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

XI CHEN,1 LAURA J. BAUERMEISTER,1 GRETCHEN N. HILL,1 MANPREET SINGH,2 SACIT F. BILGILI,1 AND SHELLY R. KEE1*

1Department of Poultry Science, Auburn University, 201 Poultry Science Building, 260 Lem Morrison Drive, Auburn, Alabama 36849; and 2Department of Food Science, Purdue University, West Lafayette, Indiana 47907, USA

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ABSTRACT

Ground chicken is likely to have higher microbiological loads than whole carcasses and parts. Therefore, it is necessary to identify antimicrobials that reduce pathogens and overall microbial loads without negatively impacting meat quality. The objectives of this research were to evaluate the effect of various postchill antimicrobials on reducing Salmonella and Campylobacter, and determine the impact of these treatments on shelf life and quality attributes of ground chicken. Five treatments (0.003% chloride, 0.07 and 0.1% peracetic acid [PAA], and 0.35 and 0.6% cetylpyridinium chloride [CPC]) were evaluated. Samples (n = 120) of skin-on chicken breast and thigh meat were inoculated with Salmonella Typhimurium (10^8 CFU/ml) and C. jejuni (10^8 CFU/ml). Following a 30-min attachment time, parts were rinsed with either chloride, PAA, or CPC in a decontamination tank for 23 s. Parts then were ground, samples (25 g) were plated, and reduction of Salmonella Typhimurium and C. jejuni was determined. Noninoculated ground breast and thigh meat were used for sensory and shelf-life determination. Samples (n = 200) for shelf-life determination were collected on days 1, 4, 7, and 10 to estimate spoilage microflora of ground chicken stored at 4°C. Additionally, color measurement and sensory evaluation were conducted on days 1, 4, and 7. Ground chicken treated with 0.07 and 0.1% PAA had the greatest reductions (P ≤ 0.05) in Salmonella and Campylobacter providing approximately a 1.5-log reduction, followed by a 0.8-log reduction after treatment with 0.35 and 0.6% CPC. Chlorine (0.003%) was the least effective treatment (P ≥ 0.05), while treatments with 0.07 and 0.1% PAA also extended the shelf life of ground chicken for 3 days. None of the treatments had negative impact on color or sensory attributes of ground chicken patties during the storage (P ≤ 0.05). Results from this study indicated that using PAA as an antimicrobial agent in a postchill decontamination tank to treat ground poultry parts is effective for the reduction of Salmonella and Campylobacter while maintaining product quality.

Salmonella and Campylobacter are two major foodborne pathogens in the United States. In total, they are responsible for approximately 20% of domestic foodborne illnesses, 50% of hospitalizations due to foodborne illness, and 34% of relevant fatal cases (3). Contaminated raw or undercooked poultry and poultry product are considered to be the dominant vehicles of transmission for Salmonella and Campylobacter to humans (8). According to Batz et al. (8), every year over 20% of salmonellosis and 70% of campylobacteriosis cases in the United States were caused by poultry products.

Compared with other poultry products, ground poultry is more likely to be contaminated with Salmonella and Campylobacter as these pathogens potentially can contaminate batches of meat through processes, such as cutting and grinding. One of the most recent recalls related to ground poultry occurred in August 2011, in which 36 million pounds of ground turkey were recalled due to the contamination by a multidrug-resistant strain of Salmonella Heidelberg (2). In addition, 182 people were infected during this outbreak, with 1 death. Because of the potential health risk of consuming accidently undercooked ground poultry product, the U.S. Department of Agriculture, Food Safety and Inspection Service (USDA-FSIS) released new prevention-based regulations to improve the safety of ground poultry (4). Therefore, it is necessary for the poultry industry to reevaluate the current antimicrobial intervention strategies, and to apply new antimicrobial agents and/or technologies to meet the stricter regulations.

Postchill application of antimicrobials is one of the new strategies used in the poultry industry, which is applied immediately after the primary chiller (15). Compared with prechill and regular immersion chill, the application of antimicrobials in a postchill system has several benefits. Initially, water has less organic buildup than the chill tanks and antimicrobials can be added at higher levels because of the shorter contact times. Therefore, pathogens attached on

* Author for correspondence. Present address: USA Poultry and Egg Export Council, 2300 West Park Place Boulevard, Stone Mountain, GA 30087, USA. Tel: 770-413-0006; E-mail: smkeec@usapec.org.
chicken carcasses and parts, such as *Salmonella* and *Campylobacter*, can be reduced effectively at these steps. Moreover, as the contact time typically is shorter than the primary immersion chill step (less than 30 s versus 1.5 to 2 h), higher concentration of antimicrobials can be used without creating negative impacts on product quality. Finally, volumes of water necessary for postchill application are far less than those required for immersion chill applications, which makes postchill a cost-effective step to treat product with antimicrobials.

