MICROBIOLOGY AND FOOD SAFETY

Antimicrobial interventions to reduce *Salmonella* and *Campylobacter* populations and improve shelf life of quail carcasses

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ABSTRACT Quail (*Coturnix japonica*) is processed and marketed as fresh meat, with limited shelf life. The objective of this study was to evaluate the efficacy of antimicrobial interventions during slaughter on reducing *Salmonella* and *Campylobacter* contamination and to determine the microbiological shelf life of quail during refrigerated (4°C) storage. Three antimicrobials, peracetic acid (400 ppm; **PAA**), Citrilow (pH 1.2), and Cecure (cetylpyridinium chloride [**CPC**], 450 ppm), along with a water and no-treatment control were evaluated. Quail carcasses (n = 75) were inoculated with a cocktail of nalidixic acid–resistant *Salmonella* Typhimurium and gentamicin-resistant *Campylobacter coli*. After 30 min of attachment time, quail carcasses were submerged in each antimicrobial solution for 20 s with air agitation. Non-inoculated quail carcasses (n = 25) were similarly treated, packaged, and stored under refrigeration (4°C). Aerobic plate counts (**APC**), psychrotroph counts (**PC**), Enterobacteriaceae counts (**ENT**), total coliform counts (**TCC**), and *Escherichia coli* counts on quail carcasses were determined on 1, 4, 7, and 10 d. *Salmonella* and *Campylobacter* populations were determined by plating on Petrifilm APC supplemented with 200-ppm nalidixic acid and Campy Cefex agar supplemented with 200-ppm gentamycin, respectively. No significant reductions in ($P > 0.01$ log cfu/mL) in APC, PC, ENT, TCC, and *E. coli* counts were observed on carcasses submerged in water. However, treatments with PAA, Citrilow, and CPC significantly reduced ($P \leq 0.05$) *Salmonella* and *Campylobacter coli* contamination. Citrilow showed greater ($P \leq 0.05$) reduction in *Salmonella* and *Campylobacter* population (1.90 and 3.82 log cfu/mL reduction, respectively) to PAA and CPC. Greater ($P \leq 0.05$) reductions in APC, PC, ENT, TCC, and *E. coli* counts (2.22, 1.26, 1.47, 1.52, and 1.59 log cfu/mL, respectively) were obtained with the application of CPC. Application of antimicrobial interventions resulted in a reduction in *Campylobacter* and *Salmonella*, APC, PC, and ENT populations after treatments (day 0) and throughout the storage period (day 10). Use of antimicrobial interventions after slaughter can improve the microbiological safety and shelf life of quail.

Key words: *Salmonella*, *Campylobacter*, quail carcass, shelf life, antimicrobial

INTRODUCTION

Fresh poultry and poultry products are highly perishable. Depending on the degree of processing after slaughter, the shelf life of these products varies between 4 and 10 D under refrigeration (Patsias et al., 2006). Within the consumer market, quail meat currently makes up a small proportion of poultry sales compared with broiler meat. However, there is growing consumer interest in the quail meat as an alternative to chicken and turkey meat (Purohit et al., 2016). Prevalence of *Salmonella* and *Campylobacter* in fresh poultry products is relatively higher than that in other meat (Geornaras et al., 1998). Current food safety trends focus on achieving best practices in pathogen control during grow out and during processing. In recent year, methods for reducing contamination by pathogens during poultry processing such as postchill decontamination tanks have provided an alternative approach for pathogen reduction during poultry processing when used in combination with other interventions throughout the plant (Russell, 2010; Nagel et al., 2013). Cox et al. (2017) reported *Campylobacter* prevalence of up to 100%, varying

extensively from 0 to 100%, on different sampling visits to the processing operations. Antimicrobial interventions are applied to poultry products to reduce foodborne pathogen populations such as *Salmonella* and *Campylobacter* in US processing plants to meet performance standards (Scott et al., 2015). Chemical treatments may also inhibit subsequent microbial growth and extend the product shelf life (Bolton et al., 2014).

