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Steam Pasteurization of Commercially Slaughtered Beef Carcasses: Evaluation of Bacterial Populations at Five Anatomical Locations

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ABSTRACT

A steam pasteurization process (patent pending) has been shown to effectively reduce pathogenic bacterial populations on beef tissue and to significantly reduce naturally occurring bacterial populations on commercially slaughtered beef carcasses. The objective of this study was to determine the effectiveness of the steam pasteurization treatment for reducing bacterial populations at several anatomical locations on commercially slaughtered carcasses. Before and after pasteurization treatment (82.2°C, 6.5-s exposure time), a sterile sponge was used to sample 300 cm^2 at one of five locations (inside round, loin, midline, brisket, or neck). Eighty carcasses (40 before treatment and 40 after treatment) were sampled per anatomical location over 2 processing days. Before treatment, aerobic plate counts (APCs) were found to be highest ($P \leq 0.01$) at the midline (4.5 log_{10} CFU/100 cm^2), intermediate at the inside round, brisket, and neck (ca. 3.8 log_{10} CFU/100 cm^2), and lowest at the loin (3.4 log_{10} CFU/100 cm^2). After treatment, APCs at all locations were reduced significantly ($P \leq 0.01$). The inside round, loin, and brisket had the lowest ($P \leq 0.01$) APCs (ca. 2.6 log_{10} CFU/100 cm^2), whereas the midline and neck had APCs of 3.1 and 3.3 log_{10} CFU/100 cm^2, respectively. The lower reduction in APCs at the neck area indicated that the treatment may not be as effective there, possibly because of the design of the pasteurization equipment. Generic *Escherichia coli* populations were low at all locations before treatment, with populations on 32% of all carcasses sampled being less than the detection limit of the study (5.0 CFU/100 cm^2). After treatment, *E. coli* populations were significantly lower ($P \leq 0.01$) than populations before treatment and 85% of all carcasses sampled had *E. coli* populations below the detection limit. The maximum *E. coli* population detected after treatment was 25 CFU/100 cm^2. For enteric bacterial populations, no differences were observed in the effectiveness of the treatment among the five carcass locations.

Every year in the United States, thousands of foodborne illnesses occur. Many of these illnesses have been traced to the consumption of beef and beef products that harbored pathogenic bacteria. The Centers for Disease Control identified beef as the vehicle in 2,085 foodborne illness cases, representing 63 outbreaks, in the United States during the 5-year period 1988 to 1992. Those cases constituted approximately 2 to 3% of the total number of foodborne illnesses reported *(1)*. Many opportunities exist during production, processing, distribution, retail, marketing, and consumption for pathogens to find their way into beef and beef products. Eliminating pathogens and, therefore, the risk of contracting a foodborne illness from beef products is a monumental, if not impossible, task. Therefore, the approach must be to explore methods of risk reduction, rather than complete risk elimination.

Many research efforts have focused on reducing the risk of pathogenic bacterial contamination of beef carcasses at the slaughter level. Recently, a process for applying steam to surfaces of freshly slaughtered beef (patent pending) was shown to be very effective for reducing pathogenic bacterial contamination on prerigor beef surfaces *(7)*. The process is commercially marketed as "steam pasteurization" (Frigoscandia Food Process Systems, Bellevue, WA) *(12)*.

In laboratory studies, freshly slaughtered beef tissue was inoculated with feces containing *Escherichia coli* O157:H7, *Salmonella typhimurium,* and *Listeria monocytogenes* (ca. 5.0 log_{10} CFU/cm^2 each). A steam pasteurization treatment used alone significantly reduced levels of all three pathogens by approximately 3.5 log_{10} CFU/cm^2 *(7)*. Reductions in pathogen populations were even larger when the steam pasteurization treatment was combined with physical removal of fecal material (knife trimming, water washing, and/or hot water/steam spot vacuum cleaning).

Similar results were described by Dorsa et al. *(3)* in a study evaluating a steam application process. When a wash-steam treatment was applied to fecally contaminated sheep carcasses, bacterial populations were reduced from initial levels of approximately 6.5 log_{10} CFU/cm^2 to approximately 3.0 log_{10} CFU/cm^2. A wash-steam treatment was significantly more effective than a wash treatment alone when wash temperatures were 15.6 and 54.4°C; however, no

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difference existed in the effectiveness of the wash-steam and wash treatments at a wash temperature of 82.2°C.