Currently, more than 10 different antimicrobials are approved for use in the poultry industry during postchill processing. Based on a survey conducted by McKee (14), the most prevalent chemical used in postchill applications in the industry was peracetic acid (PAA), while cetylpyridinium chloride (CPC) was the predominant postchill antimicrobial agent when drench cabinets were used. Chlorine was not among the major chemicals used during postchill steps based on several concerns. First, it was reported that the short contact time might limit the antimicrobial effects of chlorine (15). Second, Russia, the single largest export market for the domestic poultry meat (mainly dark meat), banned imports of chlorine-treated poultry meat from the United States (24). Finally, Tamblyn and Conner (22) found that chlorine levels must be at least 0.04% to kill the attached *Salmonella* on broilers, which is not allowed according to current regulations.

Although several published data indicate the antimicrobial effects of PAA and CPC on chicken carcasses (9, 23, 25), few articles demonstrate the efficiency of postchill antimicrobials on reducing pathogens from ground chicken and their impact on product quality and shelf life. Therefore, the objectives of this research were to evaluate the effect of various postchill antimicrobials (chlorine, PAA, and CPC) used in a postchill decontamination tank on reducing *Salmonella* and *Campylobacter*, and to determine the impact on shelf life and quality attributes of ground chicken.

**MATERIALS AND METHODS**

**Inoculum preparation.** One milliliter of the frozen *C. jejuni* (isolated from the Auburn University Poultry Research Unit, Auburn, AL) stock culture was added to 10 ml of Brucella-FBP broth (Acumedia Manufacturers, Inc., Baltimore, MD). The culture was incubated at 42 °C for 48 h in an Anaero-Jar (Oxoid, Ogdensburg, NY) containing a CampyGen sachet (Oxoid) which generates a microaerophilic mixture of 5% O2, 10% CO2, and 85% N2. The culture was streaked onto Campy-Cefex agar (Acumedia) and incubated at 42 °C for 48 h under similar conditions as described previously. Isolated *C. jejuni* colonies were picked from the Campy-Cefex plates and added to 10 ml of Brucella-FBP broth tubes before incubating at 42 °C for 48 h in microaerophilic conditions. One milliliter of solution was incubated further with 99 ml of fresh Brucella-FBP broth for 48 h in the same conditions. Cultures were centrifuged (Sorval Legent RT + Centrifuge, Thermo Scientific, Thermo Electron Corp., Osterode am Harz, Germany) at 8,000 × g for 10 min at 4 °C. The pellets were suspended in equivalent amounts of buffered peptone water (BPW; Acumedia) and recentrifuged followed by resuspension in BPW to obtain a stock culture of 10⁸ CFU/ml *C. jejuni*.

Ten milliliters of tryptic soy broth was inoculated with 10 μl of a frozen nalidixic acid–resistant (35 μl/ml) strain of *Salmonella Typhimurium* (isolated from the Auburn University Poultry Research Unit), and the culture was incubated at 37 °C for 24 h. The *Salmonella* culture was streaked onto xylose lysine Tergitol 4 agar (Acumedia) containing 35 μl/ml of nalidixic acid. After incubating at 37 °C for 24 h, isolated black colonies were picked from the xylose lysine Tergitol 4 agar plates and were added to 10 ml of tryptic soy broth tubes with 1 colony per tube. The tubes were incubated at 37 °C for 24 h. One milliliter of *Salmonella* culture was added to 99 ml of tryptic soy broth in a conical flask and incubated at 37 °C for 12 h. Cultures were centrifuged and resuspended twice following the procedures described previously. A stock culture of 10⁸ CFU/ml *Salmonella Typhimurium* was prepared and mixed with 10⁶ CFU/ml *C. jejuni* before inoculating samples.

**Pilot plant study.** A total of 145.15 kg of boneless chicken breast and thigh with skin was used for the experiment (9.07 kg per treatment × 2 replications × 8 treatments). During each replication, sufficient bone-in chicken breast and thigh meat with skin were obtained 24 h before the research and stored at 4 °C at the Auburn University Poultry Science Research Unit. Chicken parts were deboned and put in sterile rinse bags with 0.91 kg of breast and 0.91 kg of thigh per bag. Bags with parts were continually stored at 4 °C for 16 h.