The efficacy of antimicrobials in reducing microbial populations during immersion chilling is highly dependent on the organic load of the chill water (higher organic loads will lead to loss of efficacy) (Smith et al., 2015). Chlorine was widely used as a sanitizer in commercial poultry processing operations in the United States because of its low cost and its ability to kill a wide range of microorganisms on carcasses, in processing water, and on processing equipment (Hinton et al., 2007). However, research has shown that the effectiveness of chlorine in immersion tanks could diminish owing to a longer residence time (Yang et al., 2001). In addition, it has been suggested that chlorine can have a negative impact on meat quality, and its susceptibility to pH changes and the amount of organic matter in the tank decrease its effectiveness over time (Wideman et al., 2016). Currently, more than 10 antimicrobials are approved for use in the poultry industry for postchill applications. In the past decade, peracetic acid (**PAA**), a combination of PAA, acetic acid, and hydrogen peroxide, has replaced chlorine as the industry standard for application during poultry processing. In addition to being highly oxidative, the low pH of the solution contributes to the enhanced antimicrobial efficacy of PAA (Nagel et al., 2013). When used at higher concentrations (>80 ppm), PAA has resulted in more than 2.0 log cfu/mL reductions in both *Salmonella* and *Campylobacter* populations (Wideman et al., 2016). Chen et al. (2014) reported that ground chicken obtained from PAA-treated (0.07 and 0.10% PAA) chicken parts resulted in increased shelf life of ground chicken for 3 D, which was further supported by organoleptic observation by sensory analysis. Cecure is a 40% concentrate of cetyl-pyridinium chloride (**CPC**), a quaternary ammonium compound that is the active ingredient in some mouth-washes, that is being used as postchill rinse in poultry processing operations (Singh et al., 2005). Exposure of inoculated chicken skin to 0.5% CPC for 1 min resulted in >4.2 log cfu/mL reduction of *Campylobacter jejuni* (Smith et al., 2015). In addition, organic acids such as citric acid (5%) contained in Citrilow applied by immersion was reported to significantly reduce *Campylobacter* counts on chicken carcasses by 1.44 log cfu/cm^2 (Meredith et al., 2013).

Although extensive research has been conducted on the antimicrobial efficacy of PAA, CPC, and organic acids on the microflora of poultry carcasses, published literature on the efficiency of postchill antimicrobial interventions on extension of shelf life and pathogen reduction of quail carcasses is lacking. The objective of this study was to evaluate the efficacy of antimicrobial interventions during slaughter on the microbiological quality and shelf life of quail during refrigerated storage.

MATERIALS AND METHODS

Bacterial Cultures

The nalidixic acid–resistant strain of *Salmonella* Typhimurium (ST^{NR}) and gentamicin-resistant strain of *Campylobacter coli* (CC^{GR}) were procured from the US National Poultry Research Center, US Department of Agriculture, Athens, GA, and used for inoculation of the carcasses.

Salmonella *and* Campylobacter *Inoculum Preparation*

The ST^{NR} cultures were grown on trypticase soy agar (Becton, Dickinson and Company, Franklin Lakes, NJ) plates containing nalidixic acid (200 ppm; Sigma-Aldrich, St. Louis, MO) for 24 h at 35 ± 1°C. Cultures were harvested by transferring 2 mL of sterile peptone water (**PW**) (0.1%) to the plates and scraping the agar surface with an L-shaped spreader. *C. coli* cultures were grown on Campy Cefex agar (Neogen Corporation, Lansing, MI) containing 200 ppm of gentamycin (Sigma-Aldrich, St. Louis, MO) and incubated for 48 h at 42 ± 1°C in a Zip-lock bag flushed with microaerobic gas containing 5% O_2, 10% CO_2, and balance N_2. The cultures were harvested by as described for ST^{NR}. The bacterial cocktail was prepared by combining equal volumes of ST^{NR} and CC^{GR} suspensions for inoculation on quail carcasses.

Carcass Inoculation and Treatment Microbial Enumeration

Eviscerated quail carcasses were collected from the processing line of a quail processing facility before application of antimicrobial interventions. Carcasses were immediately placed on ice and transported to a pilot plant scale processing facility of the Poultry Science Department at the University of Georgia, Athens, GA. Individual carcasses were inoculated with a cocktail of ST^{NR} and CC^{GR} strains (ca. 6 log cfu/mL each) and allowed to attach for 15 min at ambient temperature. Noninoculated carcasses served as the negative controls in the study, whereas inoculated, untreated carcasses served as positive controls. Carcasses were then treated with different antimicrobials as mentioned previously.

