Comparison of eggshell surface sanitization technologies and impacts on consumer acceptability

Morouj N. Al-Ajeeli,[*] T. Matthew Taylor,[†] Christine Z. Alvarado,[‡] and Craig D. Coufal[#,1]

[*]*Department of Nutrition and Food Science, Texas A&M University, College Station, TX 77843-2253;* [†]*Department of Animal Science, Texas A&M AgriLife Research, College Station, TX 77843-2471;* [‡]*Department of Poultry Science, Texas A&M AgriLife Research, College Station, TX 77843-2472; and* [#]*Department of Poultry Science, Texas A&M AgriLife Extension, College Station, TX 77843-2472*

ABSTRACT Shell eggs can be contaminated with many types of microorganisms, including bacterial pathogens, and thus present a risk for the transmission of foodborne disease to consumers. Currently, most United States egg processors utilize egg washing and sanitization systems to decontaminate surfaces of shell eggs prior to packaging. However, previous research has indicated that current shell egg sanitization technologies employed in the commercial egg industry may not completely eliminate bacteria from the surface of eggshells, and thus alternative egg sanitization technologies with the potential for increased microbial reductions on eggshells should be investigated. The objectives of this study were to compare the antimicrobial efficacy and consumer sensory attributes of industry-available eggshell sanitization methods (chlorine and quaternary ammonium compounds (QAC) applied via spray) to various alternative egg sanitization technologies. Eggs (White Leghorn hens; n = 195) were obtained for evaluation of sanitizer-induced reduction in mesophilic aerobic bacteria (n = 90) or inoculated *Salmonella* Enteritidis (SE) reduction (n = 105). Sanitizing treatments evaluated in this experiment were: chlorine spray (100 ppm available chlorine), QAC spray (200 ppm), peracetic acid spray (PAA; 135 ppm) alone or in combination with ultraviolet light (UV; 254 nm), and hydrogen peroxide (H_2O_2; 3.5% solution) spray in combination with UV (H_2O_2+UV). For enumeration of aerobic bacteria, eggs were sampled at 0, 7, and 14 days of storage at 4°C; surviving SE cells from inoculated eggs were enumerated by differential plating. Sensory trials were conducted to determine consumer liking of scrambled eggs made from eggs sanitized with chlorine, QAC, H_2O_2+UV, or no treatment (control). The H_2O_2 and UV treatment resulted in the greatest reductions in eggshell aerobic plate counts compared to other treatments throughout egg storage ($P < 0.05$). All treatments utilized reduced SE below the limit of detection by eggshell rinse. There were no differences in consumers' liking of overall flavor between the 4 treatments evaluated. The application of H_2O_2+UV treatment to shell eggs represents a novel technology that could have important implications for egg quality and safety preservation.

Key words: shell eggs, sanitization, hydrogen peroxide, UV light, *Salmonella*

2016 Poultry Science 0:1–7
http://dx.doi.org/10.3382/ps/pew014

INTRODUCTION

Poultry products, including shell eggs, have been identified by the Centers for Disease Control and Prevention (**CDC**; Atlanta, GA) as one of the principal food commodity types associated with the transmission of bacterial pathogens and the onset of foodborne illness in consumers (CDC, 2010; Painter et al., 2013). The implementation of the Food and Drug Administration's (FDA) Egg Safety Rule, and recent *Salmonella enterica* serovar Enteritidis contamination of shell eggs with ensuing outbreak of human salmonellosis, have elevated eggs to prominence and increased consumer awareness of needs for proper handling of eggs to maintain food safety (Department of Health and Human Services-Food and Drug Administration, 2009; FDA, 2010).

Currently, most United States egg processors utilize chemical sanitization systems to decontaminate surfaces of shell eggs prior to packaging. Chlorous compounds and quaternary ammonium compounds (**QAC**) are the sanitizing agents most commonly employed for shell eggs. Chlorine is approved for use by the US Department of Agriculture-Agricultural Marketing Service (**USDA-AMS**) in egg sanitizing solutions at levels of 50 to 200 ppm available chlorine (USDA-AMS, 2000). Favier et al. (2000a,b; 2001) reported that 100.0 mg/L available chlorine applied via washing for 10 min at 25°C reduced numbers of *Yersinia enterocolitica* inoculated on eggshells by 2.9 to 3.1 $\log_{10}$cfu/egg.