We inoculated 35 bags of parts per replication (five bags per treatment) with 1 ml of *Salmonella Typhimurium* (10⁶ CFU/ml) and *C. jejuni* (10⁹ CFU/ml) suspensions to target approximately a 10³ CFU/ml and to kill the attached *Salmonella* on broilers, which is not allowed according to current regulations. Inoculated parts were set aside for a 30-min attachment period before being rinsed in the decontamination tank (Continuous Online Pathogen Elimination unit, Morris & Associates, Inc., Garner, NC). The chill water treatments included 0.003% chlorine (Clorox; Clorox Company, Oakland, CA), 0.07% PAA, 0.1% PAA (Spectrum; FMC, Philadelphia, PA), 0.35% CPC, 0.6% CPC (SFC, North Little Rock, AR), and a water treatment. Chilled potable water (4 °C) was used to bring treatments to the proper concentration. Positive and negative controls also were included. Positive, or nondipped inoculated, parts were used to determine the recovery of *Salmonella* and *Campylobacter* on ground chicken. Negative, or noninoculated, parts were used to determine the prevalence of any background *Salmonella* or *Campylobacter*. Concentration of chlorine was measured using Aquacheck Water Quality Test Strips (Hach Company, Loveland, CO). The concentrations of PAA and CPC were determined using titration drop test kits (FMC; Safe Foods Corporation, North Little Rock, AR). The pH of treatments was recorded by a pH meter (HACH Company, Loveland, CO). The average pH was 3.40 ± 0.2 and 3.32 ± 0.2, respectively, for the 0.07 and 0.1% PAA treatments, and 7.10 ± 0.2 and 6.96 ± 0.2, respectively, for the 0.35 and 0.6% CPC treatments. The average pH of the chlorine treatments was adjusted to 5.62 by 1 N HCl, allowing for the development of hypochlorous acid (17). The temperature of all the treatments ranged from 10 to 15 °C.

Chicken parts were rinsed using a Continuous Online Pathogen Elimination tank (Morris and Associates) filled to capacity (49.21 liters) for approximately 23 s. After treatment of parts (1.81 kg at a time), the parts were collected and placed into sterile rinse bags. However, the CPC treatments were sprayed (using a manual spray bottle for approximately 3 s) with sterile water after dipping in the tank, simulating requirement of the regulations for using CPC in poultry processing by the USDA (5). When finishing the antimicrobial treatments, each batch of 1.81 kg
of parts was ground once (within 30 min of treatment), using separate mini-grinders (Megaforce 3000, STX, Lincoln, NE) for each treatment and was collected aseptically in a sterile rinse bag (3M, St. Paul, MN). Samples were kept on ice and stored in coolers for 1 h before transporting to the laboratory at Auburn University Department of Poultry Science for analysis. In addition, cleaning and sanitation procedures were conducted between each treatment. Specifically, the remaining chicken tissue and antimicrobial agents first were rinsed off the decontamination tank using potable water. Then, chlorinated foam cleaner (Soft Jam Co., Alta Loma, CA) was applied on the decontamination tank, followed by scrubbing and rinsing. The next step was to apply BioQuat 20 disinfectant sanitizer (HACCO, Inc., Randolph, WI) to the tank. After sitting for 20 min, the tank was again rinsed with water.

Ground chicken sampling, and enumeration of Salmonella and Campylobacter. Raw meat and poultry product sampling methods described in the USDA-FSIS Microbiological Laboratory Guidebook were used for sampling and enumeration with several modifications (6). Once the samples arrived at the laboratory, fresh ground meat was mixed thoroughly by hand. Four 25-g samples were weighed from each 1.81-kg batch and placed into sterile filtered Whirl-Pak bags (69 oz/2,041 ml; Nasco, Fort Atkinson, WI) containing 50 ml of BPW. Individual bags were stomached for 1 min using a laboratory blender (400 Circularizer, Seward Ltd., Wessex, England) to homogenize samples. Based on preliminary tests, reducing the BPW volume from 225 to 50 ml did not (P > 0.05) negatively affect the recovery of Salmonella or Campylobacter. In fact, 50 ml of the BPW had the better recovery than 100 or 225 ml.

Direct-plating methods were used for enumerating inoculated samples. The ground meat was diluted by BPW (1:10) to make serial dilutions. Then, samples were added to selective media in duplicate. For Salmonella, 0.1 ml of the sample from the proper dilution was added onto the xylose lysine Tergitol 4 agar media containing nalidixic acid (35 μl/ml) and spread evenly using a sterile plastic disposable spreader before it was dried. Following this, the plates were inverted and incubated at 37°C for 24 h. Bacterial populations were converted and reported as log CFU per gram of ground meat.