Carcass Treatments

Three independent replications were conducted on different processing days. Quail carcasses (15 per treatment per replication; a total of 75 per replication) were assigned to each of the 5 treatment groups—3 antimicrobial treatments: 1) 400 ppm PAA (Peragon; Safe Foods Corporation, North Little Rock, AR), 2) 0.45% CPC (Cecure; Safe Foods Corporation, North Little Rock,

Table 1. *Salmonella* and *Campylobacter* population (log cfu/mL) recovered from quail carcasses after immersion in antimicrobial solutions for 20 s.

Treatments	*Salmonella*	*Campylobacter*
Control	5.04 ± 0.06[a]	4.52 ± 0.55[a]
Water	4.33 ± 0.15[b]	4.02 ± 0.62[a]
PAA	3.41 ± 0.28[c,d]	2.57 ± 0.51[b]
Citrilow	3.14 ± 0.25[d]	0.70 ± 0.70[c]
CPC	3.65 ± 0.28[c]	2.90 ± 0.92[b]

[a-e]Same superscripts within the same column indicate no significant differences ($P > 0.05$) between the treatments; ±, SEM, where n = 5 per replication per treatment.

Abbreviations: CPC, cetylpyridinium chloride; PAA, peracetic acid.

AR), and 3) citric and hydrochloric acid aqueous solution, pH 1.2 (Citrilow; Safe Foods Corporation, North Little Rock, AR), along with a no-treatment control and a water treatment (to evaluate whether the reductions obtained were due to washing effect); a total of 5 treatments were evaluated. Concentrations of the particular antimicrobials were chosen based on common usage in poultry processing operations, regulatory limits, or the manufacturer's recommendations. Concentrations of PAA and CPC were determined using titration drop test kits (FMC; Safe Foods Corporation, North Little Rock, AR). The pH for the Citrilow treatment was confirmed using a pH meter (Edge; HANNA Instruments Inc., Woonsocket, RI). A stock solution of 9.5 L of each antimicrobial was made, and carcasses were immersed in sanitized plastic buckets adapted with a hose to inject air (50 psi; 345 kPa) simulating agitation in the commercial poultry chillers. A dwell time of 20 s was used for immersion treatments.

A modified USDA whole carcass rinse method was used for microbial sampling, detection, and enumeration (USDA-FSIS, 2004) using 200 mL of buffered PW (**BPW**) instead of 400 mL as recommended by USDA Food Safety and Inspection Service. Sodium thiosulfate (0.1%; AquaPhoenix Scientific, Inc., Hanover, PA) or lecithin (7.0%; Acros Organics, Fairlawn, NJ) were added to the carcass rinsate to neutralize PAA and CPC, respectively. This reduction in volume used for rinsing the birds did not affect the recovery of pathogenic microorganisms (Nagel et al., 2013). Serial dilutions were prepared in 0.1% PW and in 0.1% PW supplemented with 200 ppm of nalidixic acid and spread plated onto Campy Cefex agar (Neogen Corporation) containing 200 ppm of gentamycin and aerobic plate count (**APC**)

Petrifilm (3M Food Safety, St. Paul, MN) for enumeration of *Campylobacter* and *Salmonella*, respectively. Plates were incubated as described earlier, and typical *Campylobacter* and *Salmonella* colonies were enumerated and expressed as log cfu/mL.