Received June 18, 2015.
Accepted January 6, 2016.
[1]Corresponding author: ccoufal@poultry.tamu.edu

Chlorine efficacy has, however, been reported to be neutralized by the presence of high organic load and suspended solids in wash waters (Moats, 1981; Knape et al., 1999). McKee et al. (1998) reported a 200 ppm QAC application to eggshell surfaces reduced aerobic bacteria and *Salmonella* Typhimurium by 3.3 and 6.5 $\log_{10}$ cfu/egg, respectively, compared to untreated controls. Numbers of surviving *S.* Typhimurium cells, however, did not differ in QAC-treated eggs versus hypochlorite (chlorine)-treated eggs. In studies applying a combination of a multi-QAC compound with biguanide (100 ppm), only 5% of treated broiler hatching eggs were positive for *S.* Enteritidis following treatment as compared with eggs treated by water spraying (90% *S.* Enteritidis-positive after spraying) (Buhr et al., 2013). Similar reductions in the numbers of *Salmonella*-positive hatching eggs were observed following the application of a four QAC-containing system applied at 40,000 ppm (Cox et al., 2007).

In addition to chlorous and QAC sanitizers, oxidizers such as peracetic acid (**PAA**) and hydrogen peroxide (H_2O_2) have been explored. Such compounds have been used alone and in combination with other process technologies such as ultraviolet light (**UV**) application. Cox et al. (2007) reported application of 14,000 ppm H_2O_2 to broiler hatching eggshells reduced the number of *S.* Typhimurium-positive eggs by 70% versus the non-treated control. Jones (2010) reported application of 200 ppm PAA to egg loader cups reduced the numbers of *Enterobacter cloacae* to a greater extent than did 200 ppm sodium or calcium hypochlorite. Hartman and Carlin (1957) reported 2,000 ppm PAA application significantly reduced the numbers of naturally contaminating pathogenic microbes on eggshell surfaces. In experiments combining the application of 1.5% H_2O_2 with 8 min of UV (UV-C; 254 nm) exposure, researchers reported a 3.5 $\log_{10}$cfu reduction in eggshell surface-contaminating microbes versus non-treated controls (Wells et al., 2010). It was determined that the combination of H_2O_2 and UV (H_2O_2+UV) is more effective at reducing eggshell bacterial counts than H_2O_2 or UV independently. In addition, Rajala-Mustonen et al. (1997) reported the combination of PAA with UV exposure reduced the time required for DNA or RNA degradation in coliphages in waste waters.

More recent research has found that the H_2O_2+UV process can be used to sanitize eggshell surfaces without impacting interior egg quality (Woodring, 2011). In that study, only 33.5% of consumer panelists in a triangle test comparing non-treated control eggs and eggs sanitized with the H_2O_2+UV process correctly distinguished between the cooked egg samples. In order to further investigate if the H_2O_2+UV process could be utilized to sanitize shell eggs without affecting consumer sensory attributes of the eggs, a more detailed consumer study was of interest. Consumer sensory testing of any alternative egg treatment technologies must be completed to provide egg producers and regulatory authorities such as USDA-AMS assurance that interior egg quality and consumer acceptance of egg products will not be negatively impacted. In addition, it was of interest to investigate if the same oxidative process and microbial reductions resulting from the combined use of H_2O_2 and UV would also be observed with the combined application of PAA and UV. Therefore, the overall objectives of this study were to: 1) compare the antimicrobial efficacy of chlorine, QAC, PAA alone or in combination with UV, and H_2O_2 in combination with UV for reduction of eggshell microbial counts, and 2) determine the consumer acceptability of eggs treated by various sanitization methods via standard human sensory research methods.

MATERIALS AND METHODS

Application of Treatments

Eggs were collected from caged White Leghorn hens at the Poultry Research Center on the campus of Texas A&M University (College Station, TX). A total of 195 eggs were randomly assigned for evaluation of sanitizer-induced reduction of mesophilic aerobic bacteria (n = 90) or inoculated *Salmonella* Enteritidis (n = 105). Sanitizing treatments applied were: chlorine (100 ppm available chlorine, Antibac B, Diversey Care Sealed Air Corp., Sturtevant, WI); QAC (200 ppm; Disan-1, Synco, Spring Branch, TX); PAA (135 ppm, FMC Corp., Philadelphia, PA) alone or in combination with UV; and H_2O_2 (3.5%, Brainerd Chemical Co., Inc., Tulsa, OK) in combination with UV (G20T5, Sankyo Denki, Japan). Sanitizing treatments were compared to untreated/non-inoculated (negative) and untreated/*Salmonella* Enteritidis (**SE**)-inoculated (positive) controls. The chlorine and QAC solutions were prepared by mixing the commercial products with deionized water according to the directions on the manufacturer's label to achieve the desired concentrations. The PAA and H_2O_2 solutions were prepared by diluting concentrated stock solutions obtained from the manufacturer with deionized water. The PAA solution concentration was verified using a PAA test kit provided by FMC Corp. (Kit 7191-02-FMC). All solutions were prepared immediately before use. Eggs were randomly assigned to treatments with 5 eggs per treatment being sampled at 0, 7, and 14 d post-treatment (15 eggs total per treatment). Eggs for sampling at 7 and 14 d of storage were placed in new, clean Styrofoam cartons and cartons were placed in sterile bags (Whirl-Pak, Nasco, Fort Atkinson, WI). Eggs were stored in a walk-in cooler at 4°C. The experiment was replicated over 3 trials for a total of 15 eggs per treatment per day of storage.

