.214^{a}	2.31 ± 1.577^{a}	6.26 ± 0.277^{bc}	7.09 ± 0.336^{b}
Day 15	0.01% PAA	ND[2]	1.91 ± 0.945^{a}	7.03 ± 0.545^{ab}	9.53 ± 0.622^{b}
	0.015% PAA	ND	2.13 ± 1.212^{a}	6.29 ± 1.313^{a}	8.68 ± 0.970^{ab}
	0.02% PAA	ND	2.56 ± 1.493^{ab}	5.89 ± 0.305^{a}	8.24 ± 1.041^{a}
	0.003% Cl	ND	2.78 ± 0.374^{ab}	6.85 ± 0.648^{ab}	8.83 ± 0.331^{ab}
	Control	ND	2.06 ± 0.692^{a}	6.88 ± 0.779^{ab}	9.32 ± 0.299^{b}

[a–c]Values with the same letter within each storage period and treatment are the same ($P \leq 0.05$).

[1]Mean ± SD; n = 200.

[2]Not detected.

1987; Izat et al., 1990; Dickens and Whittemore, 1995). Therefore, the other objective of this study was to validate the quality and shelf-life of carcasses treated with different levels of PAA to determine the optimal level for product safety while maintaining product quality.

On d 1 of the current study, the PAA treatments at 0.015% and 0.02% had lower *E. coli* and coliforms and total APC than the carcasses treated with 0.01% PAA, 0.003% chlorine, and water (Table 1). On d 1, PSY were lowest for the 0.015% PAA treatment, whereas the 0.02% PAA, 0.01% PAA, and 0.003% chlorine treatments were similar (Table 1). Although these treatments were similar, the 0.02% PAA treatment had lower PSY compared with the water control. These trends among bacterial populations and treatment effects suggest that as early as d 1, the greater levels of PAA (0.015% and 0.02%) resulted in modest bacteria reductions. By d 7, there were no differences noted in the *E. coli* or coliforms among any of the treatments tested (Table 1). However, differences among APC and PSY were evident at d 7. Specifically, aerobic bacteria populations were slightly greater for the 0.003% chlorine treatment when compared with all other treatments, whereas the 0.003% chlorine, water, and 0.01% PAA treatments had greater PSY levels when compared with the 0.015% and 0.02% PAA treatments. By d 10, no differences were detected in *E. coli,* coliforms, and PSY among treatments; however, aerobic populations were lower for the carcasses treated with 0.015% and 0.02% PAA. By d 15, *E. coli* was no longer detectable, and no differences existed in coliforms, aerobic, or psychotropic bacteria populations. The nondetectable *E. coli* results at d 15 could have been due to the competition of other bacterial populations; however, it is uncertain. It is also important to note that although differences in bacteria levels were not detected at d 15, the only treatments not exhibiting off-odors and colors indicative of product spoilage were the carcasses treated with 0.015% and 0.02% PAA. In general, it appeared that PAA at 0.015% and 0.02% had positive effects on reduction of bacterial populations early during the storage study; however, these effects were not sustained throughout the duration of the study. Moreover, organoleptic changes indicating product spoilage were not noted in 0.015% and 0.02% PAA, which may suggest that the microflora on these carcasses were different than microflora from other carcasses and treatments; however, this was not determined in the current study.

Peracetic acid may have variable effects depending on the bacteria type and attachment; King et al. (2005) found that peroxyacetic acid applied as a spray to beef carcasses did not decrease *E. coli* O157:H7 and *Salmonella* Typhimurium. They suggested that some organisms may be more susceptible to peroxyacetic acid than others, and the degree of the attachment of the organism to the product surface could affect the effectiveness of the peroxyacetic acid. Furthermore, results from the current study also suggest that PAA used in a chiller application was more effective against *Salmonella* than *Campylobacter* (Figures 1 and 2).

