

The effects of commercial cool water washing of shell eggs on Haugh unit, vitelline membrane strength, aerobic microorganisms, and fungi

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ABSTRACT Current egg washing practices use wash water temperatures averaging 49°C and have been found to increase internal egg temperature by 6.7 to 7.8°C. These high temperatures create a more optimal environment for bacterial growth, including *Salmonella* Enteritidis if it is present. *Salmonella* Enteritidis is the most common human pathogen associated with shell eggs and egg products. Its growth is inhibited at temperatures of 7.2°C and below. The objective of this study was to determine if commercially washing eggs in cool water would aid in quickly reducing internal egg temperature, preserving interior egg quality, and slowing microbial growth. During 3 consecutive days, eggs were washed using 4 dual-tank wash water temperature schemes (HH = 49°C, 49°C; HC = 49°C, 24°C; CC = 24°C, 24°C; CH = 24°C, 49°C) at 2 commercial processing facilities. A 10-wk storage study followed, in which vitelline membrane strength, Haugh unit, and

aerobic microorganisms and fungi (yeasts and molds) were monitored weekly. As storage time progressed, average Haugh unit values declined 14.8%, the average force required to rupture the vitelline membrane decreased 20.6%, average numbers of bacteria present on shell surfaces decreased 11.3%, and bacteria present in egg contents increased 39.5% during storage. Wash water temperature did not significantly affect Haugh unit values, vitelline membrane strength, or the numbers of aerobic microorganisms and fungi within the shell matrices of processed eggs. Results of this study indicate that incorporating cool water into commercial shell egg processing, while maintaining a pH of 10 to 12, lowers postprocessing egg temperatures and allows for more rapid cooling, without causing a decline in egg quality or increasing the presence of aerobic microorganisms and fungi for approximately 5 wk postprocessing.

Key words: shell egg, cool wash, egg quality, bacteria, fungi

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INTRODUCTION

Shell egg processors who choose to produce USDA shielded eggs must abide by specific USDA regulations. One such regulation states that egg wash water must be at least 32.2°C, or 11.1°C warmer than the warmest egg entering the processing line [7 CFR 56.76(f)(3)]. Due to this regulation, eggs from in-line operations (hen houses directly connected to the processing facility) can be washed in water as hot as 48.9°C. Research supporting the regulation was conducted by Brant et al. in 1966 (Brant et al., 1966). In 1940, Haines and Moran observed that when eggs are placed in a bacteria suspension cooler than their internal temperature,

a negative pressure gradient is created, drawing bacteria through the shell and into the interior of the egg (Haines and Moran, 1940). In 1952, Lorenz and Starr discovered that eggs washed in cold water were more likely to spoil than eggs washed in warm water (Lorenz and Starr, 1952). When this research was conducted, however, the most common way to wash eggs was by immersion washing. Eggs were placed in a wire basket, a household laundry or dish detergent was added, the basket and the eggs were submerged in water, and they were agitated for approximately 1 to 3 min (Hutchison et al., 2003). In 1975, immersion washing was banned in the United States and replaced by spray washing (USDA, 1975).

The most recent regulation pertaining to egg processing applies to all shell eggs and requires them to be stored in a postprocessing environment of 7.2°C or below (USDA, 1999). This regulation was established to control potential spoilage and foodborne pathogens

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(specifically *Salmonella* Enteritidis) that may contaminate eggs. Studies have shown that due to washing, grading, and packaging, postprocessing internal egg temperatures can be 6.1 to 7.8°C higher than initial egg temperatures (Anderson et al., 1992). When compared with a single-wash tank, dual-wash tank systems commonly used by most egg processors mean that the shell eggs will stay in a hot wet environment for a longer period of time (Curtis, 1999). After being processed, eggs are typically packaged in pulp or foam cartons or cardboard flats, placed in cases, and palletized. In addition to the initial increase, insulation provided by packaging conditions can cause the internal temperature of the eggs to continue to increase (Anderson et al., 1992). The internal temperature of packaged eggs can continue to increase for up to 6 h after eggs are placed in a cooler. In fact, it may actually take the centermost egg in a pallet 5 to 6 d to reach an internal temperature of 7.2°C when stored in an environment with an ambient temperature of 7.2°C (Anderson et al., 1992; Chen et al., 2002; Jones et al., 2002b). It is important for the internal temperature of an egg to be below 7.2°C as quickly as possible because *Salmonella* Enteritidis, the organism most often associated with egg-borne outbreaks, does not grow well below this temperature (Gast and Holt, 2000; Bell and Kyriakides, 2002). Because most eggs reach the retail outlet in a relatively short period of time (Bell et al., 2001; Patterson et al., 2001), reducing their internal temperature to 7.2°C or below before they are purchased by consumers can be challenging.