Shelf Life Study

Similar to the microbial challenge study (*Salmonella* and *Campylobacter* reductions), 5 treatments were used: 1) 400 ppm PAA, 2) 0.45% CPC, 3) Citrilow, 4) no-treatment control, and 5) water treatment. For each treatment and sampling day, a set of 5 carcasses/treatment/sampling day (20 carcasses/treatment) were treated as described previously, individually vacuum sealed (Henkelman, Hertogenbosch, Netherlands) in vacuum pouches (Clarity Vacuum; Bunzl, St. Louis, MO), and placed in refrigerated storage at 4°C for analysis on days 1, 4, 7, or 10 after processing. The microbial flora of the carcasses was sampled using the whole carcass rinse procedure (USDA-Food Safety and Inspection Service) by adding 200 mL of BPW (Difco Co., Detroit, MI) solution to the plastic bags containing the carcasses and shaking for 30 s. Sodium thiosulfate or lecithin were added to the carcass rinsate as described earlier. Carcass rinses were serially diluted in PW for enumeration of total aerobic counts (APC) plated on APC Petrifilm and incubated at 37°C for 48 h and at 4°C for 7 D for psychrotrophs; total coliform counts (**TCC**) and *Escherichia coli* plated on *E. coli*–coliforms Petrifilm and incubated at 37°C for 24 h and Enterobacteriaceae (**ENT**) plated on Petrifilm Enterobacteriaceae (3M, St. Paul, MN) at 37°C for 24 h.

Statistical Analysis

Three independent replications were performed for each experiment with 20 birds per treatment per replicate. Microbial data (populations of *Salmonella* and *Campylobacter*) were analyzed by ANOVA using the GLM procedure of the Statistical Analysis System (release 9.04; SAS Institute, Inc., Cary, NC). Fisher's least significant difference (P value; α = 0.05) was used to separate means of the microbial populations (log cfu/mL) for the samples.

Table 2. Aerobic plate counts (log cfu/mL) on quail carcasses subsequent to immersion in antimicrobial solutions for 20 s and subsequent refrigerated storage (4°C) for 10 D.

Day	Control	Water	PAA	Citrilow	CPC
Day 1	3.05 ± 0.61[a,y]	3.01 ± 0.57[a,y]	1.76 ± 1.43[a,x,y]	2.21 ± 1.11[a,x,y]	0.82 ± 1.06[a,x]
Day 4	4.41 ± 0.40[a,y]	4.15 ± 0.03[a,y]	3.08 ± 0.73[a,x,y]	2.66 ± 0.14[a,x,y]	1.38 ± 0.88[a,x]
Day 7	6.14 ± 0.77[b,y]	6.90 ± 0.41[b,z]	5.74 ± 0.61[b,y]	4.65 ± 0.09[b,x,y]	3.40 ± 0.98[b,x]
Day 10	7.51 ± 0.29[b,y]	7.76 ± 0.61[b,y]	7.18 ± 0.50[b,y]	6.36 ± 0.36[c,y]	4.37 ± 0.41[b,x]

[a-c]Same superscripts within the same column indicate no significant differences ($P > 0.05$) between the treatments.

[x-y]Same superscripts within the same row indicate no significant differences ($P > 0.05$) between the treatments. ±, SEM, where n = 20 per replication per treatment.

Abbreviations: CPC, cetylpyridinium chloride; PAA, peracetic acid.

Table 3. Psychrotroph populations (log cfu/mL) on quail carcasses subsequent to immersion in antimicrobial solutions for 20 s and subsequent refrigerated storage (4°C) for 10 D.

Day	Control	Water	PAA	Citrilow	CPC
Day 1	$1.59 \pm 1.53^{a,x}$	$1.75 \pm 1.48^{a,x}$	$1.02 \pm 1.76^{a,x}$	$0.92 \pm 1.59^{a,x}$	$0.34 \pm 0.59^{a,x}$
Day 4	$4.30 \pm 0.81^{a,b,y}$	$4.27 \pm 0.79^{b,y}$	$2.03 \pm 1.32^{a,x}$	$2.21 \pm 0.20^{a,x,y}$	$1.34 \pm 1.72^{a,b,x}$
Day 7	$5.96 \pm 0.71^{b,c,y}$	$6.47 \pm 0.02^{c,y}$	$4.27 \pm 0.60^{b,x,y}$	$4.52 \pm 0.77^{b,x,y}$	$2.86 \pm 1.85^{b,x}$
Day 10	$7.44 \pm 0.13^{c,y}$	$7.88 \pm 0.51^{c,y}$	$4.32 \pm 2.82^{b,x,z}$	$6.32 \pm 0.71^{b,y,z}$	$3.10 \pm 2.11^{b,x}$

[a–c]Same superscripts within the same column indicate no significant differences ($P > 0.05$) between the treatments.