Because treatment with antimicrobials can affect the organoleptic properties of a product, it is important to determine quality of carcasses treated with antimicrobials. In the current study, the appearance, flavor, texture, juiciness, and overall acceptability of the product was evaluated up to d 15 of storage at 4°C. On d 1 (Table 2), there were no differences between 0.015% PAA, 0.02% PAA, 0.003% chlorine, and the control in any of the sensory attributes. The 0.01% PAA treat-

Table 2. Sensory analysis of breast fillets from carcasses treated with varying levels of peracetic acid (PAA) and Cl during storage[1]

Storage period	Treatment	Appearance[2]	Flavor[2]	Texture[3]	Juiciness[4]	Overall[2]
Day 1	0.01% PAA	3.00 ± 0.88[a]	3.36 ± 1.07[a]	3.21 ± 1.91[a]	2.91 ± 1.44[a]	3.16 ± 1.02[a]
	0.015% PAA	2.58 ± 0.82[c]	3.12 ± 1.28[abc]	2.86 ± 1.27[ab]	3.11 ± 1.37[a]	2.98 ± 1.08[ab]
	0.02% PAA	2.73 ± 0.88[abc]	3.29 ± 1.23[ab]	3.00 ± 1.25[ab]	3.14 ± 1.37[a]	3.09 ± 1.21[a]
	0.003% Cl	2.86 ± 0.82[ab]	2.95 ± 1.02[bc]	2.89 ± 1.18[ab]	2.79 ± 1.22[a]	2.89 ± 0.98[ab]
	Control	2.64 ± 0.72[bc]	2.77 ± 1.04[c]	2.70 ± 1.09[b]	2.66 ± 1.15[a]	2.63 ± 0.89[b]
Day 7	0.01% PAA	2.58 ± 0.94[a]	3.00 ± 1.25[a]	2.88 ± 1.13[a]	2.80 ± 1.32[a]	2.89 ± 1.19[a]
	0.015% PAA	2.89 ± 1.18[a]	3.12 ± 1.31[a]	2.82 ± 1.32[a]	3.09 ± 1.42[a]	3.04 ± 1.22[a]
	0.02% PAA	2.96 ± 1.19[a]	3.30 ± 1.34[a]	3.11 ± 1.23[a]	3.01 ± 1.42[a]	3.14 ± 1.22[a]
	0.003% Cl	2.67 ± 0.89[a]	3.09 ± 1.20[a]	2.93 ± 1.05[a]	2.64 ± 1.26[a]	2.96 ± 1.09[a]
	Control	2.82 ± 1.21[a]	3.07 ± 1.08[a]	2.86 ± 1.22[a]	3.01 ± 1.34[a]	2.95 ± 1.12[a]
Day 15	0.01% PAA	—[5]	—	—	—	—
	0.015% PAA	2.56 ± 0.92[a]	2.83 ± 1.13[a]	2.63 ± 1.16[a]	3.10 ± 1.33[a]	2.90 ± 1.05[a]
	0.02% PAA	2.63 ± 0.99[a]	3.23 ± 1.18[a]	2.94 ± 1.18[a]	3.06 ± 1.24[a]	2.92 ± 1.27[a]
	0.003% Cl	—	—	—	—	—
	Control	—	—	—	—	—

[a–c]Values with the same letter within each storage period are the same ($P \leq 0.05$).

[1]Mean ± SD; n = 167 (n = 58 for d 1, n = 57 for d 7, and n = 52 for d 15).

[2]Where 1 = like extremely; 8 = dislike extremely.

[3]Where 1 = extremely tender; 8 = extremely tough.

[4]Where 1 = extremely juicy; 8 = extremely dry.

[5]Data not collected.

ment ranked lower than the control in appearance, flavor, and texture evaluation by the panelists; however, they were not different from the chlorine control. By d 7, panelists were not able to determine any differences in any of the sensory attributes between treatments. At d 15, only 2 samples were evaluated by panelists and again they were unable to determine any differences between the samples. Similarly, Dickens et al. (1994) found no differences in sensory quality of breast fillets when exposed to a prechill treatment of 0.6% acetic acid (10 min) compared with a control. However, results from studies using hydrogen peroxide alone have indicated that carcasses may have a bleached appearance (Lillard and Thomson, 1983; Mulder et al., 1987; Izat et al., 1990). The levels of hydrogen peroxide used in the studies greatly exceeded (0.66% to 1.2%) the 0.012% allowed in the PAA mixture, and the greater levels of hydrogen peroxide are the likely cause of the negative quality characteristics. Similar to the current study, Bell et al. (1997) found that combining organic acids such as acetic acid with hydrogen peroxide increased the antimicrobial efficacy allowing lower levels (1% acetic/3% H_20_2) to be utilized in beef carcasses washes while maintaining product quality. In the current study, the PAA treatments did not exhibit any deleterious quality changes, and the 0.015% and 0.02% PAA treatments were the only samples that could be served to panelist on d 15. These results suggest that the greater levels of PAA may extend product shelf-life.

