Journal of Food Protection, Vol. 67, No. 6, 2004, Pages 1177–1183

Reduction of *Salmonella* by Two Commercial Egg White Pasteurization Methods

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MS 03-269: Received 13 June 2003/Accepted 20 October 2003

ABSTRACT

The effect of pH, processing temperatures, and preheating steps in two commercial egg white pasteurization procedures (Armour and Standard Brands methods) were evaluated using a five-strain cocktail of *Salmonella.* We devised a benchtop pasteurization system that would more closely resemble the two commercial processes than could the traditional capillary tube method. The pasteurization methods both require hydrogen peroxide to be metered into the egg white stream between a required initial preheat step and the main heating regimen. Both processes were evaluated at three pH levels (pH 8.2, 8.6, 9.0), at four temperatures (51.7°C/125°F, 53.1°C/127.5°F, 54.4°C/130°F, 55.8°C/132.5°F), and over four residence times to allow calculation of *D*-values at each temperature. When compared at the minimum allowable time and temperatures for each process, our results showed at least a 1-log greater log reduction ($P < 0.05$) for the Standard Brands method than the Armour method in 10 of 12 of the pH and temperature combinations tested. Almost all runs at any given temperature showed more reduction at pH 9.0 than at pH 8.2 except for the Standard Brands method at 54.4°C and 55.8°C, which showed the most consistent reduction across all three pH levels tested. Analysis of the preheat portion of the two methods showed that there was no contribution ($P > 0.05$) toward *Salmonella* reduction when compared with the identical process without the preheating step. We generally observed a greater reduction of *Salmonella* with egg white at pH 9.0 that is typical of older, off-line processing than with low pH egg white (i.e., 8.2) that is typical of modern in-line processing facilities. This difference was as much as 3.5 log cycles depending on the processing conditions. The data has been used to make recommendations for minimum processing conditions for hydrogen peroxide–based egg white pasteurization.

Salmonella spp. and outbreaks of salmonellosis have long been associated with egg and poultry products *(3).* Contamination of broken-out raw liquid egg with *Salmonella* spp. could be due to several reasons, including external shell-surface contamination, transshell migration, transovarian infection, or contamination during manufacture *(2, 4, 5, 11, 28).* This has been especially true with eggs, for which *Salmonella* Enteritidis is known to cause transovarian infection whereby egg white or egg yolk surfaces are contaminated before the eggs are formed, allowing subsequent migration of *Salmonella* across the membrane into the yolk *(4, 31).* As a result of internally infected shell eggs, the frequency of *Salmonella* Enteritidis–related salmonellosis reported to the Centers for Disease Control and Prevention reached a high of 3.8 per 100,000 in 1995 and then declined to 1.9 per 100,000 by 1999 *(20).* Outbreak investigations and case control studies revealed that the rise from 1976 to 1996 was due to the consumption of raw or undercooked shell eggs *(19).* Estimates vary for the number of eggs infected with *Salmonella*; however, Mason *(17)* stated that 1 in 10,000 retail shell eggs may be contaminated and that from 1 in 200 to 1 in 12 may come from infected flocks. A model designed to estimate *Salmonella* Enteritidis–contaminated eggs produced annually states that between 1 in 30,000 and 1 in 12,000 *Salmonella* Enteritidis–infected eggs are produced yearly in the United States *(8).* More recently, Hope et al. *(12)* estimated that over 660,000 people will be infected by *Salmonella* Enteritidis from the consumption of 2.3 million contaminated eggs of the 69 billion eggs produced per year.

In one study, over 5,700 naturally contaminated eggs were tested for the presence of *Salmonella,* resulting in 32 positive results and showing that the albumen was usually the site of contamination *(14).* In addition, *Salmonella* Enteritidis phage type 4 has been isolated from ovaries and oviducts of infected hens, suggesting egg contents can also be contaminated before the egg is laid via transovarian infection *(5, 13).* Gast and Holt *(10)* further indicated that *Salmonella* Enteritidis could survive storage in egg albumen. In addition to *Salmonella* Enteritidis, other species such as *Salmonella* Typhimurium and *Salmonella* Heidelberg have been isolated from the ovaries and feces of chickens *(26).* Stadelman *(28)* further reported that bacterial contamination on the shell surface may be pulled to the interior of the egg as the egg cools from negative pressure that develops inside the egg from contraction during cooling. Therefore, egg pasteurization processes should be designed such that they are sufficient to eliminate *Salmonella* spp. that are typically associated with eggs.