The sanitization treatments were applied using a prototype egg treatment device equipped to administer both spray treatments and UV (Figure 1). Two spray and 2 UV-treatment stations were accomplished by chambers positioned above and below the conveyor

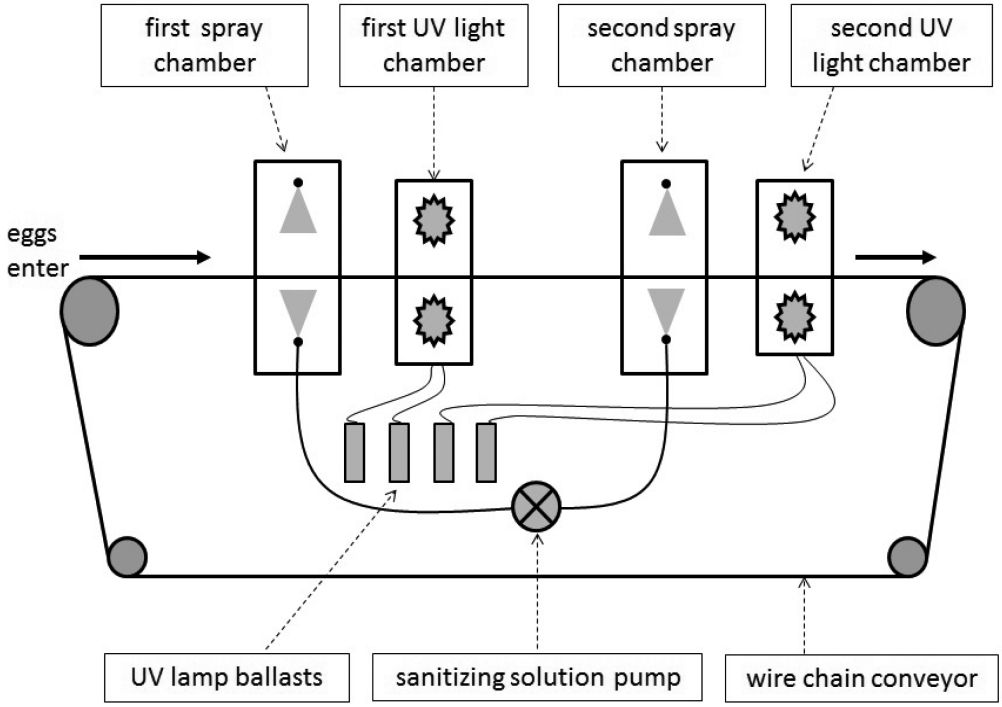

Figure 1. Schematic of egg sanitization device allowing for application of sanitizing solution, UV, or combined application of sanitizing solution and UV via operator control.

in alternating order (spray, UV, spray, UV). A wire chain conveyor carrying the eggs through the device allowed for the spray and UV treatments to impact all eggshell surfaces without the need for egg rotation. Power was supplied to the UV chambers independently of the pump providing fluid to the spray nozzles in the spray chambers; therefore treatments which utilized spraying only were accomplished by disconnecting power to the UV lamps. Each UV chamber consisted of 4 lamps above and 4 lamps below the conveyor approximately 4 cm from the surface of the eggs and provided 8 to 12 mW/cm^2 of UV-C (254 nm) to the eggshell surface. All spray treatments utilized both spray chambers; therefore eggs received two doses of each spray treatment. Egg residence time in all chambers (spray and UV) was approximately 5 s. The time for eggs to travel through the entire sanitization device was 38 s.

Procedures for S. Enteritidis Inoculation on Eggshells

A sponge method was used to inoculate the eggs with a culture of $\sim 10^8$ cfu/mL SE selected for resistance to Novobiocin (**NO**) and Nalidixic Acid (**NA**) (Sigma-Aldrich, St. Louis, MO). A suspension of SE was prepared by reviving the SE isolate from −80°C storage by transferring 100 μL of frozen culture into 10 mL Tryptic Soy Broth (TSB; Oxoid Ltd., Basingstoke, Hampshire, England) with 20 μg/mL NO and 25 μg/mL NA and incubated for 24 h at 37°C. Following the revival process, 100 μL of overnight culture was passed in 10 mL of TSB with NO and NA and incubated for 24 h at 37°C.