Measuring Haugh unit (HU) values and vitelline membrane strength are 2 ways to assess internal quality of an egg. Determining the HU is a common way to assess interior egg quality (Haugh, 1937) and has been accepted by USDA-Agricultural Marketing Service as a valid and reliable method (USDA, 2000). It is a function of egg weight and the height of the thick albumen (Haugh, 1937). The HU value, like vitelline membrane strength, tends to decline as the egg ages (Williams, 1992; Jones et al., 2002b; Jones and Musgrove, 2005; Samli et al., 2005). The vitelline membrane, which surrounds the yolk, is responsible for keeping the yolk contents separate from the albumen. Determining vitelline membrane strength is important because a strong vitelline membrane will prevent the yolk contents from diffusing into the albumen. The yolk contains nutrients that are a good growth medium for bacteria (Clay and Board, 1991; Humphrey and Whitehead, 1993; Gast and Holt, 2000). When the vitelline membrane weakens or breaks, these nutrients can contaminate the albumen and possibly inhibit its antimicrobial properties (Clay and Board, 1991; Humphrey and Whitehead, 1993; Humphrey, 1994; Gast and Holt, 2000) or allow bacteria to penetrate the yolk (Jones et al., 2002a; Conner et al., 2003; Chen et al., 2005).

Scientists have been focusing on ways to reduce the internal temperature of an egg during and after processing. Methods based on the use of cryogenic gases as well

as forced cool air to rapidly cool shell eggs postprocessing have been developed (Curtis et al., 1995; Thompson et al., 2000). Although it has been shown that egg quality is maintained or even enhanced by these methods of rapid cooling (Curtis et al., 1995; Thompson et al., 2000; Jones et al., 2002b), the use of these methods by the egg industry has been limited due to cost and space constraints. It has been suggested that washing eggs in cool water, as opposed to warm water, would help diminish the increase in internal egg temperature during processing. This would, in turn, aid in reaching and maintaining a postprocessing internal egg temperature of 7.2°C more economically.

Previous research indicates that washing eggs in cool water could be a viable means of maintaining or enhancing egg cooling and subsequent physical and microbial quality during storage. Cooler wash water temperatures help to reduce the amount of time needed to cool eggs (Lucore et al., 1997). By commercially processing shell eggs at 4 different wash water temperature schemes, this study examined how cool water washing affects interior egg quality, as well as aerobic bacterial levels and yeasts and molds on and within the egg.

MATERIALS AND METHODS

Egg Processing

This study was conducted in 2 commercial shell egg processing facilities (A and B). At each facility, shell eggs were washed after regular processing hours over 3 consecutive days (replicates). Both facilities were operated by the same integrator, were producing USDA shielded product, and used dual-washer systems from the same manufacturer to wash eggs. To determine the effects of washing shell eggs in cool water, the wash water used in this study was collected after it had been recirculated for 4 h during the regular processing day and included organic and microbial contaminants. This created a worst-case scenario and enabled us to better determine the effects of cool water washing by taking into account the recycling of wash water. The previously used wash water in each wash tank was pumped into four 55-gal (208.2 L) drums (Consolidated Plastics Co. Inc., Twinsburg, OH). To prevent rust contamination, the interior of each drum was treated with a corrosive inhibitor. Once the drums were filled with the previously used wash water, they were placed in the postprocessing cooler of the processing facility, which had an ambient temperature of approximately 7.2°C. The temperature of the wash water was then lowered to 23.9°C or slightly lower. To lower the wash water temperature, the drums remained in the postprocessing cooler of the facility for approximately 5 to 12 h before conducting the study.

Eggs were processed using 4 wash water temperature schemes: 48.9°C, 48.9°C (**HH**); 48.9°C, 23.9°C (**HC**); 23.9°C, 23.9°C (**CC**); and 23.9°C, 48.9°C (**CH**) (temperature of the first and second washer, respectively).

The pH of the wash water from each plant was also monitored to ensure that it was maintained between 10 and 12 (sensION 156, Hach Co., Loveland, CO). The average wash water pH was 11.14 and 10.85 from facility A and B, respectively. Approximately 1 pallet of eggs for each temperature scheme was processed in the same order (HH, HC, CC, CH) each day at each facility. After processing, the eggs were packaged in new, clean pulp flats containing 30 eggs per flat. The flats were packaged in cardboard cases, and the cases were palletized. One 30-case pallet (case = 30 dozen eggs, $n = 10,800$) was formed for each temperature scheme. As the eggs were being palletized, a DataWatch data logger (Global Sensors, Mount Holly, NC) was placed into 3 different cases in the pallet for each wash water temperature scheme. Cases containing a data logger were placed on the top, in the middle, and at the bottom of the pallets. All eggs were then stored at 7.2°C in the postprocessing cooler of the facility. The data loggers collected internal and external egg temperatures every 3 min for 2 wk postprocessing. Figure 1 shows a graphical representation of the average cooling data gathered from each processing facility.