Until recently, the main treatise on egg pasteurization was the U.S. Department of Agriculture (USDA) *Egg Pasteurization Manual (32).* The *Egg Pasteurization Manual*

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was written when most egg pasteurization was with eggs produced off line. With off-line egg production, eggs spend time in storage before they are pasteurized into liquid egg. During this storage time, the egg white pH normally rises to pH 9.0 by the time of processing from loss of CO_2 from the shell during storage *(15).* Since then, many egg production facilities have in-line liquid egg pasteurization processes in which the pH of fresh egg whites can be as low as pH 7.8 at the time of processing. It is well known that *Salmonella* spp. are more susceptible to heat pasteurization if processed at the higher alkaline pH levels than at lower egg white pH conditions *(21, 24, 27).* Liquid egg white (LEW) is prone to thermal denaturation of albumen and is pasteurized at lower temperatures than liquid whole egg, and the combination of the low pH of fresh egg whites and lower processing temperatures raises a concern for the effectiveness of current pasteurization processes. Processing aids have either enhanced microbial reductions under current heating conditions or allowed egg products to withstand higher egg processing temperatures *(7).* Hydrogen peroxide (H_2O_2) has been used in several recognized processes (the Armour and Standard Brands methods) as a processing aid to enhance pasteurization effectiveness *(32).* The current work examines the efficacy of these two commonly used H_2O_2-based egg white pasteurization methods on *Salmonella* reduction with egg white of varying pH and various pasteurization temperatures.

MATERIALS AND METHODS

Cultures. Five strains of *Salmonella* used in this study (*Salmonella* Enteritidis phage type 4, *Salmonella* Enteritidis phage type 13, *Salmonella* Typhimurium TM-1, *Salmonella* Heidelberg, *Salmonella* Blockley) were obtained from Dr. Glenn Froning and Diane Peters (University of Nebraska, Lincoln, Nebr.). The *Salmonella* strains were chosen by the United Egg Association's Technical Committee in conjunction with input from USDA-Food Safety and Inspection Service on the basis of their frequency of occurrence in the field and thermal tolerance. We selected for novobiocin-resistant (Sigma, St. Louis, Mo.) variants within the population by spread plating 0.1 ml of overnight culture on tryptic soy agar containing 100 μg/ml of novobiocin. Novobiocin is an antibiotic that is commonly used in selective media for various enteric pathogens, including *Salmonella (25).* Novobiocin was used in our media for recovery of *Salmonella* after pasteurization because of concern for potential contamination of other background flora during the egg breaking and homogenizing process. Individual strains of *Salmonella* were freshly transferred for overnight culture in brain heart infusion broth without novobiocin (Difco, Becton Dickinson, Sparks, Md.) at 37°C for use the next morning in inoculation trials. The overnight cultures were poured together in a 500-ml centrifuge bottle and centrifuged at 5,468 × *g* for 12 min at 10°C. The cells were washed with 50 ml of saline solution (0.7% NaCl), recentrifuged, and concentrated by a final resuspension in 5 ml of saline solution for inoculation of egg white.

Egg white preparation and inoculation procedures. Fresh eggs were collected daily at the Oklahoma State University poultry egg-production facility managed by Dr. Joe Berry (OSU Poultry Extension Specialist). The eggs were washed with Dial liquid hand soap obtained at a local supermarket (Dial Corporation, Scottsdale, Ariz.) to remove gross organic and fecal material. Washed eggs were either used immediately for fresh egg white (i.e., pH 8.2) or stored at 3.3°C (38°F) for 3 to 10 days to obtain egg white at pH 8.6 or 9.0. Prior to breaking, the shells of the eggs were sanitized with 70% ethanol for approximately 2 min and allowed to dry for 5 min. After separation of egg white from yolks in a separate sterile beaker, egg whites were pooled in a larger sterile 1,000-ml beaker. Once the volume of LEW in the beaker reached 800 ml, the LEW was blended slowly with a household blender (PowerPro, Black & Decker Corp., Towson, Md.) to homogenize the thick and thin portions of the LEW. Care was taken not to incorporate air or cause albumin denaturation by excessive shearing. The homogenized egg white was held at 3.3°C before straining through four layers of sterile cheesecloth suspended over a sterile beaker to remove any chalazae suspended in the LEW. The pH of the LEW was recorded (Model 8000 pH meter, VWR Scientific) and adjusted immediately after straining. Fine adjustments to egg white pH were made by adding egg whites from older or fresher eggs so that the targeted egg white pH was derived by natural means. The LEW was inoculated with a 1% inoculum of the concentrated *Salmonella* suspension and mixed by use of a sterile stir bar and magnetic stir plate. Approximately 200 ml of the inoculated LEW was placed in a sterile bottle inside a larger beaker with an ice slurry and constantly stirred on a magnetic stir plate during processing. This amount was sufficient to obtain duplicate samples over four residence times at a given temperature; the remaining LEW was used at the other three temperatures. Each of the two methods (Armour and Standard Brands methods) were processed at three pH treatments (pH 8.2, 8.6, 9.0), four residence times (dependent on pH and temperature), and four temperatures (51.7°C/125°F, 53.1°C/127.5°F, 54.4°C/130°F, 55.8°C/132.5°F), and repeated in triplicate. Replications were performed in triplicate and two samples were retrieved for each processing condition within each of the three replications. Different replications were processed on different days with a different batch of egg white and fresh *Salmonella* cultures.