Following incubation, the suspension was centrifuged at 852 × ***g*** for 10 min and the supernatant was discarded. Then, 10 mL sterile phosphate buffered saline (**PBS**) (pH 7.2) was gently mixed with the bacterial pellet and centrifuged as above; the supernatant was again discarded and the pellet was gently mixed with 10 mL PBS. To estimate the cfu/mL of SE in the re-suspended pellet, decimal dilutions were prepared in PBS and SE cells were spread on Petri dishes containing brilliant green agar (**BGA**) (Becton, Dickinson and Co., Sparks, MD) with 20 μg/mL NO and 25 μg/mL NA added. Each egg was sponged by a sterile cotton ball saturated with the $\sim 10^8$ cfu/mL SE suspension. Sponged eggs were then allowed to dry at 25°C for 30 min prior to treatment application. This method resulted in mean SE counts of 4.3, 3.2, and 3.2 $\log_{10}$cfu/egg of SE for the 3 replicate trials, respectively, performed in this study.

Enumeration of Aerobic Bacteria and Salmonella Enteritidis from Eggshells

For enumeration of aerobic bacteria, 5 eggs per treatment were sampled at days 0, 7, and 14 of storage at 4°C. Eggs were individually placed in sterile Whirl-Pak sample bags containing 20 mL PBS and gently massaged for 1 min. One mL volumes were then transferred aseptically from sample bags into tubes containing sterile PBS and necessary decimal dilutions prepared for plating. One mL volumes from each rinse bag and

dilution blanks were plated on surfaces of 3M Aerobic Plate Count (**APC**) Petrifilms (3M Health Care, St Paul, MN); inoculated films were then incubated for 48 h at 37°C (Morton, 2001). After incubation, colonies were counted and counts were transformed to $\log_{10}$ cfu/egg for statistical analysis. The limit of detection for this procedure was 20 cfu/egg. Therefore, films with no discernible colonies were assigned a value of 10 cfu/egg (1.0 $\log_{10}$ cfu/egg) for the purpose of statistical analysis.

For SE enumeration, 5 eggs per each treatment were individually placed in Whirl-Pak bags containing 20 mL PBS and gently massaged for 1 min prior to decimal dilution preparation. One hundred μL of each dilution was spread plated on BGA plates supplemented with NO and NA as previously described. Plates were aerobically incubated for 48 h at 37°C prior to enumeration. Plate counts were transformed to $\log_{10}$ cfu/egg for statistical analysis.

Sensory Evaluation of Impacts of Egg Sanitization on Egg Acceptability to Consumers

A consumer acceptability trial was conducted to determine consumers' acceptance of scrambled eggs prepared from eggs treated with various sanitizers compared to untreated control eggs. A total of 120 eggs were collected from caged White Leghorn hens at the Texas A&M University Poultry Research Center. The eggs were randomly assigned to 4 groups (n = 30) and sanitized using chlorine spray, QAC spray, H_2O_2+UV (as previously described), or remained untreated to serve as the control group. In order to reduce the number of sensory treatments to prevent sensory overload for the consumers, the PAA and PAA+UV treatments were not used since these treatments were not found to be superior in bacterial reduction compared to chlorine or QAC sprays which are typically used to sanitize shell eggs in the commercial industry. In addition, PAA was found to be considerably more expensive than chlorine or QAC products and therefore not likely to be used in commercial application. Following treatment, all eggs were stored under refrigeration (4°C) at the Human Sensory Research Laboratory (Department of Animal Science, Texas A&M University, College Station, TX) for 1 wk prior to the sensory evaluation. Eggs were stored to mimic the transport period typically required for eggs to travel through the marketing chain and reach the consumer. A panel of 50 subjects (age 18 to 50 years) were recruited as volunteers. Following storage, eggs were beaten in separate bowls per treatment for 2 min to ensure homogenous mixing of albumen and yolk fractions and then scrambled using separate pans. Canola oil spray was used to coat the bottom of the pan prior to cooking. The same amount of oil spray was used to ensure consistent cooking methods. All scrambled eggs were cooked to an endpoint temperature of 176.7°C (350°F). Samples were then placed into separate stainless steel containers with lids under heat lamps to maintain temperature and ensure samples were presented to subjects warm. All sensory trials were conducted in accordance with, and approved by, the Texas A&M University Office of Research Compliance and Biosafety Institutional Review Board (IRB) for the use of Human Subjects in Research (IRB2011-0153).