Storage Study

For 10 wk postprocessing, processed eggs were stored in an environment with an ambient temperature of ap-

proximately 7.2°C until analysis. Each week of storage included 3 replicates from each processing facility (representing the 3 consecutive days of processing at each facility). During each week of storage (wk 0 = week of processing), eggs were randomly selected to undergo testing to determine their internal and microbial quality.

HU

Each week of storage, HU values were determined for the 3 replicates from each processing plant. For each replicate, HU values were determined for 18 eggs per temperature scheme (72 eggs per replicate) using the procedure described by Haugh (1937). The eggs were removed from storage and candled to exclude any cracked eggs. Shortly after being removed from storage, while the eggs were still cool, HU values, along with albumen height and egg weight, were determined using an Egg Multi-Tester EMT 5200 (Robotmation Co. Ltd., Tokyo, Japan).

Vitelline Membrane Strength

Vitelline membrane strength was also determined for 3 replicates per storage week for each processing plant. For each replicate, a 21-egg sample from each temperature scheme (84 eggs per replicate) was removed from

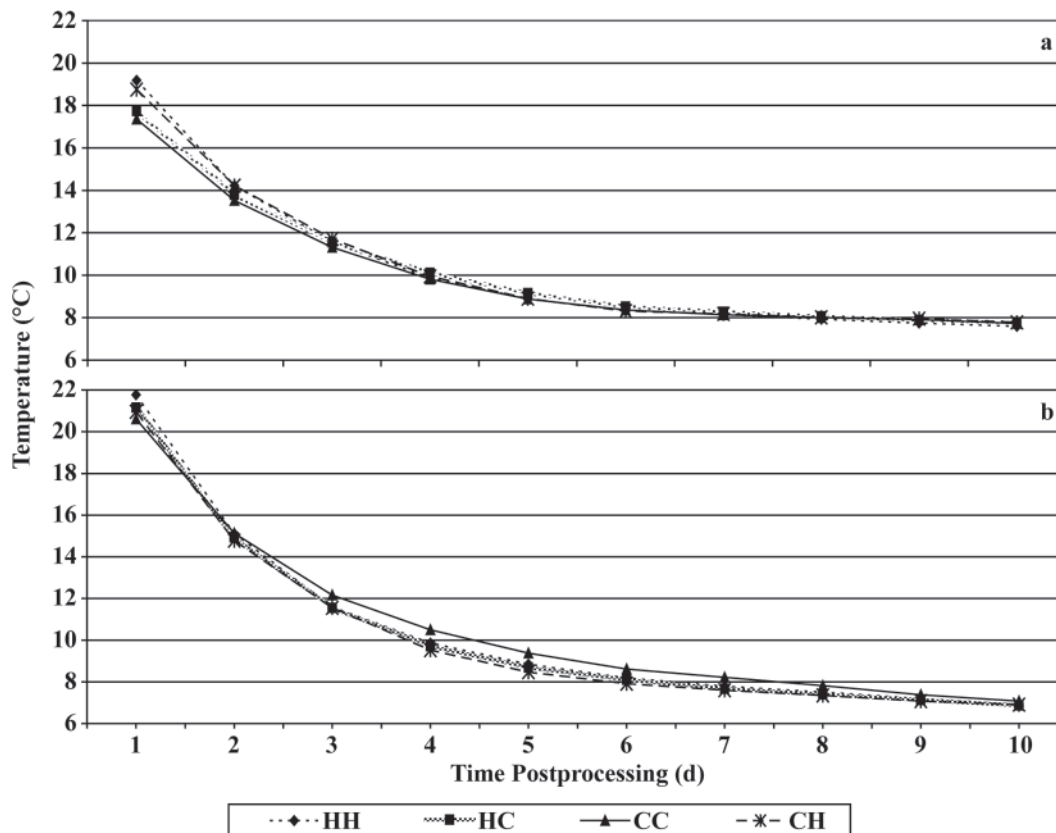


Figure 1. Average postprocessing cooling curves for eggs processed at facility A (a) and facility B (b). HH = 49°C , 49°C ; HC = 49°C , 24°C ; CC = 24°C , 24°C ; CH = 24°C , 49°C .

storage. Shortly after being removed from storage, while the eggs were still cool, vitelline membrane strength was determined using a Texture Technologies TA-XT2i texture analyzer (Texture Technologies, Scarsdale, NY). A texture analyzer determines vitelline membrane strength using static compression (Jones et al., 2002b; Conner et al., 2003; Keener et al., 2006). Before the assessment was conducted, all eggs were candled, and cracked eggs were excluded from testing. Each egg was individually broken into a shallow dish and the yolk was positioned under a 1-mm, rounded end, stainless steel probe. Because Lyon et al. (1972) reported that the strongest section of the vitelline membrane is near the chalazae, care was taken to ensure that measurements were not obtained from this area. Direct pressure was applied to the yolk until the vitelline membrane ruptured and the probe penetrated the yolk. Compression measurements were made using a 5-kg load cell (calibrated using a 2-kg weight), 0.1 g of trigger force, and 3.2 mm/s test speed. Vitelline membrane breaking strength was recorded as grams of force required to rupture the membrane. The force required to break the vitelline membrane corresponds to its strength; a strong membrane requires more force to break.