Flow-injected pasteurization process. The pasteurizing system was developed similar to one used previously *(21, 22)* but modified to more closely resemble the Armour and Standard Brands methods *(32)* of egg white pasteurization (Fig. 1). The methods differ mainly on the temperature and time of preheating of the egg white before addition of hydrogen peroxide, which occurs just prior to the main heat treatment as well as the level of hydrogen peroxide: 0.0875% H_2O_2 (minimum) in the Standard Brands method versus 0.05% H_2O_2 (minimum) in the Armour method (Fig. 1). Reagent-grade H_2O_2 (30%; Sigma) was used to make fresh dilutions of H_2O_2 that were maintained in covered bottles for use in our trials. The modifications also included the use of three acrylic baths, with recirculating submersion heaters in each of the first two baths (Fisher Isotemp Model 2150; Fisher Scientific, Houston, Tex.) to achieve the necessary temperatures for preheating and pasteurization, while the third was used as an ice water bath (Fig. 1). In order to resemble the commercial process, the H_2O_2 dilution had to be metered into the egg flow between the preheat and the main heating bath. Final concentrations of H_2O_2 used were those specified in the USDA *Egg Pasteurization Manual (32)* for the Armour (0.05% H_2O_2) and Standard Brands (0.0875% H_2O_2) methods. Two variable-speed peristaltic pumps (Rainin Rabbit, Rainin Inst. Co., Emeryville, Calif.) were used: one with an eight-channel head to provide four channels each of LEW and H_2O_2 and a four-channel pump to inject sterile air into each egg line. This setup provided four complete and separate channels, one for each residence time. Each complete