The ballot instruction included a 9-point hedonic scale test for flavor and texture of scrambled eggs in addition to overall like or dislike (Meilgaard et al., 2007). Prior to testing, panelists were provided with written instructions as to ballot completion along with a consent form to indicate willingness to participate in the study. Following reading and return of completed consent forms, panelists were served with sets of randomized three digit-coded samples. Each panelist was served with four weigh boats of the samples under random 3-digit codes, as well as unsalted saltine crackers and a cup of double distilled deionized water to allow panelists to clear/rinse their palate between samples (Meilgaard et al., 2007). Samples were served under red light to prevent visual bias by consumers (Meilgaard et al., 2007). Questions were asked in the ballot to indicate overall like/dislike for the flavor and texture of each sample. A scale of 9 points was used to rate the overall like or dislike for the flavor and texture of each sample that panelist perceived. Panelists were asked to indicate their like or dislike by placing a mark in the box of the point scale (1: dislike to 9: like) indicating their preference in each sample of the anonymously coded groups.

Statistical Analysis

All data from eggshell APC determination were analyzed by one-way analysis of variance (ANOVA); Tukey's Honestly Significant Differences (**HSD**) test was used to separate differing means at $P < 0.05$. For 3M Petrifilms that had zero counts (below limit of detection), a value of 10 cfu/egg was assigned for the corresponding egg. Antimicrobial effects of sanitization treatment for reduction of SE were analyzed in the same manner as described for aerobic bacteria. For the sensory evaluation, means for the texture and flavor were differentiated by analysis of variance (ANOVA). Significantly different means were separated by Duncan's Multiple Ranges Test for flavor and texture of all treatments and means were separated at $P < 0.05$. All statistical analysis of data was completed using JMP v.9.0 statistical analysis software (SAS Institute, Inc., Cary, NC).

RESULTS AND DISCUSSION

Reduction of Aerobic Bacteria by Sanitization Treatments

The purpose of this experiment was to evaluate the antimicrobial efficacies of current sanitization

Table 1. Mean aerobic plate counts of eggshell surfaces of eggs treated by various sanitization methods and stored for 0, 7, or 14 d.

Treatment[1]	Day 0	Day 7 $-\log_{10}$ cfu/egg[2]	Day 14
Control	$3.17^{a} \pm 0.22$	$3.48^{a} \pm 0.13$	$3.58^{a} \pm 0.12$
Chlorine	$2.92^{a,b,x} \pm 0.11$	$2.70^{b,x} \pm 0.07$	$2.40^{b,y} \pm 0.11$
QAC	$1.99^{d} \pm 0.20$	$1.88^{c} \pm 0.16$	$1.82^{c} \pm 0.16$
PAA	$2.60^{b,c,x} \pm 0.10$	$1.83^{c,y} \pm 0.17$	$2.08^{b,c,y} \pm 0.12$
PAA+UV	$2.23^{c,d} \pm 0.20$	$2.02^{c} \pm 0.22$	$2.16^{b,c} \pm 0.15$
H_2O_2+UV	$1.30^{e} \pm 0.14$	$1.05^{d} \pm 0.05$	$1.10^{d} \pm 0.08$

[a–e]Means within a column with different letters are significantly different ($P < 0.05$).

[x,y]Means within a row with different letters are significantly different ($P < 0.05$).

[1]Each treatment (n = 5): Control (no treatment); Chlorine spray (100 ppm available chlorine, Antibac B, Diversey Care Sealed Air Corp., Sturtevant, WI); QAC spray (200 ppm, Disan-1, Synco, Spring Branch, TX); PAA (135 ppm, FMC Corp., Philadelphia, PA) alone or in combination with UV (G20T5, Sankyo Denki, Japan); H_2O_2 (3.5%, Brainerd Chemical Co., Inc., Tulsa, OK) in combination with UV.

[2]n = 15 eggs total per treatment per day.

treatments used in shell egg industry and to compare those to various alternative technologies. Chlorine and QAC are currently the sanitizing agents most commonly used in egg processing to disinfect eggshell surfaces (Al-Ajeeli, 2013). The chlorine and QAC products utilized in this study are commonly used in the commercial shell egg industry and were utilized in accordance with the manufacturer's labeled directions. The concentrations used in this study are within the guidelines established by USDA-AMS for shell eggs (USDA-AMS, 2000). Results of this experiment indicate that the H_2O_2+ UV treatment produced the greatest reduction in eggshell APC when compared to other treatments during 0, 7, and 14 d of storage (Table 1). While on day 0 mean APC did not differ between control and chlorine-treated eggs, significantly lower APC were observed for eggs treated with all other sanitization treatments compared to the untreated control ($P < 0.05$). Musgrove et al. (2006) reported application of 100 or 200 ppm of chlorine did not result in significantly fewer aerobic bacteria on washed eggs compared with eggs rinsed with water only. Favier et al. (2000a; 2001) reported the application of 100 ppm available chlorine produced a 1.5 $\log_{10}$ reduction in eggshell aerobes, comparable to the 1.2 $\log_{10}$ cfu/egg reduction observed at 14 d of storage in the present study (Table 1).