[x–z]Same superscripts within the same row indicate no significant differences ($P > 0.05$) between the treatments; $\pm$, SEM, where n = 20 per replication per treatment.

Abbreviations: CPC, cetylpyridinium chloride; PAA, peracetic acid.

RESULTS AND DISCUSSION

Effects of Antimicrobials on Salmonella and Campylobacter

Salmonella and *Campylobacter* populations of 5.04 and 4.52 log cfu/mL, respectively, were recovered from the inoculated carcasses (Table 1). Immersion of inoculated quail carcasses in water resulted in 0.71 and 0.50 log cfu/mL reductions in ST^{NR} and CC^{GR} populations, respectively. Immersion of quail carcasses in antimicrobial solutions containing PAA, Citrilow, and CPC significantly reduced ($P \leq 0.05$) the ST^{NR} and CC^{GR} populations compared with the positive and water controls. Specifically, immersion in Citrilow showed greater reductions on *Salmonella* and *Campylobacter*, ca. 1.90 and 3.82 log cfu/mL, respectively. Peracetic acid and CPC were equally effective ($P > 0.05$) in reducing *Salmonella* and *Campylobacter* populations on quail carcasses. The results obtained are in agreement with the study of Chen et al. (2014) who reported 1.5 and 0.8 log reduction in *Salmonella* and *Campylobacter* on chicken parts during postchill treatment with PAA and CPC. Yang et al. (2011) reported the similar reduction (2.0 log cfu/carcass) in *Salmonella* counts when CPC was sprayed on chicken carcasses for 17 s. Smith et al. (2015) reported 0.71 and 1.42 log cfu/mL (of rinsate) reductions in *Campylobacter* populations after immersion of poultry carcasses in 100 and 200 ppm PAA, respectively, for 60 s. Citrilow containing citric acid and hydrochloric acid effectively reduced the populations of Shiga toxin–producing *E. coli* and non–Shiga toxin–producing *E. coli* on fresh beef (Pohlman et al. 2010; Wheeler et al. 2014). Kalchayanand (2012) reported 1.5 log reductions in *E. coli* O157:H7, non–O157 Shiga toxin–producing *E. coli*

(O26, O45, O103, O111, O121, and O145 serogroups), and *Salmonella* on fresh beef sprayed with 2.0% Citrilow. Published literature on application of Citrilow, an antimicrobial solution that relies on low pH as the mechanism for antimicrobial efficacy, for poultry and poultry parts is lacking. Landrum et al. (2017) reported reductions in *Campylobacter* populations by 2.41 and 2.16 log cfu/mL upon immersion (25 s; with air agitation) in Poultry pHresh (pH 1.4) solution on split chicken breasts (skin on) and chicken thighs (skin on), respectively. Immersion treatment of skin-on chicken parts in antimicrobial solutions with low pH seems to provide greater reduction in *Campylobacter* populations at lower concentrations. Alternatively, higher concentrations (>100 ppm) of antimicrobials that solely rely on oxidative mechanism such as PAA are required to achieve the similar reductions in *Campylobacter* on poultry carcasses and parts.

Microbiological Quality of Quail Carcasses After Antimicrobial Treatments

Aerobic plate counts on the quail carcasses on day 1 were 3.05 log cfu/mL (Table 2). Immersion in PAA and Citrilow solutions for 20 s resulted in 0.61 and 0.56 log cfu/mL reductions ($P > 0.05$) in APC, respectively, whereas immersion in CPC solution for the same time resulted in 2.22 log cfu/mL reduction ($P \leq 0.05$). The mean APC populations were lower in PAA- and Citrilow-treated quail than that in the nontreated quail up to day 7. The APC populations were consistently lower ($P \leq 0.05$) in CPC-treated quail throughout the refrigerated storage, with 4.37 log cfu/mL on day 10. Psychrotroph counts significantly increased as refrigeration storage period increased for all treatments

Table 4. *Escherichia coli* counts (log cfu/mL) on quail carcasses subsequent to immersion in antimicrobial solutions for 20 s and subsequent refrigerated storage (4°C) for 10 D.