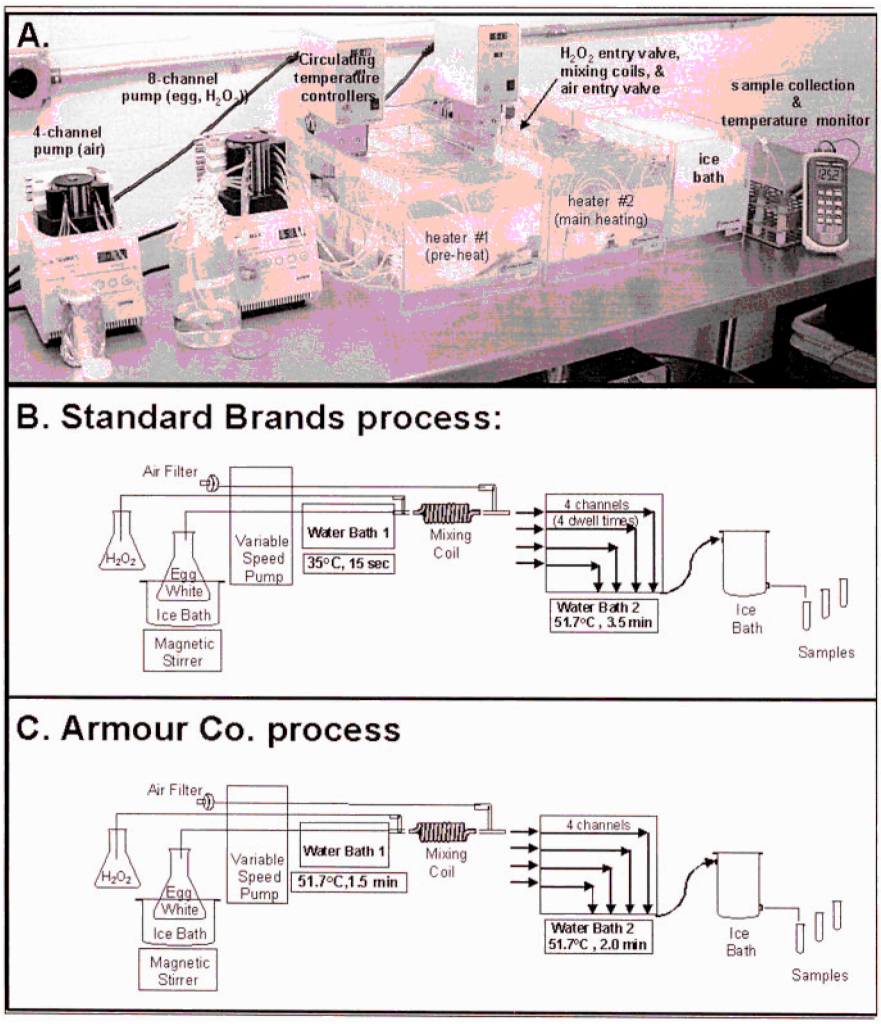

FIGURE 1. *(A) Layout of the benchtop pasteurizer used for both the Standard Brands and Armour methods. (B) Schematic of the Standard Brands method and setup. (C) Schematic of the Armour method setup. The preheat values are as indicated while the main pasteurization conditions for the two methods shown are minimum time and temperature conditions.*

processing line representing a different residence time comprised three separate pump lines: egg white, hydrogen peroxide, and air. The entire system had four complete processing lines running simultaneously (i.e., 12 lines total). Various lengths of flexible Tygon tubing (3.175-mm inner diameter for the LEW and sterile air, 0.794-mm inner diameter for the H_2O_2) were placed in the water baths to achieve the different residence times in the main heating chamber. The injection of air created liquid egg plugs separated by segments of sterile air and allowed for more uniform heating because of rotating flow within the plug (as opposed to a continuous laminar stream). Flow rate and residence times were calculated by timing the flow of a liquid segment through the portion of tube in the heating chamber and by quantifying the amount of egg white collected after timed intervals. After each run, the tubing was cleaned with 0.5 M NaOH to remove any egg residue that may have been deposited and was sanitized with 200 ppm chlorine solution followed by a rinse with sterile water.

Sample plating. After pasteurization, the four individual channels of LEW (i.e., four different residence times) entered the ice water bath and were aseptically collected in sterile plastic test tubes (Fisher Scientific) containing 50 μl of catalase (100 IU; Sigma) solution capable of decomposing 100 μmoles of H_2O_2/min *(34)*. Sufficient sample was collected at each sampling (3 to 4 ml collected, representing 1.5 to 2% of the total inoculated volume of egg white) that the addition of catalase solution would not significantly dilute the remaining cells in the pasteurized egg sample. Samples and dilutions (0.1% peptone water) were pour plated with tryptic soy agar containing 100 μg/ml of novobiocin and enumerated for survivors after 48 h at 37°C. Select colonies from plated samples were tested on xylose lysine desoxycholate agar to ensure they were *Salmonella* spp. Baseline levels of inoculated LEW were obtained from inoculated (nonpasteurized) egg white. Samples for each trial replication were run in pairs and recorded as the average of the paired samples and each trial was performed in triple replications. Collected samples were also tested with a semiquantitative dip-strip assay (Quantofix Peroxide 25 and 100; Sigma-Aldrich, St. Louis, Mo.). Quantofix Peroxide 100 (0 to 100 mg/liter H_2O_2) was used on dilutions of egg white (after addition and mixing with H_2O_2) to ensure expected levels were initially obtained. Quantofix Peroxide 25 (0 to 25 mg/liter H_2O_2) was used directly on egg white after addition of catalase to ensure removal of H_2O_2 prior to plating.

Thermal death time determinations. The decimal reduction value (*D*-value) is defined as the time required at any given temperature to destroy 90% of the population *(29)*. Although *D*-values are typically obtained with single strain populations, an increasing number of studies have evaluated thermal inactivation against a mixture of strains of the target organism as would be required of a process in actual commercial application *(6, 9, 16, 19, 23, 24)*. Similarly, we used an equal mixture of five *Salmonella* strains representing four *Salmonella* serotypes in which the inactivation curves and resulting *D*-values should conservatively reflect the most heat-resistant strain. Plate counts from duplicate samples retrieved for each processing condition (within a replication) were

TABLE 1. D- *and* z-*values obtained for the two pasteurization methods using egg white at pH 8.2, 8.6, and 9.0 processed at 51.7°C (125°F), 53.1°C (127.5°F), 54.4°C (130°F), and 55.8°C (132.5°F);* D-*values are followed by standard deviations derived from triplicate replications; numbers in parentheses are regression coefficients* (r^2) *of the* z-*value plots; regression coefficients for the* D-*value plots were 0.952 or higher*