Plating methods for Campylobacter were similar to those for Salmonella, while Campy-Cefex agar was used for enumerating Campylobacter (21). Then, plates were inverted and incubated at 42°C in AnaeroPack rectangular jars (Mitsubishi Gas Chemical America, Tokyo) in a microaerophilic environment as described previously for 48 h. Results also were converted to log values and reported as log CFU per gram of ground meat.

Shelf-life and quality determination. A total of 90.72 kg of ground chicken meat (2.27 kg per treatment × 2 replications × 5 treatments × 4 days) was prepared at the Auburn University Poultry Science Research Unit. Specifically, boneless chicken breast and thigh meat were transported from a local supplier (1 day after processing) and stored at 4°C at the Auburn University Poultry Science Research Unit before use. On day 0, chicken parts were divided randomly among the five postchill antimicrobial treatments (0.003% chlorine, 0.07% PAA, 0.1% PAA, 0.35% CPC, and 0.6% CPC). Parts were dipped for approximately 23 s and ground twice through a grinder (Mini-32, Biro Manufacturing Marblehead, OH). Following grinding, the ground meat was stuffed into E-Z Pak Poly bags (Manchester Packaging, Saint James, MO) using a piston stuffer (SC-50 Hydraulic, Koch Equipment, Kansas City, MO) with 0.45 kg of meat per bag. Then, bags were clipped using a poly-clipper (Poly-clip System LLC, Mundelein, IL) and distributed in a walk-in refrigerator (Therm-Kool, Mid-South Industries, Inc., MS) at Auburn University Department of Poultry Science and maintained at 4°C for the duration of the storage study.

Aerobic plate counts (APC) and psychrotrophs (PSY) were analyzed to determine the level of spoilage in the ground meat. Specifically, tests were conducted in duplicate on days 1, 4, 7, and 10. At each storage period, 10 bags from each treatment (5 bags in the morning and 5 in the afternoon) were selected randomly for analysis. Samples (four 25-g samples of ground meat per bag) were collected aseptically in a sterile Whirl-Pak bag (69 oz/2,041 ml; Nasco). Samples were homogenized; 25 g of ground meat with 50 ml of BPW and serial dilutions were made following the procedures described previously. Then, 100 μl of the appropriate dilution was added to Standard Methods Agar (Acumedia) using the spread-plating method to enumerate APC and PSY. The APC plates were incubated at 37°C for 24 h and PSY were incubated at 4°C for 10 days.

Quality determination, which included color measurement and sensory evaluation, was conducted in duplicate at days 1, 4, and 7. Patties (40 g) were made for each treatment. The color value of each patty was recorded using a Minolta Colorimeter (DP-301, Minolta Corp., Ramsey, NJ) before cooking. Results were converted to numerical values using the Hunter L*, a*, and b* color coordinate system in which L* = lightness, redness, and yellowness, respectively.

All sensory tests were approved by Auburn University Institutional Review Board (IRB). Sensory evaluations were conducted in duplicate (one panel in the morning and one in the afternoon) with untrained panelists (30 in the morning and 30 in the afternoon) in the Auburn University Department of Poultry Science. After color measurement, all chicken patties were cooked to an internal temperature of 74°C in muffin top trays in a convection oven (Viking Professional Series, VESC Series, Greenwood, MS) set at 177°C. Cooked patties were cut into bite-sized pieces and placed into coded sampling cups with lids (Solo Cup Company, Highland Park, IL). Samples were stored in a warmer at 93°C for less than 1 h until they were served to panelists. Samples were served one at a time and panelists were asked to evaluate chicken patties based on a modified 8-point hedonic scale. Attributes in the hedonic scale included appearance (like extremely to dislike extremely), odor (like extremely to dislike extremely), flavor (like extremely to dislike extremely), juiciness (extremely moist to extremely dry), and overall acceptability (like extremely to dislike extremely).

Statistical analysis. Two replications were conducted for the experiment with 35 bags of parts per replication (9.07 kg per treatment × 2 replications × 8 treatments). Counts of Salmonella, Campylobacter, APC, and PSY were converted to log CFU per gram of sample. All the counts of 0 were replaced by 0.1 log CFU for statistical analysis. Data were reported as means with standard deviations (SD) and analyzed with ANOVA in the GLM of SAS 9.1 (SAS Institute, Cary, NC). Differences were considered significant at P ≤ 0.05.