Day	Control	Water	PAA	Citrilow	CPC
Day 1	$2.00 \pm 0.11^{a,y}$	$1.80 \pm 0.33^{a,y}$	$1.30 \pm 0.18^{a,b,x}$	$1.29 \pm 0.23^{a,x}$	$0.41 \pm 0.29^{a,x}$
Day 4	$2.34 \pm 0.67^{a,y}$	$2.01 \pm 0.31^{a,y,z}$	$1.22 \pm 0.31^{a,b,x,y}$	$0.92 \pm 0.30^{a,x,z}$	$0.54 \pm 0.93^{a,x}$
Day 7	$2.47 \pm 0.62^{a,y}$	$2.50 \pm 0.67^{a,y}$	$2.27 \pm 0.52^{a,y}$	$1.25 \pm 1.26^{a,x,y}$	$0.84 \pm 0.81^{a,x}$
Day 10	$2.13 \pm 2.06^{a,y}$	$1.17 \pm 1.27^{a,y}$	$0.00 \pm 0.00^{b,x}$	$0.82 \pm 1.41^{a,x,y}$	$0.62 \pm 0.63^{a,x}$

[a–b]Same superscripts within the same column indicate no significant differences ($P > 0.05$) between the treatments.

[x–y]Same superscripts within the same row indicate no significant differences ($P > 0.05$) between the treatments. $\pm$, SEM, where n = 20 per replication per treatment.

Abbreviations: CPC, cetylpyridinium chloride; PAA, peracetic acid.

Table 5. Total coliform counts (log cfu/mL) on quail carcasses subsequent to immersion in antimicrobial solutions for 20 s and subsequent refrigerated storage (4°C) for 10 D.

Day	Control	Water	PAA	Citrilow	CPC
Day 1	$2.13 \pm 0.17^{a,x}$	$2.10 \pm 0.22^{a,x}$	$1.56 \pm 0.28^{a,x}$	$1.49 \pm 0.04^{a,x}$	$0.66 \pm 0.43^{a,x}$
Day 4	$2.83 \pm 0.83^{a,c,x}$	$2.53 \pm 0.40^{a,b,x}$	$1.93 \pm 1.28^{a,x}$	$1.68 \pm 0.63^{a,x}$	$1.38 \pm 1.04^{a,x}$
Day 7	$4.01 \pm 0.83^{b,c,y}$	$4.13 \pm 1.43^{b,y}$	$3.84 \pm 1.14^{b,y}$	$3.68 \pm 1.92^{b,y}$	$1.78 \pm 0.20^{a,x}$
Day 10	$4.84 \pm 1.08^{b,y}$	$4.50 \pm 1.67^{b,y}$	$5.01 \pm 0.98^{b,y}$	$3.57 \pm 1.40^{b,x,y}$	$2.04 \pm 2.01^{a,x}$

[a–c]Same superscripts within the same column indicate no significant differences ($P > 0.05$) between the treatments.

[x–y]Same superscripts within the same row indicate no significant differences ($P > 0.05$) between the treatments. $\pm$,SEM, where n = 20 per replication per treatment.

Abbreviations: CPC, cetylpyridinium chloride; PAA, peracetic acid.

(Table 3). However, PAA, Citrilow, and CPC showed lower ($P > 0.05$) psychrotrophic counts on days 4, 7, and 10 than the control.