Pasteurization method	pH	*D*-values (min)[a]				*z*-values (°C) (r^2)
		51.7°C	53.1°C	54.4°C	55.8°C	
Armour	8.2	1.32 ± 0.24	0.92 ± 0.03 a	0.63 ± 0.06 a	0.33 ± 0.01 a	6.95 (0.982)
	8.6	0.98 ± 0.22 a	0.68 ± 0.22 A ab	0.48 ± 0.26 A ab	0.23 ± 0.001 a	6.64 (0.964)
	9.0	0.80 ± 0.12 a	0.49 ± 0.09 B b	0.34 ± 0.02 BC b	0.22 ± 0.004 C a	7.47 (0.997)
Standard brands	8.2	1.12 ± 0.07 a	0.69 ± 0.09 a	0.53 ± 0.04 a	0.29 ± 0.01 a	7.34 (0.984)
	8.6	1.03 ± 0.10 a	0.68 ± 0.07 a	0.52 ± 0.03 a	0.29 ± 0.001 a	7.76 (0.983)
	9.0	0.81 ± 0.06	0.56 ± 0.08 A	0.51 ± 0.07 A a	0.29 ± 0.001 a	9.83 (0.930)

[a] Within a given method, values are not significantly different ($P > 0.05$) if they have the same small capital letters in the same row or the same lowercase letters in the same column.

averaged and the means of data from triplicate replications were again averaged for a given processing condition; these data were then plotted to obtain survivor curves. Linear regression lines for the plots were used to obtain *D*-values at each of the four temperatures and three pH conditions that were evaluated for the two processes. The *D*-value at a particular temperature is represented by $D_{temp} = t/(\log N_0 - \log N)$, where N_0 is the initial population and N is the population at time t. Similarly, thermal death time curves of D_{temp} (log scale) versus temperature (linear scale) were plotted and the inverse slope of the linear regression line was used to determine the *z*-value *(9).*

Effect of preheat and hydrogen peroxide. In order to evaluate the contributions of the H_2O_2, the preheating, and the main heating regimen in the two pasteurization methods, we processed egg white (pH 8.2) inoculated with *Salmonella* spp. (i) with and without H_2O_2 (0.0875%, vol/vol), (ii) with and without the preheat step (none, 15 s at 35°C/95°F, 1.5 min at 51.7°C/125°F), and (iii) the main heating regimen (1.5 and 2.0 min at 51.7°C/125°F) without H_2O_2 or the preheat. The trials were run in duplicate replications with two samples taken per replication (i.e., four samples in total per condition tested). In addition, the processing of two different heat treatment times for the main heating regimen (1.5 min and 2.0 min) is doubly confirmative of the analysis.

Statistical analyses. Statistical analysis was performed for multiple comparison of the means and standard deviations obtained for a 3 × 4 factorial arrangement of treatments (pH × temperature) for each method. Experiments evaluating egg white pH were doubly sampled and conducted in triplicate replication ($n = 6$); experiments evaluating preheat were doubly sampled and run in duplicate replication ($n = 4$). Analysis of variance was performed using the Holm-Sidak Test for pairwise multiple comparisons to determine significant differences ($P < 0.05$) using the software program SigmaStat 3.0 (SPSS Inc., Chicago, Ill.).

RESULTS AND DISCUSSION

In our study, we used a continuous-flow benchtop egg pasteurization system that was configured to resemble the minimum processing conditions of the Armour and Standard Brands egg white pasteurization methods, which require preheating egg white before addition of H_2O_2 (Fig. 1). In a previous study, Muriana *(21)* used a simple heat plus hydrogen peroxide process in which there was no preheating step and which used a single processing line that required recalibration of pump speed to achieve different dwell times to study an egg white process used by a local egg processor. The requirement to meter in H_2O_2 during midprocess makes it virtually impossible to evaluate these types of egg white pasteurization methods by conventional capillary tube decimal reduction trials.

Some of the modifications in this study included the use of several multichannel pumps, the simultaneous running of four separate channels, a preheat water bath, Y-connectors to introduce H_2O_2 between the preheat and main pasteurization heating baths, and mixing coils to mix the adjoined streams. In our current system, we utilized 12 pump channels (eight- and four-channel pumps) so that we could operate four complete processing lines and acquire data from four dwells times simultaneously. Each of the four complete processing lines required one egg line, one air line, and one H_2O_2 line. More important, the four-line system provided greater consistency in egg white processing because all four egg lines drew sample from the same inoculated raw egg white preparation and simultaneously processed four different resident times. In the prior single-line system *(21),* different batches of egg white and inoculum preparation had to be prepared for analysis of different residence times at the same temperature.