Table 3. Color of chicken skin on carcasses treated with various levels of peracetic acid (PAA) or Cl during storage[1]

Storage period	Treatment	L* value[2]	a* value[3]	b* value[4]
Day 1	0.01% PAA	73.79 ± 2.352[b]	1.94 ± 0.667[bc]	0.04 ± 1.820[ab]
	0.015% PAA	73.77 ± 2.017[b]	1.38 ± 0.857[ab]	−0.90 ± 1.482[a]
	0.02% PAA	76.17 ± 1.218[b]	0.51 ± 0.389[a]	−0.14 ± 1.758[ab]
	0.003% Cl	70.95 ± 2.295[a]	2.90 ± 0.772[c]	3.75 ± 2.967[c]
	Control	73.77 ± 1.470[b]	2.36 ± 1.510[bc]	2.43 ± 2.859[bc]
Day 7	0.01% PAA	73.32 ± 1.734[a]	0.01 ± 0.579[a]	−0.26 ± 1.353[a]
	0.015% PAA	72.94 ± 2.127[a]	0.17 ± 0.651[a]	−0.10 ± 2.042[a]
	0.02% PAA	75.54 ± 1.925[b]	−0.13 ± 0.393[a]	1.07 ± 1.904[a]
	0.003% Cl	71.97 ± 1.490[a]	0.55 ± 0.124[a]	0.17 ± 1.627[a]
	Control	71.38 ± 1.556[a]	0.42 ± 0.653[a]	−0.59 ± 1.649[a]
Day 15	0.01% PAA	73.19 ± 1.348[bc]	−0.29 ± 0.947[ab]	1.87 ± 0.978[bc]
	0.015% PAA	72.49 ± 2.058[ab]	−0.52 ± 0.350[ab]	−1.57 ± 3.130[a]
	0.02% PAA	75.00 ± 2.143[c]	−0.59 ± 0.737[a]	1.72 ± 2.379[bc]
	0.003% Cl	71.92 ± 1.307[ab]	−0.14 ± 0.678[ab]	2.41 ± 2.050[c]
	Control	70.44 ± 1.683[a]	0.37 ± 0.455[b]	−0.35 ± 1.381[ab]

[a–c]Values with the same letter within each storage period are the same ($P \leq 0.05$).

[1]Mean ± SD; n = 150.

[2]Where L* = 0 is black, L* = 100 is white.

[3]Where +a* is red, −a* is green.

[4]Where +b* is yellow, −b* is blue.

Throughout the storage study, the 0.02% PAA treatment was lighter in color than the chlorine control (Table 3). However, by d 7, there were no differences in the lightness (L*) values of the lower PAA levels, 0.01% and 0.015%, and the chlorine control. There are slight differences in the redness (a*) values and the yellowness (b*) values at d 1 and again at d 15; however, these differences are small and would be difficult for consumers to detect. Lillard and Thomson (1983) reported that when hydrogen peroxide was added to poultry chill water at 0.11% to 1.2%, the birds had a bloated and bleached appearance, but this disappeared after 19 h. Bilgili et al. (1998) reported that when breast skin samples were dipped in acetic acid at 0.5, 1.0, 2.0, 4.0, and 6.0%, a darkening and yellowing effect was present when comparing measurements taken pre- and posttreatment. The results of the current study suggest that although 0.02% PAA lightened carcasses, there were very few other notable changes in product color, and none of these changes would be considered negative in terms of product quality.

Results from this study indicate that PAA could be used in poultry chillers as an effective intervention strategy to decrease the incidence of *Salmonella* Typhimurium and *C. jejuni*. In addition, PAA may extend the shelf-life of products in the processing facility without compromising the organoleptic properties of the product. In commercial processing plants, PAA is usually added to poultry chill water through controlled pumping equipment. In the current study, it was observed that broilers treated with PAA were slightly lighter in color, but carcass quality was not negatively affected, and the difference in color disappeared over time. Therefore, PAA may be used as an effective intervention strategy in poultry chiller applications to decrease levels of *Salmonella* and *Campylobacter* while maintaining product quality attributes.

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