Microbial Analysis

During each week of storage, microbial analysis was conducted for the 3 replicates per processing facility. For each replicate, 27 eggs per temperature scheme (108 eggs per replicate) were aseptically removed from storage and candled. Cracked eggs were excluded from testing. Each egg was placed into a sterile plastic bag with 25 mL of buffered peptone water (BPW). Each bag was then gently shaken for approximately 1 min. The BPW rinses for 9 eggs were combined, resulting in 3 sets of pooled exterior rinse samples. Three 3M Petrifilm Aerobic Count plates and three 3M Petrifilm Yeast & Mold Count plates (3M, St. Paul, MN) per pooled sample were inoculated with 1 mL each from the exterior rinse samples. Eggs were individually removed from the plastic bags using sterile tongs. To sanitize the exterior shell surface, each egg was briefly dipped into 95% ethyl alcohol and momentarily passed through the flame of a laboratory burner. The eggs were then cracked, using the edge of a sterile surface, and the contents of 9 eggs were placed in a sterile plastic bag. The shells of those 9 eggs were also placed into a separate sterile plastic bag. This resulted in 3 pooled sets of egg contents and 3 pooled sets of egg shells. The shells were then gently crushed by hand once they were inside the sterile bag. Due to the use of 3M Petrifilm plates, BPW (90 mL) was added to the egg shell and content pools in accordance with 3M Petrifilm sample preparation guidelines. The sterile bags containing the egg shells and BPW were then gently shaken for approximately 1 min. Three 3M Petrifilm Aerobic Count plates and three 3M Petrifilm Yeast & Mold Count plates per pooled sample were inoculated with 1 mL of BPW

from the crushed (interior) shell rinse. Because the shell membranes were not separated from the actual shell, interior shell samples include what is located between the inside of the shell and the shell membranes. To create a 1:10 dilution, 10 mL of egg contents was removed from each pooled set and added to 90 mL of BPW. Before three 3M Petrifilm Aerobic Count plates and three 3M Petrifilm Yeast & Mold Count plates per pooled sample were inoculated with 1 mL of a 1:10 dilution of egg contents, the mixture was placed in a Seward Stomacher (Seward Ltd., Norfolk, UK) and homogenized for 1 min at 200 rpm. All inoculated 3M Petrifilm Aerobic Count plates were incubated at 37°C for approximately 48 h, and all 3M Petrifilm Yeast & Mold Count plates were incubated at 20°C for approximately 5 d. After incubation, colonies were enumerated according to recommendations of the manufacturer.

Statistical Analysis

Previous research conducted to determine the effects of cool water washing of shell eggs has been performed in a laboratory setting (Lucore et al., 1997; Jones et al., 2005). Thus, the main purpose of this study was to determine the effects of cool water washing when conducted in a commercial setting, rather than a controlled laboratory environment, there can be many variables. In this study, the presence of these variables (facility and employee sanitation, environmental conditions, and management) allowed us to more realistically compare cool water washing to the high temperatures currently required for egg processing. Variables such as management, sanitation, egg age, type of processing (in-line vs. off-line), and postprocessing cooler temperature were different at each processing facility. Because processing environments differed, significant facility differences were found in the data collected. An example of these differences can be seen in the postprocessing cooling data (Figure 1), average HU scores (Figure 2a), and average amounts of bacteria present on exterior shell surfaces (Figure 2b). As seen in Figure 1, eggs processed at facility A had lower average postprocessing temperatures than eggs processed at facility B. Figure 2a shows that, until wk 4 of storage, eggs processed at facility A had higher average HU values than those processed at facility B. Also, throughout 10 wk of storage, eggs processed at facility B had more bacteria present on exterior shell surfaces than eggs processed at facility A. Due to confounding variables, data from both processing facilities were combined before statistical analysis and a randomized complete block experimental design (block = processing facility) was used to compare effects of wash water temperature scheme and extended storage.

All data were analyzed using SAS Institute (1999). Force required to rupture the vitelline membrane, HU values, and albumen height were analyzed according to the GLM. All aerobic microorganisms, yeasts, and

mold count data were also analyzed according to the GLM; however, the raw data were subjected to a log transformation before analysis. Because serial dilutions in BPW were prepared from all samples, bacterial counts from plates with no bacterial growth were recorded as 0.9 after log transformation. Any means that were found to be significantly different ($P \leq 0.05$) were separated using the least squares means option of the GLM procedure.