We examined the Armour and Standard Brands methods using egg white at three pH levels, four residence times, and four processing temperatures. The processing dwell times were centered around the minimum allowable times and temperatures for the respective processes: 2.0 min at 51.7°C (125°F) for the Armour method and 3.5 min at 51.7°C (125°F) for the Standard Brands method. Linear regression trend lines for our decimal reduction survival curves showed good fit, with all showing linearity correlations (r^2) of 0.952 or higher (data not shown). The data for both methods show the obvious effect of increasing temperature leading to an increase in reduction of *Salmonella* as evidenced by the lower *D*-values (Table 1). Both pasteurization methods also showed a statistically significant difference ($P < 0.05$) in *D*-value at pH 8.2 compared with pH 9.0 at all temperatures except 55.8°C (132.5°F), the highest temperature tested. The main concern is the potential for lower microbial reduction with egg white of low pH and this may be more a problem for in-line processors

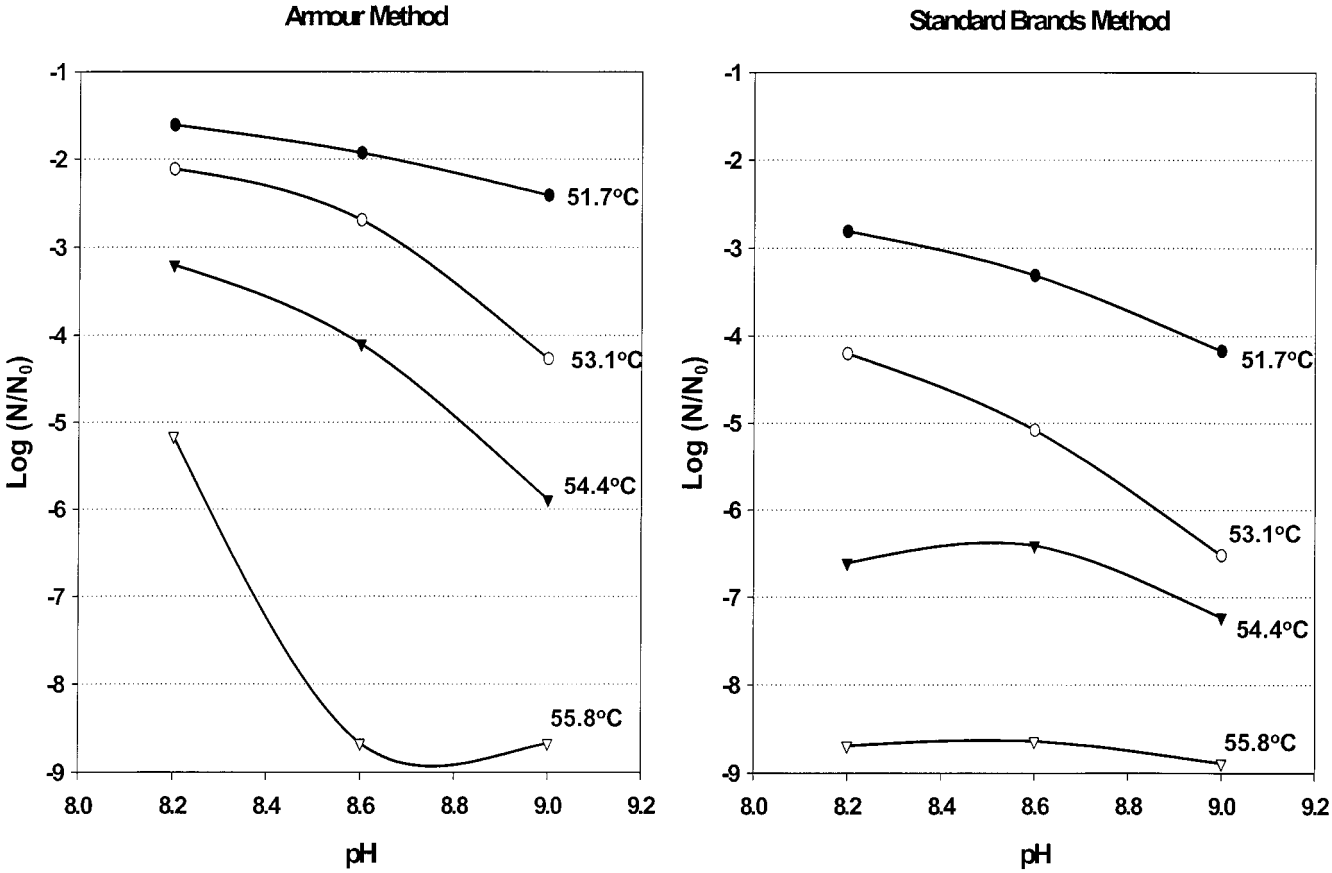

FIGURE 2. *Plot of the effectiveness of the two commercial processes over pH (8.2, 8.6, 9.0) and temperature (51.7°C, 53.1°C, 54.4°C, 55.8°C) at their minimum allowable time and temperature parameters.* N_0 *represents the initial CFU/ml of* Salmonella *spp. inoculated in egg white.* N *represents the CFU/ml of* Salmonella *spp. after processing in the main heating regimen for the minimum allowable time at the specified temperatures. The minimum allowable time was 2.0 min for the Armour method and 3.5 min for the Standard Brands method. The uppermost curve in either chart represents the reduction of* Salmonella *spp. obtained at both the minimum allowable processing time and temperature for the main heating regimen.*