E. coli counts were similar during refrigerated storage within each antimicrobial treatment (Table 4). Immersion of the quail carcasses in PAA and Citrilow was significantly different compared with the control on days 1 and 4 ($P \leq 0.05$), whereas CPC was significant on day 1 and 4 and on day 10, respectively. TCC increased ($P \leq 0.05$) as refrigeration storage period increased for all treatments (Table 5). Cetylpyridinium chloride showed a greater reduction ($P > 0.05$) for all storage periods than the control. As TCC and *E. coli* counts increased with the refrigeration storage period, ENT counts also increased ($P \leq 0.05$) as refrigeration storage period increased for all treatments (Table 6), except for CPC on days 1 and 4 (Table 4). CPC and Citrilow showed lower ($P \leq 0.05$) ENT counts for all storage periods than the control; whereas PAA showed lower ($P \leq 0.05$) ENT population on day 4. Overall, the results showed greater shelf-life extension of quail carcasses treated with CPC and are similar to the results demonstrated by Bai et al. (2007) who reported improved microbiological quality of boneless, skinless chicken thigh meat when sprayed with 1.0% CPC and stored at 2.5°C. These finding are also in agreement with that of the study by Gilbert et al. (2015) who reported extension in carcass and poultry part shelf life by 1–2 D at 1 to 7°C after treatment with 0.3% CPC. However, Gilbert et al. (2015) reported that any extension in product shelf life was likely due to slight reductions in APC at the time of treatment and may not be due to altered microbial growth during refrigerated storage. Furthermore, Scott et al. (2015) reported an interaction between antimicrobial type and storage time. All tested antimicrobial treatments ($P \leq 0.001$) reduced the *Salmonella* and aerobic bacterial populations from the chicken wings compared with the control, similar to that reported by our study. He further demonstrated that efficacy against *Salmonella* at 0 h increased in the order CPC < SSS < PAA; however, after 24 h of storage, pathogen counts of sulfuric acid and sodium sulfate blend and PAA-treated wings did not significantly differ. Chen et al. (2014) reported that treatment with 0.07 and 0.1% PAA extended the shelf life of ground chicken by 3 D compared with 0.35 and 0.6% CPC. These contrasting results can be attributed to the higher PAA concentration (700 and 1,000 ppm) used by Chen et al compared with PAA concentration (400 ppm) used in our study. Similar to our study, minimal storage effect of PAA (100 and 200 ppm) was observed on *Campylobacter* reductions on chicken carcasses (Meredith et al., 2013).

Overall, application of antimicrobial interventions resulted in a reduction in APC, psychrotrophs, and ENT populations after treatment (day 0) and throughout the storage period (day 10) of the quail compared with control. Reductions in *Salmonella* and *Campylobacter* populations were obtained with Citrilow application. Therefore, use of antimicrobial interventions during processing can improve the shelf life of quail. However, concentration of the antimicrobial, contact time, application methods, and dwell time makes substantial difference in the reduction of pathogenic populations, irrespective of type of antimicrobial used. Therefore, further studies related to sequential treatment combinations on microbiological

Table 6. Enterobacteriaceae counts (log cfu/mL) on quail carcasses subsequent to immersion in antimicrobial solutions for 20 s and subsequent refrigerated storage (4°C) for 10 D.

Day	Control	Water	PAA	Citrilow	CPC
Day 1	$2.38 \pm 0.12^{a,y}$	$1.66 \pm 1.10^{a,x,y}$	$1.75 \pm 0.16^{a,x,y}$	$1.72 \pm 0.15^{a,x,y}$	$0.86 \pm 0.62^{a,x}$
Day 4	$3.41 \pm 1.09^{b,z}$	$3.49 \pm 0.24^{b,z}$	$2.81 \pm 0.90^{c,y,z}$	$2.04 \pm 0.17^{a,y}$	$0.50 \pm 0.08^{a,x}$
Day 7	$5.71 \pm 0.26^{c,z}$	$5.87 \pm 0.35^{c,z}$	$5.30 \pm 0.61^{c,y,z}$	$4.68 \pm 1.03^{b,y}$	$2.95 \pm 0.81^{b,x}$
Day 10	$6.86 \pm 0.52^{d,z}$	$6.52 \pm 0.70^{c,y,z}$	$5.99 \pm 0.17^{c,y,z}$	$5.70 \pm 0.45^{c,y}$	$4.02 \pm 0.08^{c,x}$

[a–d]Same superscripts within the same column indicate no significant differences ($P > 0.05$) between the treatments.

[x–z]Same superscripts within the same row indicate no significant differences ($P > 0.05$) between the treatments. $\pm$, SEM, where n = 20 per replication per treatment.

Abbreviations: CPC, cetylpyridinium chloride; PAA, peracetic acid.

properties of quail and rate of microbial growth, during storage, and after treatments with chemical interventions are warranted to enhance food safety.

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