RESULTS AND DISCUSSION

Antimicrobial effects of various treatments on Salmonella and Campylobacter. The reduction values of Salmonella Typhimurium and C. jejuni on ground chicken that were treated with various antimicrobials (0.003% chlorine, 0.07% PAA, 0.1% PAA, 0.35% CPC, and 0.6% CPC) were evaluated (Figs. 1 and 2). The PAA and CPC treatments significantly (P ≤ 0.05) decreased Salmonella
and Campylobacter on ground chicken compared with the positive control, water control, and chlorine treatments. Specifically, 0.07 and 0.1% PAA had the greatest reductions on *Salmonella* and *Campylobacter*, which were approximately 1.5- and 1.3-log reductions, respectively. Both CPC treatments (0.35 and 0.6%) also achieved an approximate 0.8-log reduction on *Salmonella* and *Campylobacter*. Treatment with chlorine (0.003%) was no different than treatment with water and was the least effective. Specifically, the chlorine treatment resulted in levels of *Salmonella* and *Campylobacter* that were only slightly lower than levels of positive control. There was no difference in the reduction of *Salmonella* and *Campylobacter* (P > 0.05) between the two different concentrations of PAA and CPC. Likewise, no significant differences (P > 0.05) have been reported on the reduction of *Salmonella* and *Campylobacter* when chicken carcasses were treated in a postchill immersion tank with different levels of PAA (0.04 and 0.1%) (17). Nalidixic acid-resistant *Salmonella* populations were below the detection limit of 15 CFU/g and were not recovered from the negative control. However, *Campylobacter* spp. were on the negative control, indicating some chicken parts were contaminated with *Campylobacter* before initiation of the study. *Campylobacter*-positive chicken is not uncommon in the United States, as researchers have reported that *Campylobacter* was recovered from over 70% of retail chicken meat in several states (11, 27).

Although chlorine has been applied widely in the poultry industry, it was less effective in reducing *Salmonella* and *Campylobacter* from ground chicken in the current study. This may be caused by the high organic load in the chill water, which can drastically reduce the antimicrobial effectiveness of chlorine (9). On the other hand, many studies demonstrated the efficacy of PAA and CPC on removing pathogens from poultry and meat product. As the most prevalent chemical used in postchill applications in the poultry industry (14), in PAA, like other oxidizing agents, the mechanism of action is denaturing proteins, disrupting cell wall permeability, and oxidizing sulfur bonds in proteins and other metabolites (10, 16). Rio et al. (19) reported that, through dipping inoculated chicken legs into a treatment of 0.022% PAA for 15 min, a significant reduction of various microflora, including *Enterobacteriaceae*, *Micrococcaceae*, enterococci, *Brochothrix thermosphacta*, pseudomonads, lactic acid bacteria, molds, and yeasts, was achieved. In another study, Ellebracht et al. (12) reported a reduction of *Salmonella* Typhimurium by 1.0 log CFU/cm² when beef trimmings (100 cm² by 3 cm) were dipped into 0.02% PAA treatments for 15 s. Meanwhile, the antimicrobial mechanism of CPC was discussed by many researchers, who reported that CPC can damage the cell membrane and cause leakage of cellular materials while strongly interacting with negatively charged surfaces of microorganisms (13, 20). Yang et al. (26) reported a reduction of *Salmonella* by 2 log CFU per carcass when chicken carcasses were sprayed with CPC (0.5%) at 35°C at a pressure of 413 kPa for 17 s.

**Microbiological quality of ground chicken after various treatments.** Noninoculated ground chicken samples treated with 0.003% chlorine, 0.07% PAA, 0.1% PAA, 0.35% CPC, and 0.6% CPC were analyzed on days 1, 4, 7, and 10 for growth of total APC and PSY (Table 1). The initial recovery of APC and PSY on day 1 was significantly lower (P ≤ 0.05) in PAA treatments compared with other treatments. Moreover, APC and PSY in PAA treatments maintained lower growth levels than the other treatments through day 7 of storage. The APC and PSY counts increased at a lower rate between sampling days in PAA treatments compared with the CPC and chlorine treatments during the same storage period. By day 10, APCs were still the lowest for 0.07 and 0.1% PAA, whereas all treatments were similar for PSY. The fact that PAA treatments extended shelf life was further supported by organoleptic observation using sensory analysis. By day 7, the only two treatments not exhibiting off-odors were 0.07 and 0.1% PAA.