who process fresh, low-pH, egg white that may not provide as great a reduction during pasteurization as old, high-pH egg white. The pH-related differences in *D*-values were nearly nonexistent in the Standard Brands method at the higher temperatures tested (54.4 and 55.8°C) when compared with the Armour method (Table 1). Although the Armour method had lower *D*-value at pH 9.0 for the three highest processing temperatures, the Standard Brands method had the least pH-related variation (Table 1).

We examined *Salmonella* reduction obtained with inoculated egg white at each of three pH levels using the minimum allowable dwell times and temperatures described for the two methods as well as the same dwell times at higher processing temperatures (Fig. 2). Neither process provided adequate reduction of *Salmonella* at the lowest processing time and temperature combinations, especially at low pH. The Armour method's minimum conditions gave approximately a 1.5- to 2.4-log reduction whereas the Standard Brands' minimum conditions gave a 2.85- to 4.2-log reduction over the range of pH 8.2 to 9.0. At all higher temperatures (53.1, 54.4, and 55.8°C), the Armour method still showed as much as a 3.5-log difference between *Salmonella* reduction obtained at 53.1°C; these differences were minimal at 54.4°C and essentially nonexistent at 55.8°C (Fig. 2). After observation of similar enhanced reductions at high pH values, Shuman and Sheldon *(27)* suggested that either the adjustment of egg pH to 9.0 or the use of older eggs would boost the effect of a pasteurization process. The use of egg white pH adjustment using established processing aids may be more applicable now than was previously used because of the tendency toward in-line processing systems that results in low egg white pH.

One of the main differences between the two methods is the shorter main pasteurization regimen (2.0 versus 3.5 min) in the Armour method that was supposedly offset by the extended preheat period (1.5 min versus 15 s) (Fig. 1). The preheat regimen was implemented to inactivate indigenous egg white catalase that may inactivate the introduced H_2O_2. However, the greater reduction obtained with the Standard Brands method could conceivably be attributed to a longer main processing time. In order to evaluate the effectiveness of the preheating regimen, we used a common main processing condition with several preheat variations. We used the short (15 s) and extended (1.5 min) preheat conditions of the Standard Brands and Armour processes, respectively, followed by a standardized main pasteuriza-

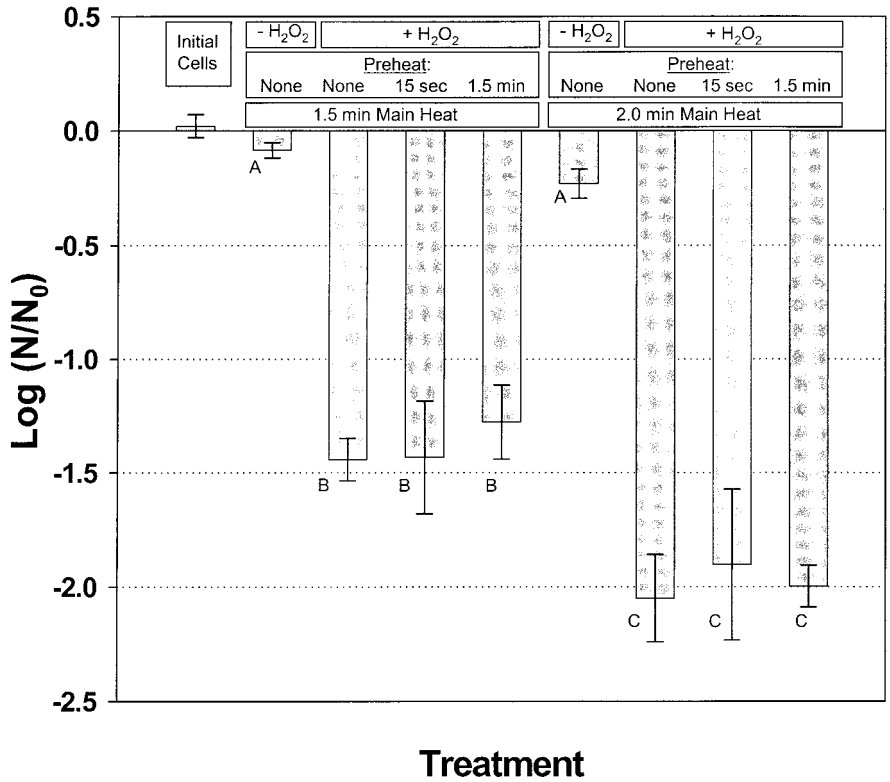

FIGURE 3. *Evaluation of the effectiveness of H_2O_2 and the different preheat times specified by the Armour (15 s at 35°C/95°F) or Standard Brands (1.5 min at 51.7°C/125°F) methods against a mixture of* Salmonella *spp. using pH 8.2 egg white and a 1.5- or 2.0-min main heating regimen at 51.7°C. The data represent the means of two replications sampled twice per condition per replication (errors bars are standard deviations of the means). Chart bars with the same letter are not significantly different (*P > 0.05*).*