The effectiveness of the steam pasteurization process for reducing naturally occurring bacterial populations on commercially slaughtered beef carcasses has been evaluated in a large commercial beef slaughter facility *(6)*. Tissue samples were excised from beef carcasses immediately before, immediately after, and 24 h after a steam pasteurization treatment (steam exposure time of 8 s). Total aerobic bacterial populations were significantly reduced ($P \leq 0.01$) immediately after the pasteurization treatment from initial levels of approximately 2 $\log_{10}$ CFU/cm^2 to approximately 1 $\log_{10}$ CFU/cm^2. Total aerobic bacterial populations 24 h after treatment (following carcass chilling) were not different from the populations observed immediately after treatment. Before the pasteurization treatment, enteric bacterial populations were very low (often undetectable with a detection limit of 0.6 $\log_{10}$ CFU/cm^2). Before pasteurization, *E. coli,* total coliform, and *Enterobacteriaceae* populations were detected on 23 of 140, 53 of 140, and 65 of 140 carcasses, respectively. After pasteurization (immediately and after a 24-h chill), *E. coli,* total coliform, and *Enterobacteriaceae* populations were detected on 0 of 140, 9 of 140, and 12 of 140 carcasses, respectively.

Theoretically, the gaseous steam vapor used in the steam pasteurization treatment would reach all surfaces of a carcass uniformly, resulting in consistent bacterial destruction over the entire carcass surface. However, because samples were collected from only one anatomical region of the carcasses in our previous study *(6)*, no microbiological data exist to support or refute this supposition. Therefore, the primary objective of the current study was to determine whether a steam pasteurization treatment effectively reduced bacterial populations at several anatomical locations on commercially slaughtered beef carcasses. A secondary objective was to compare, in a general manner, data observed in this study with generic *E. coli* standards for beef slaughter as outlined in the U.S. Department of Agriculture's recently published Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) Systems; Final Rule *(10)*.

MATERIALS AND METHODS

Slaughter facility. The steam pasteurization equipment *(12)* was installed in a large commercial beef slaughter facility, which operated at an average line speed of 290 animals per h. The facility was located at an altitude of 1,341 m above sea level and processed fed cattle only. Samples for this study were collected from carcasses during two production days (both A and B shifts). Slaughter procedures of this facility were typical of standard industry practices *(6)* and included the use of steam vacuum technology at points along the slaughter chain prior to the final carcass wash.

Steam pasteurization treatment. The steam pasteurization equipment used in this study has been described in detail in a previous report *(6)*. Briefly, the steam pasteurization system consisted of three steps: water removal, steam application, and cold water spray. The steam pasteurization treatment followed the final carcass wash and was the final step in the slaughter process. In this study, all carcasses were treated with a steam exposure time of 6.5 s with the equipment operating at an average temperature (atmospheric temperature inside steam chamber) of 82.2°C.

Sample collection. Samples were collected from randomly selected carcasses before and after the steam pasteurization treatment. Samples taken before pasteurization were collected from carcasses immediately after exiting the final carcass wash before entering the water removal step of the steam pasteurization system. Samples taken after pasteurization were collected from carcasses within 20 min of exiting the pasteurization equipment and placement in the coolers (hot boxes). To assure that carcasses sampled in the cooler had received the steam treatment, exposed cut lean surfaces were visually examined for a slight gray discoloration.

Five anatomical carcass locations (Fig. 1) were sampled, including the inside round (IR), loin (L), midline (ML), brisket (BK), and neck (N). Steps were taken to attempt to prevent inadvertent contamination of the sampling sites posttreatment by sampling the sites immediately after the sides exited the pasteurization equipment. If this was not possible, plant personnel working in the coolers were instructed not to handle carcass sides at anatomical locations designated for sampling. On each of two successive processing days, samples were collected before pasteurization from 20 randomly selected carcasses per anatomical location (total of 200 carcasses sampled before pasteurization; 100 each processing day). On those same processing days, samples also were collected after pasteurization from 20 randomly selected carcasses per anatomical location (total of 200 carcasses sampled after pasteurization; 100 each processing day). The carcasses sampled before pasteurization were not the same carcasses that were sampled after pasteurization. That is, only one sample was collected from each randomly selected carcass (one anatomical location at one sampling time). High line speeds employed at the plant resulted in a large separation of carcasses sampled before and after pasteurization treatment.