On the other hand, 0.35 and 0.6% CPC had slightly lower APC levels than 0.003% chlorine at day 1, while no differences (P > 0.05) were detected in the following sampling days. In terms of PSY levels, CPC treatments also were significantly lower (P ≤ 0.05) than chlorine on days 1 and 10. Both 0.003% chlorine and CPC (0.35 and 0.6%) had reached spoilage levels by day 7, so they were no longer served for sensory analysis. Greater shelf-life extensions of

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**FIGURE 1.** Effects of various antimicrobial treatments against *Salmonella* Typhimurium. (a through e) Means with no common letter differ significantly (P ≤ 0.05).

**FIGURE 2.** Effects of various antimicrobial treatments against C. jejuni. (a through e) Means with no common letter differ significantly (P ≤ 0.05).
On days 1 through 4, PAA treatments were lighter in color than CPC treatments or chlorine control, but by day 7 the 0.35% CPC had the lightest color, followed by PAA, 0.6% CPC, and chlorine control. In terms of the redness values, CPC and chlorine were significantly higher than PAA on days 1 and 7, while only 0.35% CPC had a higher $a^*$ value ($P > 0.05$) than others on day 4. Yellowness, or $b^*$ value, did not show any particular trends throughout the storage study. Only chlorine on day 4 and 0.1% PAA on day 7 were significantly lower than other treatments. The lighter color occurring in meat treated with PAA was also

### TABLE 2. Color of chicken patties during storage treated with various antimicrobials$^a$

<table>
<thead>
<tr>
<th>Storage period</th>
<th>Treatment</th>
<th>L* value$^b$</th>
<th>a* value$^c$</th>
<th>b* value$^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>0.003% chlorine</td>
<td>66.87 ± 2.01 G</td>
<td>5.78 ± 1.43 EF</td>
<td>10.73 ± 2.67 E</td>
</tr>
<tr>
<td></td>
<td>0.07% PAA</td>
<td>69.44 ± 2.18 E</td>
<td>5.72 ± 2.36 EF</td>
<td>10.76 ± 1.89 E</td>
</tr>
<tr>
<td></td>
<td>0.1% PAA</td>
<td>69.42 ± 1.13 E</td>
<td>5.58 ± 1.31 F</td>
<td>11.57 ± 1.31 E</td>
</tr>
<tr>
<td></td>
<td>0.35% CPC</td>
<td>69.25 ± 1.13 EF</td>
<td>6.38 ± 1.32 E</td>
<td>11.60 ± 1.55 E</td>
</tr>
<tr>
<td></td>
<td>0.6% CPC</td>
<td>67.38 ± 2.91 FG</td>
<td>6.41 ± 1.29 F</td>
<td>10.80 ± 1.19 E</td>
</tr>
<tr>
<td>Day 4</td>
<td>0.003% chlorine</td>
<td>63.18 ± 0.93 F</td>
<td>7.58 ± 0.77 F</td>
<td>10.78 ± 1.57 F</td>
</tr>
<tr>
<td></td>
<td>0.07% PAA</td>
<td>65.12 ± 0.92 E</td>
<td>7.57 ± 0.88 F</td>
<td>11.81 ± 0.91 E</td>
</tr>
<tr>
<td></td>
<td>0.1% PAA</td>
<td>65.39 ± 0.82 E</td>
<td>7.21 ± 1.03 F</td>
<td>12.15 ± 1.10 E</td>
</tr>
<tr>
<td></td>
<td>0.35% CPC</td>
<td>64.02 ± 0.73 EF</td>
<td>8.37 ± 0.81 E</td>
<td>11.93 ± 0.75 E</td>
</tr>
<tr>
<td></td>
<td>0.6% CPC</td>
<td>64.24 ± 0.67 EF</td>
<td>7.34 ± 0.78 F</td>
<td>11.40 ± 0.89 EF</td>
</tr>
<tr>
<td>Day 7</td>
<td>0.003% chlorine</td>
<td>69.37 ± 0.99 G</td>
<td>7.09 ± 1.05 E</td>
<td>11.13 ± 1.42 EF</td>
</tr>
<tr>
<td></td>
<td>0.07% PAA</td>
<td>70.36 ± 0.94 FG</td>
<td>6.11 ± 1.32 F</td>
<td>10.83 ± 0.69 EF</td>
</tr>
<tr>
<td></td>
<td>0.1% PAA</td>
<td>71.39 ± 0.82 F</td>
<td>5.86 ± 0.59 F</td>
<td>10.71 ± 1.29 F</td>
</tr>
<tr>
<td></td>
<td>0.35% CPC</td>
<td>72.17 ± 0.98 E</td>
<td>6.49 ± 0.93 F</td>
<td>11.74 ± 0.99 E</td>
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<tr>
<td></td>
<td>0.6% CPC</td>
<td>69.73 ± 1.13 G</td>
<td>7.13 ± 0.59 F</td>
<td>11.29 ± 1.36 EF</td>
</tr>
</tbody>
</table>

$^a$ Mean ± SD, $n = 10$. Values with the same letter within each storage period and column are the same ($P \leq 0.05$).