tion regimen (both 1.5 and 2.0 min) (Fig. 3). We also examined the absence of preheat both with and without any added H_2O_2. With no added H_2O_2 or preheat step (i.e., with just heat alone), we obtained a slight reduction of *Salmonella* spp. with no significant difference ($P > 0.05$) by heating for 1.5 or 2.0 min (Fig. 3). Reduction of *Salmonella* spp. increased dramatically when H_2O_2 was added in combination with a 1.5-min main heating process, and an even greater reduction ($P < 0.05$) occurred with a 2.0-min process (Fig. 3). These data confirm the effectiveness of H_2O_2 as a processing aid in egg white pasteurization *(1, 21, 24).* However, we found the preheat period, whether 15 s or 1.5 min, provided no significant difference ($P > 0.05$) on the reduction of *Salmonella* spp. when compared with the same main heating regimen without a preheat, and therefore, we question the contribution of this step to either process. According to recent research data, the minimum temperatures allowed for the preheat in the two methods (95°F or 125°F) are hardly sufficient to render either microbial or egg white catalase inactive. In a recent study of catalases from 16 organisms, 14 of which were from microorganisms, Switala and Loewen *(30)* found the catalases to be fairly heat stable and showed thermal half-lives as long as 720 min (i.e., *Escherichia coli*) at 65°C (149°F). Based on our results, we find that the preheat step of the process is unnecessary as we have found that it does not have a significant impact on the reduction of *Salmonella* spp. (Fig. 3).

Palumbo et al. *(24)* indicated a need to increase the pasteurization temperature for the Standard Brands method to 53.2°C (127.76°F) or the time held should be longer than 3.5 min for the simple heat treatment to achieve a 99.99% reduction of *Salmonella* Enteritidis. Muriana *(21)* found that the minimal allowable processing conditions provided a 7.5-log reduction of *Salmonella* Enteritidis and an 8.5-log reduction of *Salmonella* Heidelberg at 134°F for 4.1 min without the addition of H_2O_2. In contrast, Michalski et al. *(18)* used capillary tubes and a plate heat exchanger for the simple heat treatment *(32)* of pasteurizing egg whites at pH 9.0. They reported that a 9-*D* process was not achieved using capillary tubes but was achieved using the plate heat exchanger at 56.7°C (134°F) for 3.5 min *(18).* The difference between the H_2O_2-based methods (Armor and Standard brands) and the simple heat treatment method is that the latter is heated at a much higher temperature (56.7°C) without the addition of H_2O_2.

The data we obtained demonstrates pH-related differences in processing results for the two commercial processes examined, a factor to be considered when consistent reduction of *Salmonella* spp. is required for production of safe pasteurized egg product *(33).* We suggest that the preheating steps of both the Armour and Standard Brands methods provide no enhancement toward the pasteurization of egg whites and therefore are an unnecessary step. The main difference between the two procedures is a difference in the H_2O_2 levels used as well as differences in minimum heating times. The increased preheat in the Amour method (no effect) does not compensate for the decreased main heating (2.0 versus 3.5 min) and, because the processes show similar *D*-values (Table 1), the two methods are mainly showing differences primarily based on the length of the main heating regimen. The data obtained herein were used to recommend changes to the previous USDA *Egg Pasteurization Manual (32)* that the Standard Brands method with minimum temperature and holding time of 54.4°C and 3.5 min be established as the minimum processing conditions for egg white pasteurization (with H_2O_2). As time,

production, and processing conditions change, it is imperative to reevaluate processing effectiveness to ensure the use of adequate pasteurization processes that would otherwise lead to a hazardous product *(34)*.

ACKNOWLEDGMENTS

This manuscript was approved for publication by the Director, the Oklahoma Agricultural Experiment Station. This research was supported under project OKL0-2355 and by a grant from the United Egg Producers Association. The authors would like to thank Dr. Joe Berry for providing eggs during the course of this study from the Oklahoma State University Poultry Farm and Dr. Glenn Froning and the Technical Committee of the United Egg Association for continued technical discussions during the course of the study.

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