At each anatomical location, a sterile vinyl template was used to delineate a 300-cm^2 sampling area. For the IR, BK, and N areas the template was 17.3 by 17.3 cm. For the L and ML areas the

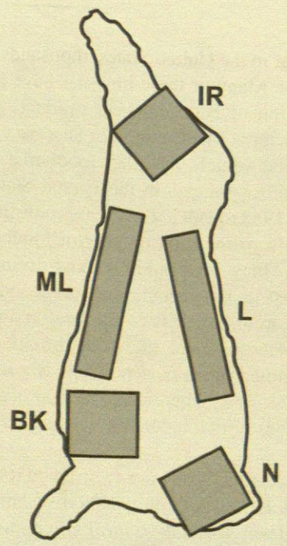

FIGURE 1. *Diagram of anatomical sampling locations (IR = inside round, L = loin, ML = midline, BK = brisket, N = neck). Sampling area per anatomical location = 300 cm^2. Gray areas represent sampling template shape and approximate size.*

template was 30 by 10 cm (see Fig. 1). Samples were collected from the carcasses using a sponge method, similar to that outlined in Dorsa et al. *(2)* and in the Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) Systems; Final Rule *(10)*. Sterile sponges (Specisponge; Nasco, Fort Atkinson, WI) were hydrated with 30 ml of 0.1% peptone diluent (Difco Laboratories, Detroit, MI) containing 0.1% Tween 20 (Fisher Scientific, St. Louis, MO). One sponge was used per anatomical location. Residual moisture was expelled from the sponge inside the Whirl-pak bag (Nasco), and the sponge was removed from the bag. Sterile gloves were worn by personnel handling the sterile sponges. One side of the sponge was used with a back-and-forth motion in the vertical direction for several passes to cover the entire template area. The sponge then was turned over, and the opposite side was used to sponge in the horizontal direction to cover the entire template area. The sponge then was returned to the original Whirl-pak bag containing the diluent. Samples were delivered to an on-site laboratory within 10 minutes of collection.

Microbiological analyses. Upon arrival at the laboratory, sponge samples were held at 4°C until plating (<2 h). Samples were stomached for 2 min in a Stomacher Lab Blender 400 (Tekmar, Cincinatti, OH). Serial dilutions were prepared in 0.1% peptone diluent containing 0.1% Tween 20. Appropriate dilutions were plated in duplicate on Aerobic Plate Count Petrifilm (3M, St. Paul, MN) to enumerate total aerobic bacterial populations, E. coli Count Petrifilm (3M) to enumerate *E. coli* and total coliform populations, and Enterobacteriaceae Petrifilm (3M) to enumerate *Enterobacteriaceae* populations. All plates were incubated at 35°C for 24 ± 2 h. All Petrifilm plates were counted according to manufacturer's instructions. The *E. coli* count plates were counted using the AFNOR method as outlined in the E. coli Count Petrifilm package insert. Using this method, all blue colonies regardless of gas formation were enumerated as *E. coli* as a more conservative estimate of population reductions. The enumeration methods described above were not designed to differentiate between injured and noninjured bacterial cells.

After plating for enumeration, all sponge samples collected on the second processing day were held at 4°C (24 h), then transported to Kansas State University, and screened for the qualitative presence of *Salmonella* spp. These included 20 samples from each anatomical location before and after steam pasteurization treatment (total of 100 samples before and 100 samples after pasteurization). Samples were transported to KSU in Styrofoam coolers with cold packs and held at 1°C until analysis.