$^b$ Where $L*$ = 0 is black, $L*$ = 100 is white.

$^c$ Where $+a^*$ is red, $-a^*$ is green.

$^d$ Where $+b^*$ is yellow, $-b^*$ is blue.
TABLE 3. Sensory analysis of ground chicken during storage treated with various antimicrobials

<table>
<thead>
<tr>
<th>Storage period</th>
<th>Treatment</th>
<th>Odor(^a)</th>
<th>Appearance(^b)</th>
<th>Flavor(^c)</th>
<th>Texture(^d)</th>
<th>Juiciness(^e)</th>
<th>Overall(^e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>0.003% chlorine</td>
<td>5.59 ± 1.19</td>
<td>5.44 ± 1.39</td>
<td>5.61 ± 1.25</td>
<td>6.37 ± 1.14</td>
<td>5.85 ± 1.46</td>
<td>5.73 ± 1.20</td>
</tr>
<tr>
<td></td>
<td>0.07% PAA</td>
<td>5.39 ± 1.39</td>
<td>5.20 ± 1.51</td>
<td>5.53 ± 1.27</td>
<td>6.36 ± 1.17</td>
<td>6.02 ± 1.37</td>
<td>5.53 ± 1.45</td>
</tr>
<tr>
<td></td>
<td>0.1% PAA</td>
<td>5.20 ± 1.24</td>
<td>5.25 ± 1.37</td>
<td>5.36 ± 1.18</td>
<td>6.14 ± 1.24</td>
<td>5.66 ± 1.36</td>
<td>5.51 ± 1.10</td>
</tr>
<tr>
<td></td>
<td>0.35% CPC</td>
<td>5.61 ± 1.23</td>
<td>5.49 ± 1.37</td>
<td>5.70 ± 1.30</td>
<td>6.22 ± 1.10</td>
<td>5.42 ± 1.33</td>
<td>5.73 ± 1.14</td>
</tr>
<tr>
<td></td>
<td>0.6% CPC</td>
<td>5.53 ± 1.29</td>
<td>5.39 ± 1.34</td>
<td>5.59 ± 1.24</td>
<td>6.19 ± 1.15</td>
<td>5.76 ± 1.34</td>
<td>5.63 ± 1.23</td>
</tr>
<tr>
<td>Day 4</td>
<td>0.003% chlorine</td>
<td>5.55 ± 1.40</td>
<td>5.29 ± 1.50</td>
<td>5.68 ± 1.02</td>
<td>5.62 ± 1.27</td>
<td>5.41 ± 1.42</td>
<td>5.43 ± 1.22</td>
</tr>
<tr>
<td></td>
<td>0.07% PAA</td>
<td>5.52 ± 1.20</td>
<td>5.54 ± 1.39</td>
<td>5.57 ± 1.37</td>
<td>5.57 ± 1.46</td>
<td>5.29 ± 1.67</td>
<td>5.63 ± 1.38</td>
</tr>
<tr>
<td></td>
<td>0.1% PAA</td>
<td>5.43 ± 1.22</td>
<td>5.25 ± 1.47</td>
<td>5.07 ± 1.35</td>
<td>5.46 ± 1.23</td>
<td>5.21 ± 1.35</td>
<td>5.07 ± 1.20</td>
</tr>
<tr>
<td></td>
<td>0.35% CPC</td>
<td>5.78 ± 1.19</td>
<td>5.86 ± 1.10</td>
<td>5.77 ± 1.20</td>
<td>5.74 ± 1.21</td>
<td>5.35 ± 1.43</td>
<td>5.59 ± 1.27</td>
</tr>
<tr>
<td></td>
<td>0.6% CPC</td>
<td>5.86 ± 1.03</td>
<td>5.52 ± 1.35</td>
<td>5.47 ± 1.38</td>
<td>6.02 ± 1.36</td>
<td>5.57 ± 1.51</td>
<td>5.67 ± 1.22</td>
</tr>
<tr>
<td>Day 7</td>
<td>0.003% chlorine</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>0.07% PAA</td>
<td>5.19 ± 1.20</td>
<td>5.11 ± 1.22</td>
<td>5.09 ± 1.29</td>
<td>5.44 ± 1.30</td>
<td>4.98 ± 1.28</td>
<td>5.04 ± 1.32</td>
</tr>
<tr>
<td></td>
<td>0.1% PAA</td>
<td>5.18 ± 1.36</td>
<td>5.23 ± 1.27</td>
<td>4.97 ± 1.59</td>
<td>5.40 ± 1.41</td>
<td>5.12 ± 1.43</td>
<td>4.97 ± 1.50</td>
</tr>
<tr>
<td></td>
<td>0.35% CPC</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>0.6% CPC</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