The use of QAC on eggshells produced the second lowest APC (2.0 $\log_{10}$ cfu/egg) compared to the control (3.2 $\log_{10}$ cfu/egg) following sanitization application. In addition, APC of QAC-treated eggshells were not different from those of PAA+UV-treated eggs (Table 1). McKee et al. (1998) reported 200 ppm of a commercial QAC produced a 3.3 $\log_{10}$ reduction in APC, a greater reduction than the 1.2 $\log_{10}$ reduction observed in the current report. This observed difference is likely due to differing sanitizer application periods (two 5 s spray applications versus 1 min of spraying reported previously) and differing QAC species used between the current study and the previous study. After 7 d of storage, there were no differences in mean APC between eggs treated by QAC, PAA, and PAA+UV ($P \geq 0.05$). However, those treatments produced significantly lower APC compared to chlorine-treated (2.7 $\log_{10}$ cfu/egg) and control eggs (3.5 $\log_{10}$ cfu/egg). Following 14 d of storage post-sanitization, APC on chlorine-treated eggs had declined to 2.4 $\log_{10}$ cfu/egg, a significant decrease compared to chlorine-treated egg APC at 7 d of storage ($P < 0.05$) (Table 1). Overall, these results are similar to those reported previously, where sanitizers produced differing APC reductions versus controls (non-treated, water washed controls) (McKee et al., 1998; Favier et al., 2000b).

Throughout the 14-day storage period, H_2O_2+UV-treated eggs had the lowest sustained APC compared to the other treatments ($P < 0.05$). Previous studies have reported the combination of H_2O_2 and UV reduced eggshell APC to very low levels (Wells et al., 2010; Gottselig, 2011; Woodring, 2011). Wells et al. (2010) concluded that the H_2O_2+UV process lowered eggshell bacterial counts from 4.0 $\log_{10}$ cfu/egg to less than 1.0 $\log_{10}$ cfu/egg.

Reduction of Salmonella Enteritidis by Sanitizing Treatment

For eggs inoculated with SE, no differences were found among the sanitization treatments used in this study as all of the treatments reduced SE below the level of detection (200 cfu/egg) at day 0 of sampling. The untreated control eggs had mean SE counts of 4.3, 3.2, and 3.2 $\log_{10}$cfu/egg for the 3 replicate trials, respectively, performed in this study. No eggs, including the untreated controls, were found to have detectable SE at 7 and 14 d of storage using the eggshell rinse procedure employed in this study. A previous study demonstrated that the application of H_2O_2+UV process effectively reduced *Salmonella* on eggshell surfaces to very low levels (Gottselig, 2011). In addition, it was reported that dipping eggs in warm QAC was more effective in reducing SE on shell eggs than chlorine (Oliveira and Silva, 2000). Favier et al. (2000b) reported no detected *Y. enterocolitica* on BGA plates following application of 100 ppm chlorine to eggshells bearing 7.0 $\log_{10}$ cfu/egg of the pathogen. The authors in that study also reported the loss of the ability to detect surviving *Y. enterocolitica* or *S.* Typhimurium via enrichment procedures on inoculated eggs 0.5 to 1.0 h following sanitizer application (Favier et al., 2001). Likewise, others have reported the loss of detection of *S.* Enteritidis on hatching eggs treated by 14,000 ppm H_2O_2 (Buhr et al., 2013). In studies applying the maximum allowable energy by pulsed light on fresh laid eggs (unwashed), SE was reduced by 3.6 $\log_{10}$ cfu/egg for 80% of eggs treated (Hierro et al., 2009). While results presented in the current study mirror those reported previously, they are somewhat surprising given previous reports of

Table 2. Mean overall consumer liking of flavor and texture for scrambled eggs prepared from various sanitization process-treated eggs.

Treatment[1]	n	Flavor	n	Texture
Control	47	6.7	46	6.9[b]
Chlorine	46	7.2	48	7.7[a]
QAC	47	6.7	46	6.6[b]
H_2O_2+UV	47	6.7	47	6.9[b]

[a,b]Means within column with differing superscripted letter are significantly different ($P < 0.05$).