Samples were screened for the qualitative presence of *Salmonella* spp. using procedures similar to those outlined in the *Bacteriological Analytical Manual* of the U.S. Food and Drug Administration *(11)*. One milliliter of diluent from the sample bag containing the sponge was transferred to separate tubes containing 9 ml of selenite cystine (SC) broth (Difco) and to 9 ml of tetrathionate (TT) broth (Difco). The SC and TT broth tubes were incubated for 24 h at 35°C and 42°C, respectively. One loopful of each selective enrichment broth was streaked for isolation on prepoured brilliant green sulfa (BGS) agar (Difco) and bismuth sulfite (BS) agar (Difco) plates. All plates were incubated for 24 ± 2 h at 35°C. After incubation, typical colonies were transferred to triple sugar iron (TSI) agar (Difco) slants and lysine iron agar (LIA; Difco) slants. All slants were incubated for 24 ± 2 h at 35°C. Growth from slants with reactions typical of *Salmonella* spp. was streaked for isolation on brain heart infusion (BHI) agar (Difco) plates and transferred to urea broth (Difco). The urea broth and the BHI plates were incubated at 35°C for 24 ± 2 h. Isolates with negative urea reactions were inoculated into API 20E identification kits (BioMerieux Vitek, Hazelwood, MO). Isolates that could not be identified positively from the API 20E results were tested serologically with *Salmonella* O antisera (poly A-I, Vi; Difco).

Temperature monitoring. Carcass surface temperatures of 10 randomly selected carcasses were monitored during steam pasteurization treatment using a Multitracker Elite Model 2000 Type K (Datapaq, Wilmington, MA). Probes (1/5000 in. [5 μm] thick, high response; Datapag) were attached to the carcass surface using stainless steel straight pins at four locations (IR, L, ML, and N). Each probe was attached so as to be in direct contact with the exterior carcass surface. The surface temperature was recorded every 0.2 s as the carcass passed through the pasteurization equipment. To avoid affecting the microbiological results, surface temperatures of carcasses that were selected for microbiological sampling were not monitored.

Statistical analyses. All microbiological data were converted to $\log_{10}$ CFU/100 cm^2 and analyzed using the General Linear Models (GLM) procedure of SAS. The data were analyzed as a completely randomized design with a five by two factorial treatment structure, with anatomical location (five levels) and sampling time (two levels) as main effects. The level of significance was set at 0.01. Chi-square analyses also were conducted on *E. coli,* total coliform, and *Enterobacteriaceae* populations to determine differences in the distribution of carcasses among specified population ranges before and after steam treatment. The significance level was set at 0.01.

The minimum detectable count (detection limit) for this study on a 1-cm^2 basis was 0.05 CFU/cm^2 (-1.3 $\log_{10}$ CFU/cm^2). Enteric bacterial populations in this study were very low, often below the detection limit. Therefore, to avoid negative log values and to simplify the interpretation of data, all microbiological data were converted to a 100-cm^2 basis. Using this basis, the minimum detectable count (detection limit) was 5.0 CFU/100 cm^2 (0.7 $\log_{10}$ CFU/100 cm^2). For statistical analyses, a value of one-half of the detection limit (2.5 CFU/100 cm^2 or 0.4 $\log_{10}$ CFU/100 cm^2) was entered for any sample in which a population was not detected.

RESULTS AND DISCUSSION

Microbiological analyses. The mean log APC results are shown in Fig. 2. Before pasteurization treatment, the L area had the lowest mean APC at 3.4 $\log_{10}$ CFU/100 cm^2. The IR, BK, and N areas had similar APCs of approximately 3.8 $\log_{10}$ CFU/100 cm^2, and the ML area was the most

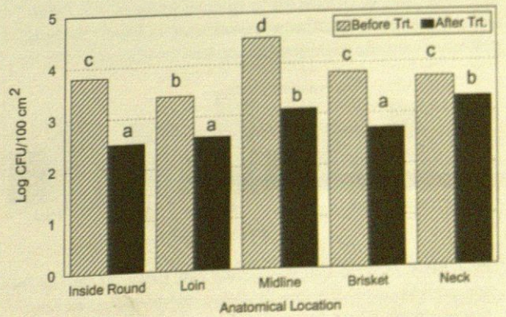

FIGURE 2. *Mean aerobic plate counts (log CFU/100 cm^2) on beef carcasses by anatomical location before and after steam pasteurization treatment. For each location and sampling time (B or A), n = 40. Means having a letter in common are not significantly difference (P > 0.01). Estimated standard error of each of the least square means = 0.08.*

heavily contaminated area with a mean APC of 4.5 $\log_{10}$ CFU/100 cm^2. The populations before pasteurization were consistent with those reported by other researchers for freshly slaughtered beef carcasses processed commercially *(2, 4–6, 8)*.