\(^a\) Mean ± SD; \(n = 174\) (\(n = 59\) for day 1, \(n = 58\) for day 4, and \(n = 57\) for day 7). Values with the same letter within each storage period and column are the same (\(P \leq 0.05\)).

\(^b\) Where 1 = dislike extremely; 8 = like extremely.

\(^c\) Where 1 = extremely tough; 8 = extremely tender.

\(^d\) Where 1 = extremely dry; 8 = extremely moist.

\(^e\) —, data not collected.

reported by other researchers. Bauermeister et al. (9) reported that chicken carcasses chilled by various concentrations of PAA (0.01, 0.015, and 0.02%) at 4°C for 2 h had higher \(L^*\) and lower \(a^*\) values than those treated by 0.003% chlorine. The lighter color of meat probably was caused by the bleaching effect of PAA, which is an oxidizing agent. In addition, the pH change of meat also can lead to the lighter color (1). The PAA treatments can decrease the pH of meat close to the isoelectric point of the myofibrillar proteins, which cause the loss of water from meat. As less moisture in the meat results in more light to be reflected, the meat of lower pH will be lighter in color. In terms of the studies on CPC, Pohlman et al. (18) found that 0.5% CPC increased the redness \(a^*\) of ground beef stored at 4°C, which may due to its effect on improving oxymyoglobin stability.

**Organoleptic evaluation of ground chicken.** Non-inoculated chicken patties treated with 0.003% chlorine, 0.07% PAA, 0.1% PAA, 0.35% CPC, and 0.6% CPC stored at 4°C were evaluated up to day 7 for their organoleptic acceptance. The products were evaluated by untrained panelists for the sensory attributes of odor, appearance, flavor, texture, juiciness, and overall acceptability. On day 1 (Table 3), panelists failed to determine any differences in sensory attributes between treatments, except for the juiciness between 0.07% PAA and 0.35% CPC \((P \leq 0.05)\). The rankings in odor, appearance, flavor, and overall acceptance of PAA treatments (0.07 and 0.1%) were slightly lower than those for CPC and chlorine, while those differences cannot be considered as significant \((P > 0.05)\). By day 4, panelists can determine only the difference \((P \leq 0.05)\) in appearance between chlorine, 0.1% PAA, and 0.35% CPC, while 0.07 and 0.1% PAA still had the lowest ranking in odor, texture, and juiciness among all the treatments. On day 7, only two PAA treatments were still served to panelists and there was no difference between them. All the sensory scores of 0.07 and 0.1% PAA decreased by day 7, which may be because those samples were nearing spoilage. Similar results also were reported in other studies. Bai et al. (7) reported that sprayed CPC treatments with 0.5, 1.0, and 1.5% did not result in any observable differences in odor or color on boneless, skinless broiler thigh meat during a 10-day shelf-life study. In another study, no difference was found in sensory quality of chicken broilers when chilled in various levels of PAA (0.1, 0.015, and 0.02%), chlorine (0.003%), and control for 2 h and stored at 4°C in 2 weeks (9).

Based on the results from this study, it can be concluded that PAA and CPC can be applied in a parts decontamination tank to control the recovery of *Salmonella Typhimurium* and *C. jejuni* on ground chicken meat. Furthermore, PAA can be used effectively to extend the shelf life of ground chicken through inhibiting the growth of APC and PSY at 4°C. Although raw ground meat treated with PAA was slightly lighter in color, a negative impact on sensory attributes of cooked chicken patties was not detected \((P \leq 0.05)\). Therefore, treatment of chicken parts before grinding with PAA or CPC not only may improve ground chicken safety, but maintain or enhance patty shelf life and quality.

**REFERENCES**