[1]Treatments: Control (no treatment); Chlorine spray (100 ppm available chlorine, Antibac B, Diversey Care Sealed Air Corp., Sturtevant, WI); QAC spray (200 ppm, Disan-1, Synco, Spring Branch, TX); H_2O_2 (3.5%, Brainerd Chemical Co., Inc., Tulsa, OK) in combination with UV (G20T5, Sankyo Denki, Japan).

sanitizers, particularly chlorine, being negatively impacted by the presence of high organic load in egg washing systems (Knape et al., 1999). Nevertheless, research has shown that aerobic bacteria on eggs collected from commercial washers after sanitizer application remain multiple $\log_{10}$-cycles higher than numbers of enteric bacteria (Musgrove et al., 2005).

Consumer Acceptance of Sanitized Eggs

Results from sensory evaluation of texture and flavor acceptability of sanitization treatment-exposed eggs are presented in Table 2. Panelists (n = 50) were asked to evaluate their overall like or dislike for egg flavor and texture for the 4 treatments. A 9-point hedonic scale (1: dislike to 9: like) was used to determine panelists' evaluation of the samples. Analysis of results indicates there was no significant difference in overall flavor perceived by panelists between any of the treatments. Mean flavor scores were 6.7, 7.2, 6.7, and 6.7 for control, chlorine, QAC, and H_2O_2+UV-treated eggs, respectively (Table 2). Conversely, egg texture evaluation did identify a significant difference between treatments with respect to acceptability/consumer liking. Panelists scored chlorine-treated eggs as having higher texture acceptability versus other treatments ($P < 0.05$). However, it is important to note that the mean difference was less than 1 point between the chlorine treated eggs and untreated eggs. While this difference was found to be statistically significant due to the large number of study participants, it is unlikely that the average consumer would detect a noticeable difference between the textures of the cooked eggs. No differences were identified by panelists in texture acceptability between the control, QAC, and H_2O_2+UV-treated eggs.

CONCLUSIONS

In summary, eggshell sanitization with the H_2O_2+UV treatment process produced the greatest reduction in eggshell-contaminating aerobic bacteria as compared to chlorine, QAC, PAA, and PAA+UV. Eggs treated with chlorine did not have different APC compared to control eggs immediately following treatment (d 0 of storage), though reductions in APC were observed at 7 and 14 d of storage. Data from eggs inoculated with SE indicate that all sanitization treatments reduced SE below the level of detection immediately following treatment. In addition, the consumer sensory analysis found that scrambled eggs prepared from eggs treated with H_2O_2+UV did not differ in consumer liking of flavor compared to untreated eggs or eggs treated with other sanitizers commonly used in the commercial egg industry (chlorine or QAC). Therefore, the use of H_2O_2+UV could be an acceptable replacement for the current sanitizers used in the processing of shell eggs, thus providing shell egg processors with the ability to enhance the microbiological safety of shell eggs. These findings could have important implications where the use of certain chemical sanitizers such as chlorine or QAC are not desirable (i.e., organic production) or the disposal of waste water containing compounds such as chlorine or QAC might be an environmental concern.

ACKNOWLEDGEMENTS

The authors would like to thank the US Poultry and Egg Association Harold E. Ford Foundation for providing financial support of this research through Project #F041. The authors would also like to thank Gerardo Casco for providing technical assistance in conducting the laboratory experiments.

REFERENCES

Al-Ajeeli. 2013. Development of best practices for shell egg disinfection based upon efficacy and eg quality. Master of Science Thesis. Texas A&M University, College Station, TX.

Buhr, R. J., J. L. Spickler, A. R. Ritter, D. V. Bourassa, N. A. Cox, L. J. Richardson, and J. L. Wilson. 2013. Efficacy of combination chemicals as sanitizers of *Salmonella*-inoculated broiler hatching eggshells. J. Appl. Poult. Res. 22:27–35.

CDC. 2010. Multistate outbreak of human Salmonella Enteritidis infections associated with shell eggs (final update). Accessed May 13, 2014. http://www.cdc.gov/salmonella/enteritidis/.

Cox, N. A., L. J. Richardson, R. J. Buhr, M. T. Musgrove, M. E. Berrang, and W. Bright. 2007. Bactericidal effects of several chemicals and hatching eggs inoculated with *Salmonella* serovar Typhimurium. J. Appl. Poult. Res. 16:623–627.

Department of Health and Human Services-Food and Drug Administration. 2009. Prevention of *Salmonella* Enteritidis in shell eggs during production, storage, and transportation (Final Rule). Fed. Regist. 74:33030–33101.