After pasteurization treatment, the mean APC for each anatomical location was lower ($P \leq 0.01$) than the mean APC before pasteurization (Fig. 2). Populations on the L and BK areas were reduced by approximately 1 $\log_{10}$ cycle, whereas populations on the IR and ML areas were reduced by approximately 1.3 $\log_{10}$ CFU/100 cm^2. The N area showed the smallest reduction of 0.4 $\log_{10}$ CFU/100 cm^2. After pasteurization, mean APCs were lowest ($P \leq 0.01$) on the IR, L, and BK areas (populations of ca. 2.6 $\log_{10}$ CFU/100 cm^2), whereas the ML and N areas had higher but similar populations (ca. 3.2 $\log_{10}$ CFU/100 cm^2).

These results are consistent with those reported in the previous commercial evaluation of a steam pasteurization process *(6)*, which assessed microbiological reductions at the brisket location only. The results of the current study indicate that the steam pasteurization process is effective at reducing APCs at all of the studied anatomical locations. However, the magnitude of the reduction in APC at the N area was not as great as that of reductions observed at the other four locations. The decreased effectiveness at the N area could have been due to several factors, including incomplete coverage of the area by the steam vapor, variations in steam temperature or heat flux within the pasteurization equipment, or the possible protective action of excess water and blood on the surface of the neck area.

Figure 3 shows the mean *E. coli* populations at the five anatomical locations before and after steam pasteurization treatment. Before pasteurization, populations were approximately 0.9 $\log_{10}$ CFU/100 cm^2 at the L and BK areas, approximately 1.0 $\log_{10}$ CFU/100 cm^2 at the IR and N areas, and 1.2 $\log_{10}$ CFU/100 cm^2 at the ML area. In the two-way analysis of variance, no significant interaction (anatomical

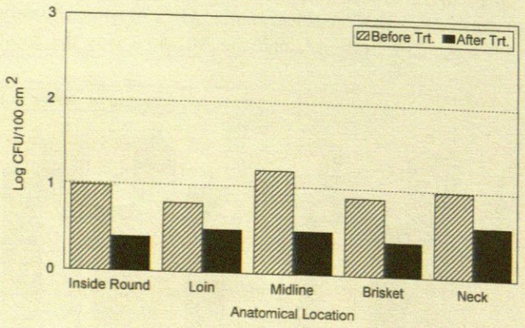

FIGURE 3. *Mean* E. coli *populations (log CFU/100 cm^2) on beef carcasses by anatomical location before and after steam pasteurization treatment. Within location and sampling time, n = 40. For all anatomical locations combined, mean populations after treatment were significantly lower ($P \leq 0.01$) than mean populations before treatment. Estimated standard error of each of the least square means = 0.03. For statistical analysis, 0.4 $\log_{10}$ CFU/100 cm^2 (one-half of the detection limit in this study) was entered for samples in which* E. coli *was not detected.*

TABLE 1. *Chi-square analysis of the number of carcasses (% of carcasses) found to have* E. coli *populations within specified ranges before and after a steam pasteurization treatment*[a]

	Population range (CFU/100 cm^2)		
	<5.0	5.0 to 99.0	≥100
Before treatment[b]	64 (32.0%)	124 (62.0%)	12 (6%)
After treatment[b]	170 (85.0%)	29 (14.5%)	1 (0.5%)

[a] Both before and after treatment, the total number of carcasses sampled was 200. Those 200 samples included 40 samples from each of five anatomical locations (inside round, loin, midline, brisket, and neck).

[b] The distribution of carcasses among the specified population ranges before pasteurization treatment was significantly different from the distribution of carcasses after pasteurization treatment ($P = 0.001$, chi-square = 116.3).

location × sampling time) was observed. Therefore, results for all anatomical locations were combined, and showed that populations after steam pasteurization were lower ($P \leq 0.01$) than populations before treatment. After steam treatment, populations at the IR, L, ML, and BK areas were ≤0.5 $\log_{10}$ CFU/100 cm^2, and the N area had a population of 0.6 $\log_{10}$ CFU/100 cm^2. In general, *E. coli* population reductions of approximately 0.5 $\log_{10}$ CFU/100 cm^2 were observed for all anatomical locations.