RESULTS

HU

Average HU values were not significantly different among wash water temperature schemes (HH = 67.5; HC = 68.0; CC = 67.6; CH = 68.0). However, as seen in Table 1, there was a significant ($P \leq 0.05$) difference in average HU values between storage weeks; at the end of 10 wk of storage, average HU values had declined 14.8%. Scientists have questioned the validity of the HU as an accurate indicator of interior egg quality (Silver-sides et al., 1993); therefore, as an alternative method of determining interior quality, albumen height data were also analyzed. Wash water temperature scheme did not significantly affect average albumen height (HH = 4.8 mm; HC = 4.9 mm; CC = 4.9 mm; CH = 4.9 mm). As seen in Table 1, there were, however, significant ($P \leq 0.05$) differences in the average albumen height over 10

wk of storage. Due to storage, average albumen height decreased 23.2%.

Vitelline Membrane Strength

The average force required to rupture the vitelline membrane was also not significantly affected by wash water temperature (HH = 1.57 g; HC = 1.55 g; CC = 1.57 g; CH = 1.56 g). Like average HU values and albumen height, vitelline membrane strength also significantly ($P \leq 0.05$) decreased (20.6%) during 10 wk of storage (Table 1).

Microbial Analysis

Wash water temperature did not significantly affect numbers of aerobic microorganisms (log cfu/mL) present within shell matrices (HH = 2.98; HC = 3.07; CC = 3.12; CH = 3.03). There were, however, significant ($P \leq 0.05$) temperature scheme \times storage week interactions in numbers of aerobic microorganisms present on exterior shell surfaces (Figure 3) and in egg contents (Figure 4). In this study as with previous studies, normal variation was observed in the overall growth trend of aerobic microorganisms present on exterior shell surfaces during extended storage (Jones et al., 2004, 2005). Although the number of microorganisms present decreased 90% by wk 3 of storage (1.7 vs. 2.7 log cfu/mL initially present), the greatest numbers of

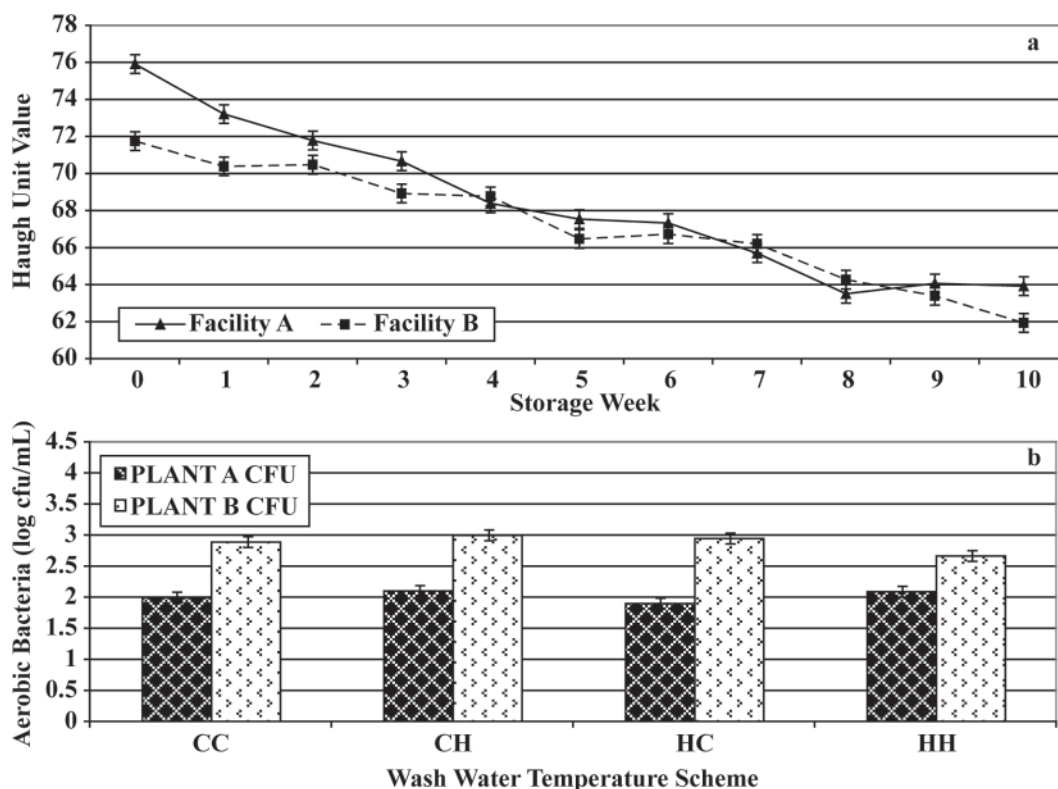


Figure 2. Effects of processing environment on average Haugh unit values over 10 wk of storage (a) and average amounts of aerobic bacteria present on exterior shell surfaces among wash water temperature schemes (b). HH = 49°C, 49°C; HC = 49°C, 24°C; CC = 24°C, 24°C; CH = 24°C, 49°C.