Favier, G. I., M. E. Escudero, and A. M. S. de Guzmán. 2001. Effect of chlorine, sodium chloride, trisodium phosphate, and ultraviolet radiation on the reduction of *Yersinia enterocolitica* and mesophilic aerobic bacteria from eggshell surfaces. J. Food Prot. 64:1621–1623.

Favier, G. I., M. E. Escudero, M. A. Mattar, and A. M. S. de Guzmán. 2000a. Survival of *Yersinia enterocolitica* and mesophilic aerobic bacteria on eggshell after washing with hypochlorite and organic acid solutions. J. Food Prot. 63:1053–1057.

Favier, G. I., M. E. Escudero, L. Velázquez, and A. M. S. de Guzmán. 2000b. Reduction of *Yersinia enterocolitica* and mesophilic aerobic bacteria in egg-shell by washing with surfactants and their effect on the shell microstructure. Food Microbiol. 17:73–81.

FDA. 2010. Recall of shell eggs. Accessed May 13, 2014. http://www.fda.gov/Safety/Recalls/MajorProductRecalls/ucm223522.htm.

Gottselig, S. M. 2011. Reduction of *Salmonella* Typhimurium on eggshell surfaces using ultraviolet light and hydrogen peroxide. Master of Science Thesis. Texas A&M University, College Station, TX.

Hartman, P. A., and F. Carlin. 1957. Peracetic acid treatment of eggs. Poult. Sci. 36:673–675.

Hierro, E., S. Manzano, J. A. Ordóñez, L. de la Hoz, and M. Fernández. 2009. Inactivation of *Salmonella enterica* serovar Enteritidis on shell eggs by pulsed light technology. Int. J. Food Microbiol. 135:125–130.

Jones, D. R. 2010. Microbiological and physical quality changes in vacuum loader cups associated with the use of various sanitizing compounds. Poult. Sci. 89:564–569.

Knape, K. D., J. B. Carey, R. P. Burgess, Y. M. Kown, and S. C. Ricke. 1999. Comparison of chlorine with an iodine-based compound on eggshell surface microbial populations in a commercial egg washer. J. Food Safety. 19:185–194.

McKee, S. R., Y. M. Kwon, J. B. Carey, A. R. Sams, and S. C. Ricke. 1998. Comparison of a peroxidase-catalyzed sanitizer with other egg sanitizers using a laboratory-scale sprayer. J. Food Safety. 18:173–183.

Meilgaard, M. C., G. V. Civille, and B. T. Carr. 2007. Sensory Evaluation Techniques. 4th ed. CRC Press, Boca Raton, FL.

Moats, W. A. 1981. Antimicrobial activity of compounds containing active chlorine and iodine in the presence of egg solids. Poult Sci. 60:1834–1839.

Morton, R. D. 2001. Aerobic plate count. Pages 63–68 in Compendium of Methods for the Microbiological Examination of Foods. F. P. Downes, and K. Ito eds. American Public Health Association, Washington, DC.

Musgrove, M. T., N. A. Cox, Jr, L. J. Richardson, D. R. Jones, and J. K. Northcutt. 2006. Comparison of shell egg sanitizers and application methods. Poult. Sci. 85:162.

Musgrove, M. T., D. R. Jones, J. K. Northcutt, M. A. Harrison, and N. A. Cox. 2005. Impact of commercial processing on the microbiology of eggs. J. Food Prot. 68: 2367–2375.

Oliveira, D. D., and E. N. Silva. 2000. *Salmonella* in table eggs: occurrence in retails, storage conditions and eggshell disinfections. Arq. Bras. Med. Vet. Zoo. 52:655–661.

Painter, J. A., R. M. Hoekstra, T. Ayers, R. V. Tauxe, C. R. Braden, F. J. Angulo, and P. M. Griffin. 2013. Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998–2008. Emerg. Infect. Dis. 19:407–415.

Rajala-Mustonen, R. L., P. S. Toivola, and H. Heinonen-Tanski. 1997. Effects of peracetic acid and UV irradiation on the inactivation of coliphages in wastewater. Water Sci. Technol. 35: 237–241.

USDA-AMS. 2000. Egg-Grading Manual. Accessed May 13, 2014. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName = STELDEV3004502.

Wells, J. B., C. D. Coufal, H. M. Parker, and C. D. McDaniel. 2010. Disinfection of eggshells using ultraviolet light and hydrogen peroxide independently and in combination. Poult. Sci. 89:2499–2505.

Woodring, K. S. 2011. Quality and sensory attributes of shell eggs sanitized with a combination of hydrogen peroxide and ultraviolet light. Master of Science Thesis. Texas A&M University, College Station, TX.