These results are very similar to reductions in *E. coli* populations observed in previous commercial evaluations of the steam pasteurization technology *(6)*. In the previous study that used a steam exposure time of 6 s, reductions of approximately 0.4 $\log_{10}$ CFU/cm^2 from very low initial levels were observed on cow carcasses.

In addition to determination of mean *E. coli* populations, a chi-square analysis of the distribution of the number of carcasses within specified ranges of *E. coli* populations (CFU/100 cm^2) also was performed (Table 1). The chi-square analysis showed that the distribution of carcasses falling within specified population ranges before pasteurization treatment was different from that after pasteurization treatment ($P = 0.001$). Before pasteurization, 32.0% of carcasses had *E. coli* populations below the detection limit of this study (5.0 CFU/100 cm^2), whereas after pasteurization, 85.0% of carcasses had *E. coli* populations below the detection limit. Similarly, before pasteurization, 94.0% of carcasses had *E. coli* populations lower than 100 CFU/100 cm^2, whereas after pasteurization 99.5% of carcasses had *E. coli* populations lower than 100 CFU/100 cm^2.

Figures 4 and 5 show the mean total coliform and *Enterobacteriaceae* populations, respectively, for the five anatomical locations before and after steam pasteurization treatment. Before pasteurization, the ML area was the most heavily ($P \leq 0.01$) contaminated with total coliforms, with populations of approximately 2.4 $\log_{10}$ CFU/100 cm^2 (Fig. 4). The IR, BK, and N areas had total coliform populations of approximately 1.6 $\log_{10}$ CFU/100 cm^2, and the L area had populations of approximately 1.2 $\log_{10}$ CFU/100 cm^2. The steam pasteurization treatment significantly reduced

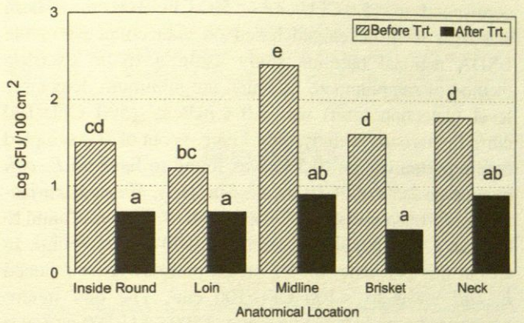

FIGURE 4. *Mean total coliform populations (log CFU/100 cm^2) on beef carcasses by anatomical location before and after steam pasteurization treatment. Within location and sampling time, n = 40. Means having a letter in common are not significantly different ($P > 0.01$). Estimated standard error of each of the least square means = 0.1. For statistical analysis, 0.4 $\log_{10}$ CFU/100 cm^2 (one-half of the detection limit in this study) was entered for samples in which total coliforms were not detected.*

($P \leq 0.01$) the total coliform populations at all five anatomical locations. After pasteurization, no differences existed ($P > 0.01$) among anatomical locations in the total coliform populations (approximately 0.6 $\log_{10}$ CFU/100 cm^2).

The results of analyses for *Enterobacteriaceae* populations (Fig. 5) were very similar to those of the total coliform analyses. The steam pasteurization treatment significantly ($P \leq 0.01$) reduced the *Enterobacteriaceae* populations at all five anatomical locations. Populations after treatment ranged from 0.5 to 1.0 $\log_{10}$ CFU/100 cm^2.

In the previous commercial evaluation that used a steam exposure time of 6 s *(6)*, total coliform and *Enterobacteriaceae* populations on fed-cattle carcasses were reduced significantly to below the detection limit of the study (0.6 $\log_{10}$ CFU/cm^2). In that study, initial total coliform populations ranged from 0.6 to 2.8 $\log_{10}$ CFU/cm^2, and *Enterobacteriaceae* populations ranged from 0.6 to 2.4 $\log_{10}$ CFU/cm^2.