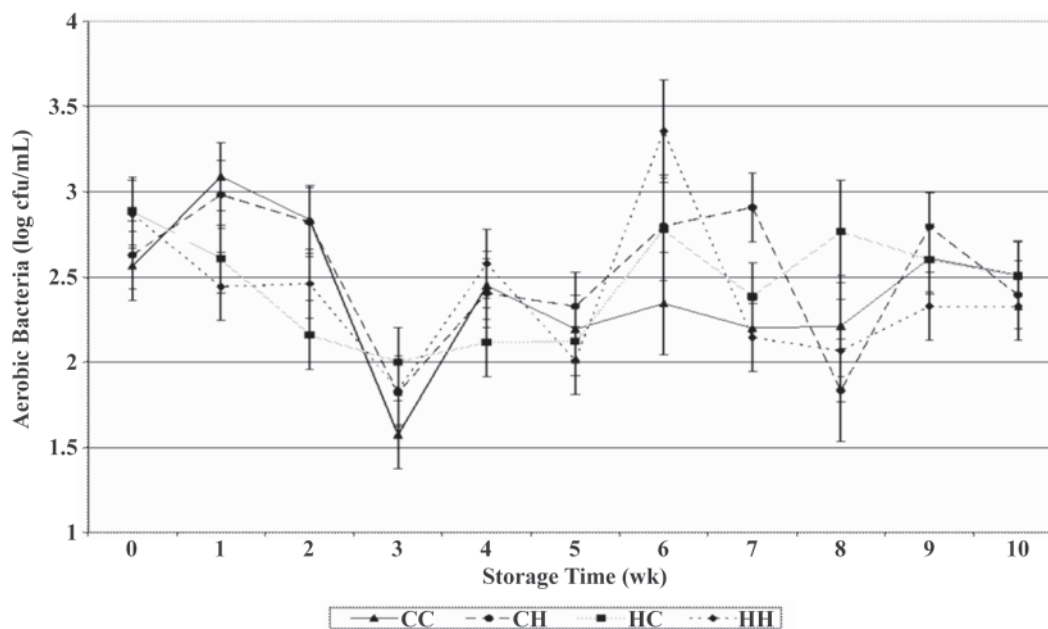


Figure 3. Effects of wash water temperature scheme and postprocessing storage time on average amounts of aerobic bacteria present on exterior shell surfaces. HH = 49°C, 49°C; HC = 49°C, 24°C; CC = 24°C, 24°C; CH = 24°C, 49°C.

microorganisms present on exterior shell surfaces (2.9 log cfu/mL) and in egg contents (3.8 log cfu/mL) during storage were recovered from eggs processed in the HH temperature treatment after 6 wk of storage. Average numbers of microorganisms present in egg contents significantly ($P \leq 0.05$) increased from 1.3 to 3.2 log cfu/mL during storage. During the first 3 wk of storage, microbial growth was minimal, but then steadily increased. Microbial growth increased from 2.4 to 3.4 log cfu/mL over 10 wk.

Amounts of fungi (yeast and molds) present within the shell matrices of eggs, nor numbers of fungi present in egg contents, were not significantly affected by wash water temperature treatments. Statistically significant ($P \leq 0.05$) differences were found between storage weeks in numbers of fungi present within the shell matrices and in egg contents (Table 2). However, the enumerated levels were extremely low and outside of the recommended levels for determination on the media.

Furthermore, the results were no more than 0.22 log cfu/mL different, which is biologically no difference.

DISCUSSION

Analysis of the data collected during this study indicates that wash water temperature does not significantly affect average HU values, albumen height, vitelline membrane strength, or average amounts of aerobic bacteria, yeast, and mold present within the shell matrix of eggs. Wash water temperature did affect average numbers of aerobic microorganisms and fungi present on exterior shell surfaces (Figures 3), average numbers of fungi present within the shell matrices of eggs, and average numbers of aerobic microorganisms present in egg contents (Figure 4) at certain sampling times during extended storage. Differences in microbial growth in egg contents due to the effects of wash water temperature and storage time did not affect microbial

Table 1. Average Haugh unit values, albumen height, and force required to rupture the vitelline membrane of eggs from combined processing facilities for each week of storage

| Storage week | Haugh unit | Albumen height | Vitelline membrane force (g) |
|--------------|--------------------|--------------------|------------------------------|
| 0 | 73.8 ^G | 5.61 ^H | 1.75 ^F |
| 1 | 71.8 ^F | 5.35 ^G | 1.72 ^F |
| 2 | 71.1 ^{EF} | 5.25 ^{FG} | 1.70 ^F |
| 3 | 69.8 ^{DE} | 5.09 ^{EF} | 1.56 ^{DE} |
| 4 | 68.6 ^{CD} | 4.94 ^{DE} | 1.59 ^E |
| 5 | 67.0 ^{BC} | 4.78 ^{CD} | 1.55 ^{CDE} |
| 6 | 67.0 ^{BC} | 4.74 ^{CD} | 1.57 ^{DE} |
| 7 | 65.9 ^B | 4.63 ^{BC} | 1.49 ^{BCD} |
| 8 | 63.9 ^A | 4.43 ^{AB} | 1.43 ^{AB} |
| 9 | 63.7 ^A | 4.40 ^A | 1.47 ^{ABC} |
| 10 | 62.9 ^A | 4.32 ^A | 1.39 ^A |
| SEM | 0.36 | 0.04 | 0.02 |

^{A-H}Means within a column with different letters are significantly different ($P \leq 0.05$).