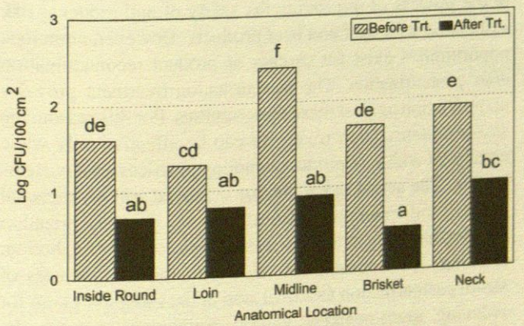

FIGURE 5. *Mean* Enterobacteriaceae *populations (log CFU/100 cm^2) on beef carcasses by anatomical location before and after steam pasteurization treatment. Within location and sampling time, n = 40. Means having a letter in common are not significantly different ($P > 0.01$). Estimated standard error of each of the least square means = 0.1. For statistical analysis, 0.4 $\log_{10}$ CFU/100 cm^2 (one-half of the detection limit in this study) was entered for samples in which* Enterobacteriaceae *were not detected.*

TABLE 2. *Chi-square analysis of the number of carcasses (% of carcasses) found to have total coliform populations within specified ranges before and after a steam pasteurization treatment*[a]

	Population range (CFU/100 cm^2)				
	<5.0	5.0 to 99.0	100 to 199	200 to 299	≥300
Before treatment[b]	19 (9.5%)	111 (55.5%)	27 (13.5%)	6 (3.0%)	37 (18.5%)
After treatment[b]	115 (57.5%)	80 (40.0%)	4 (2.0%)	0 (0.0%)	1 (0.5%)

[a] Both before and after treatment, the total number of carcasses sampled was 200. Those 200 samples included 40 samples from each of five anatomical locations (inside round, loin, midline, brisket, and neck).

[b] The distribution of carcasses among the specified population ranges before pasteurization treatment was significantly different from the distribution of carcasses after pasteurization treatment ($P = 0.001$, chi-square = 130.98).

Results of the chi-square analysis of the distribution of carcasses within specified total coliform population ranges (CFU/100 cm^2) are shown in Table 2. The distribution before pasteurization treatment was different ($P = 0.001$) from the distribution after treatment. Before treatment, 9.5% of carcasses had total coliform populations below the detection limit of the study (<5.0 CFU/100 cm^2), whereas after treatment, 57.5% of carcasses had total coliform populations below the detection limit of the study (<5.0 CFU/100 cm^2). Similarly, before treatment, 65% of carcasses had populations lower than 100 CFU/100 cm^2, whereas after pasteurization, 97.5% of carcasses had populations lower than 100 CFU/100 cm^2. Very similar trends were observed in the results of the chi-square analysis of *Enterobacteriaceae* populations (Table 3). The distributions before and after pasteurization treatment again were different ($P = 0.001$).

Qualitative screening for *Salmonella* spp. All samples analyzed were negative for the presence of *Salmonella* spp.

TABLE 3. *Chi-square analysis of the number of carcasses (% of carcasses) found to have* Enterobacteriaceae *populations within specified ranges before and after a steam pasteurization treatment*[a]

	Population range (CFU/100 cm^2)				
	<5.0	5.0 to 99.0	100 to 199	200 to 299	≥300
Before treatment[b]	15 (7.5%)	115 (57.5%)	17 (8.5%)	14 (7.0%)	39 (19.5%)
After treatment[b]	104 (52.0%)	91 (45.5%)	4 (2.0%)	0 (0.0%)	1 (0.5%)

[a] Both before and after treatment, the total number of carcasses sampled was 200. Those 200 samples included 40 samples from each of five anatomical locations (inside round, loin, midline, brisket, and neck).

[b] The distribution of carcasses among the specified population ranges before pasteurization treatment was significantly different from the distribution of carcasses after pasteurization treatment ($P = 0.001$, chi-square = 127.5).

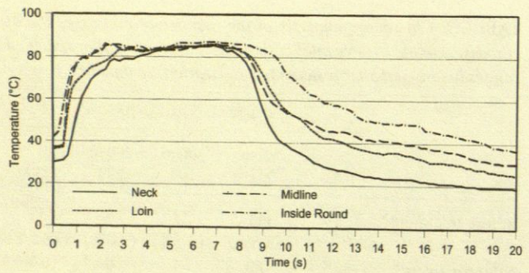

FIGURE 6. *Mean surface temperatures of beef carcasses (n = 10) at four anatomical locations during steam pasteurization treatment.*

Only samples collected on the second processing day were screened.