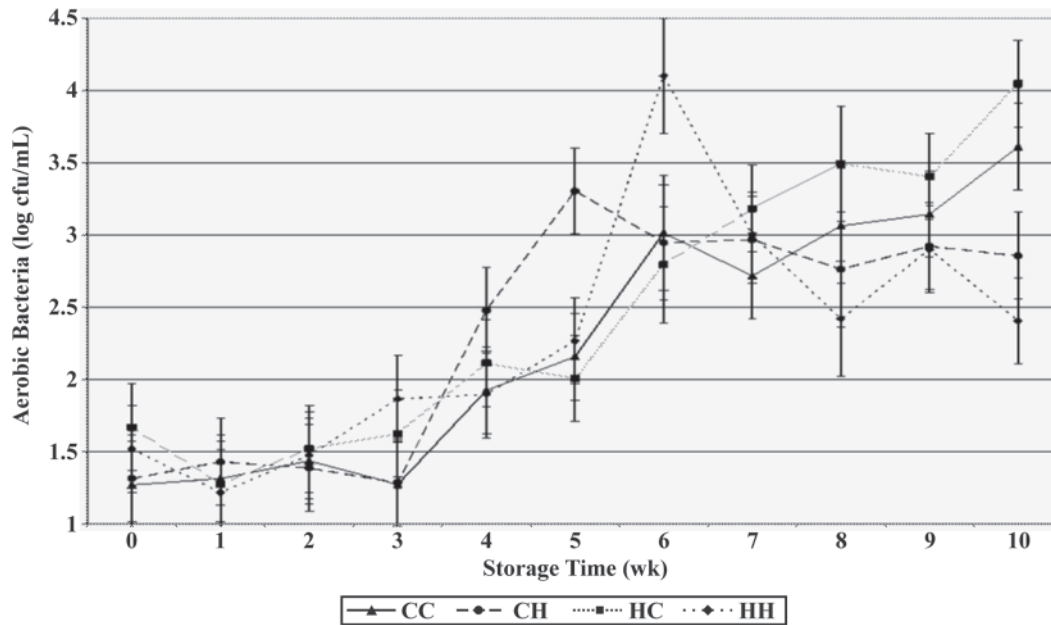


Figure 4. Effects of wash water temperature scheme and postprocessing storage time on average amounts of aerobic bacteria present in egg contents. HH = 49°C, 49°C; HC = 49°C, 24°C; CC = 24°C, 24°C; CH = 24°C, 49°C.

quality until approximately wk 5 of storage and later (Figure 4). Although significant, these differences are of little importance because it is beyond the average sell-by date of eggs. According to Bell et al. (2001) and Patterson et al. (2001), eggs currently processed in the United States have an average sell-by date of 30 d and are usually sold by 19 d postprocessing. Also, the expiration date for shell eggs, which indicates the maximum time frame for expected quality, cannot legally exceed 45 d (USDA, 2000). Furthermore, when Jones et al. (2006) examined the effects of wash water temperature scheme (HH, HC, and CC only) on the presence of *Campylobacter*, *Listeria*, and *Salmonella* within shells processed during the current study, they isolated *Campylobacter* and *Salmonella* in shell and membrane emulsion samples during the first 2 wk postprocessing from CC and HC eggs. However, no pathogens were detected on eggs from any treatment after 2 wk postprocessing.

The results of this study are consistent with those reported by Lucore et al. (1997). They reported that internal microbial counts from eggs spray-washed with water as cool as 15.5°C were no different from internal microbial counts of eggs spray-washed with 48.9°C water. In a more recent inoculation study, Hutchison et al. (2004) found that wash and rinse water temperatures did not significantly affect surface populations of *Salmonella* Enteritidis. However, they also reported that allowing wash and rinse water temperatures to decrease below 34°C caused a significant amount of content contamination. Although it is not clear why, it is possible that the results reported by Lucore et al. (1997) contradict the findings of Hutchison et al. (2004) due to a difference in wash water pH, a difference in washing environment and equipment (pilot egg processing

equipment in a pilot plant vs. a laboratory setting), or because the temperature of only the wash water was lowered and the rinse water temperature remained consistent with USDA guidelines [7 CFR 56.76(f)(11)]. It should be noted that wash water pH is essential to the effectiveness of egg washing. Catalano and Knabel (1994) reported that maintaining wash water conditions at pH 11 or above prevents possible cross-contamination caused by recycled wash water by effectively reducing the number of *Salmonella* Enteritidis present on egg shells and in wash water.