Temperature monitoring. The mean surface temperatures of 10 beef carcasses at four anatomical locations during steam pasteurization treatment are shown in Figure 6. The surface temperatures at the ML and IR areas rose quickly and reached the 82.2°C target temperature within 1.5 to 2 s. The temperature at the L area rose more slowly, reaching the target temperature within approximately 2.5 to 3 s. The N surface temperature was the slowest to reach the target, requiring approximately 4 to 4.5 s. Therefore, within the 6.5 s steam exposure time, the N area was at or above the target temperature for a shorter time than the other three anatomical locations. After the steam treatment, the temperature at the N area dropped fastest. The temperature at the L and ML areas fell somewhat more slowly than that at the N area, and the temperature at the IR area fell most slowly.

The actual carcass surface temperatures may explain why the steam pasteurization treatment was somewhat less effective at the N area. Based on the temperature graphs in Figure 6, bacterial populations at the N area likely did not receive the same steam treatment as those at the other anatomical locations. This may be an issue of equipment design, because the steam inlet valves are located at the top of the moving car.

Comparison of observed *E. coli* populations with USDA standards. Before observations made in this study are compared with standards outlined in the Pathogen Reduction; Hazard Analysis and Critical Control Point (HACCP) Systems; Final Rule *(10),* differences in sample collection procedures must be noted. In this study, one sponge was used to sample a 300-cm^2 area at a single anatomical location, whereas the USDA guidelines specify using one sponge to sample a 100-cm^2 area at each of three different anatomical locations (rump, flank, and brisket). The USDA guidelines do not require samples from the loin, midline, or neck. In this study, a total of 200 carcasses were sampled in one processing day (two production shifts). The USDA guidelines specify that carcasses be sampled at a frequency of 1 in 300. For the particular slaughter facility in this study, that frequency would correspond to eight or nine carcasses sampled in an 8-h production shift.

The USDA regulations *(10)* define the acceptable level of *E. coli* on beef carcasses to be "none detected," which corresponds to <5.0 CFU/cm^2 (<500 CFU/100 cm^2). These standards were developed based on data collected in the USDA national baseline study using a tissue excision method of sampling *(9),* in which the minimum detectable level (detection limit) was 5.0 CFU/cm^2 (500 CFU/100 cm^2). In this current study, only 1 carcass out of 200 sampled before pasteurization (0.5%) was found to have an *E. coli* population ≥500 CFU/100 cm^2. Similarly, after pasteurization, only 1 carcass out of 200 sampled (0.5%) was found to have an *E. coli* population of at least 500 CFU/100 cm^2. In all but this one case (0.5%), steam pasteurization reduced *E. coli* levels to <100 CFU/100 cm^2. The one steam-pasteurized sample having a count ≥500 CFU/100 cm^2 was from the midline area. This is a region of the carcass ordinarily handled by cooler workers while sorting and placing carcasses on the rails. Although personnel were instructed to avoid handling the carcasses at sites designated for sampling, this type of handling could have occurred possibly leading to postpasteurization recontamination. A small percentage of carcasses were not steam treated during the two sampling days because of occasional cycle failures. The one midline sample having a higher *E. coli* count might have been taken accidentally from a nontreated carcass in the low lighting conditions of the holding cooler. The lack of detectable *E. coli* on 85% of steam-pasteurized carcasses, as opposed to only 32% of nontreated carcasses, shows that steam pasteurization significantly lowers the risk of enteric populations on beef carcasses.

This study clearly demonstrated that differences exist in bacterial population levels at different anatomical carcass locations (Figs. 2, 4, and 5). This conclusion also has been reached by other researchers *(5).* This information supports the practice adopted by the USDA *(10)* of sampling multiple carcass locations for analysis of *E. coli* populations.

CONCLUSIONS

The steam pasteurization treatment (82.2°C for 6.5 s) effectively decreased the bacterial load on carcasses during slaughter, and the technology can serve as an important step in the process of improving the safety of and reducing risk associated with beef and beef products. However, numerous opportunities exist for carcass or product recontamination after pasteurization. The pasteurization treatment provides no protection against these opportunities. For this reason, the steam pasteurization treatment can be effective only when combined with safe product-handling practices after pasteurization. The actual risk reduction achieved will be impacted greatly and essentially determined by postpasteurization product-handling practices during processing, distribution, retailing, and consumption. However, the effectiveness of steam pasteurization as a final step in the slaughter phase for reducing gram-negative enteric populations reduces the likelihood of enteric pathogens being carried through further carcass conversion processes.

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