Regardless of wash water temperature, as storage time progressed, the overall average HU values, albumen height, and vitelline membrane strength significantly decreased (Table 1) as has been reported by other researchers (Elliot and Brant, 1957; Hartung and

Table 2. Average amounts of yeast present within the shell matrix (interior) and in the contents of processed eggs for each week of storage

| Storage week | Yeast (log cfu/mL) | |
|--------------|----------------------|--------------------|
| | Interior | Contents |
| 0 | 1.00 ^A | 1.00 ^A |
| 1 | 1.00 ^A | 1.00 ^A |
| 2 | 1.03 ^{AB} | 1.03 ^A |
| 3 | 1.08 ^{ABC} | 1.02 ^A |
| 4 | 1.10 ^{ABCD} | 1.12 ^B |
| 5 | 1.12 ^{ABCD} | 1.06 ^{AB} |
| 6 | 1.17 ^{CD} | 1.06 ^{AB} |
| 7 | 1.22 ^D | 1.06 ^{AB} |
| 8 | 1.06 ^{ABC} | 1.05 ^{AB} |
| 9 | 1.13 ^{BCD} | 1.04 ^{AB} |
| 10 | 1.11 ^{ABCD} | 1.05 ^{AB} |
| SEM | 0.02 | 0.01 |

^{A-D}Means within a column with different letters are significantly different ($P \leq 0.05$).

Stadleman, 1963; Williams, 1992; Silversides and Scott, 2001; Jones et al., 2002b; Conner et al., 2003; Chen et al., 2005; Jones and Musgrove, 2005; Samli et al., 2005).

Because scientists have questioned the validity of the HU as an accurate indicator of interior egg quality (Silversides et al., 1993), albumen height was measured throughout this study as an alternative means of determining egg quality. Although the HU is commonly used to measure interior quality, there are limitations associated with HU measurements. The HU is a relationship between egg weight and height of the thick albumen. The calculation is weighted exclusively for a 56.7-g (2 oz) egg (US size large), which is why scientists have argued that the calculation is inaccurate for eggs other than size large. More recently, scientists have reported that albumen height and the HU value equally portray albumen quality (Silversides and Villeneuve, 1994). Analysis of data gathered in the current study indicates the same.

Maintaining interior egg quality is important because quality decline is generally accompanied by increased microbial growth. The 2005 risk assessments of *Salmonella* Enteritidis in shell eggs and *Salmonella* spp. in egg products predicted that rapid cooling of eggs would be one of the most effective means of reducing illnesses from *Salmonella* Enteritidis-contaminated eggs (USDA, 2005). The physiological and chemical changes responsible for quality decline in eggs are accelerated by high temperatures, which is why it is important to cool eggs as quickly as possible (Romanoff and Romanoff, 1949; Rhorer, 1991; Chen et al., 2002; Conner et al., 2002; Kim et al., 2003). Data collected by Jones et al. (2006) and the postprocessing cooling data collected during this study show that washing eggs in cool water successfully reduces the excessive temperature caused by high water temperatures in dual-wash tanks. Jones et al. (2006) found that the surface temperature of shell eggs decreased when exposed to 23.9°C wash water. In the current study, eggs processed using the CC temperature scheme had the lowest average postprocessing temperatures, and eggs washed in the HH scheme had the highest. Although eggs processed in the HC and CH temperature schemes did not have the lowest postprocessing temperatures, they cooled more quickly than eggs processed by the HH treatment. By replacing the warm water from one wash tank with cool water, eggs are exposed to less heat during processing and are able to cool much faster than eggs processed using only hot water.

The overall results of this study suggest that commercially washing shell eggs with cool water, while maintaining a pH of 10 to 12, has the potential to reduce internal egg temperature during and after processing, without causing a decline in egg quality or increasing the presence of microorganisms and fungi for approximately 5 wk postprocessing. The data collected during this study indicate that incorporating cool water

into commercial shell egg processing lowers postprocessing internal egg temperatures and allows for more rapid cooling. A more prompt reduction of internal egg temperature has the potential to enhance the physical qualities of eggs and improve their microbial quality. Maintenance of egg quality factors such as vitelline membrane strength and HU values combined with reducing internal egg temperature will aid in preventing the growth of any potential pathogenic bacteria present. Excessive wash temperatures reduce profits due to the costs associated with heating wash water and cooling eggs postprocessing (Anderson et al., 1992). Cool water washing could also provide economic benefits to the egg industry by reducing the energy needed to heat wash water, as well as by decreasing the amount of energy needed to cool eggs after processing.

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