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Evaluation of a Steam Pasteurization Process in a Commercial Beef Processing Facility

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ABSTRACT

The effectiveness of a steam pasteurization process for reducing naturally occurring bacterial populations on freshly slaughtered beef sides was evaluated in a large commercial facility. Over a period of 10 days, 140 randomly chosen beef sides were microbiologically analyzed. Each side was sampled immediately before, immediately after, and 24 h after steam pasteurization treatment. Total aerobic bacteria (APC), *Escherichia coli* (generic), coliform, and *Enterobacteriaceae* populations were enumerated. The process significantly ($P \leq 0.01$) reduced mean APCs from 2.19 log CFU/cm^2 before treatment to 0.84 log CFU/cm^2 immediately after and 0.94 log CFU/cm^2 24 h after treatment. Before pasteurization (8 s steam exposure), 16.4% of carcasses were positive for generic *E. coli* (level of 0.60 to 1.53 log CFU/cm^2), 37.9% were positive for coliforms (level of 0.60 to 2.26 log CFU/cm^2), and 46.4% were positive for *Enterobacteriaceae* (level of 0.60 to 2.25 log CFU/cm^2). After pasteurization, 0% of carcasses were positive for *E. coli,* 1.4% were positive for coliforms (level of 0.60 to 1.53 log CFU/cm^2), and 2.9% were positive for *Enterobacteriaceae* (level of 0.60 to 1.99 log CFU/cm^2). Of the 140 carcasses evaluated, one carcass was positive for *Salmonella* spp. before treatment (0.7% incidence rate); all carcasses were negative after steam treatment. This study indicates that steam pasteurization is very effective in a commercial setting for reducing overall bacterial populations on freshly slaughtered beef carcasses. The system may effectively serve as an important critical control point for HACCP systems at the slaughter phase of beef processing. In conjunction with other antimicrobial interventions (mandated by USDA to achieve zero tolerance standards for visible contamination) and good manufacturing practices, this process can play an important role in reducing the risk of pathogenic bacteria in raw meat and meat products.

Key words: Steam pasteurization, beef, pathogens, meat safety, decontamination

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The microbiological safety of meat and meat products has received increased attention from regulators, consumers, researchers, industry, and the media. This increased attention largely was sparked by an *Escherichia coli* O157:H7 outbreak in the Pacific Northwest *(4).* The United States Department of Agriculture's Food Safety and Inspection Service (USDA) has promulgated regulatory changes in the processing of meat and meat products. Many of the changes focus on the implementation of hazard analysis and critical control point (HACCP) systems *(8),* which are aimed at helping to ensure the microbiological safety of products.

Extensive research has been conducted on methods for reducing bacterial contamination on beef carcasses during the slaughter phase of processing. Although many studies have been conducted in laboratory settings, few studies have evaluated the effectiveness of decontamination treatments in commercial processing situations. Data generated in laboratory experiments often are extrapolated to predict efficacy in commercial use. However, many variables encountered in commercial situations cannot be recreated or duplicated in laboratory experiments. Therefore, to obtain accurate and practical information about the effectiveness of decontamination treatments, they also should be evaluated under conditions of industry use. Researchers have used commercial settings to evaluate interventions such as knife trimming *(10, 11, 17);* water washing *(2, 10, 11, 17);* application of lactic acid *(16);* application of chlorine *(6, 12);* and postexsanguination dehairing *(18).*

Knife trimming of a predesignated area on commercially slaughtered beef carcasses significantly reduced the aerobic plate count (APC) in that area *(17).* However, the trimming was performed carefully by researchers using sterile instruments and procedures that were more aseptic than those typically used by slaughter-line workers. The same study also showed that carcass washing after knife trimming increased the APCs in the trimmed area.

Barkate et al. *(2)* decontaminated commercially slaughtered beef carcasses with hot (95°C), sterilized, distilled water, which raised carcass surface temperature to 82°C. Treated carcasses had significantly lower APCs (1.1 to 1.5 log CFU/cm^2) than control carcasses (2.3 to 2.4 log CFU/cm^2).

A 1% lactic acid spray applied to commercially slaughtered beef carcasses both after dehiding and after eviscera-

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tion reduced APCs on treated carcasses by 2.3 log CFU/cm^2 compared to APCs of control carcasses (3.9 log CFU/cm^2) *(16)*. After chilling for 72 h, treated carcasses had APCs 1.4 log CFU/cm^2 lower than those of control carcasses, which then had APCs of 3.5 log CFU/cm^2.

Emswiler et al. *(6)* used chlorine solutions of various concentrations to treat commercially processed, chilled, market beef forequarters. Overall, the chlorine treatments were ineffective at reducing APCs.

Schnell et al. *(18)* used a chemical treatment (10% sodium sulfide) to dehair 10 commercially slaughtered beef carcasses immediately after exsanguination. Although treated carcasses had fewer residual hairs on the surfaces, the treatment did not significantly decrease the microbial load of the treated carcasses when compared to control carcasses.

A recently invented steam pasteurization process *(20)* for decontaminating beef tissues has been shown in laboratory experiments to be very effective against high levels of pathogenic bacterial contamination *(15)*. The objective of this study was to determine the effectiveness of this process for reducing naturally occurring populations of aerobic bacteria, *E. coli* (generic), total coliforms, and *Enterobacteriaceae* on the surfaces of commercially slaughtered beef carcasses. A secondary objective was to determine differences in effectiveness of the process on cow carcasses compared to fed cattle carcasses caused by uniformity differences. While the term "pasteurization" typically refers to the destruction of all vegetative pathogenic bacteria, throughout this manuscript the term will be used to describe the steam pasteurization process as it is commercially marketed.

Stunning
↓
Shackling
↓
Sticking
↓
Skinning front and rear legs
↓
Loosening bung
↓
Skinning over inside round, cod/udder, midline, brisket
(followed by steam vacuum spot cleaning)
↓
Siding
↓
Skinning over outside round
↓
Hide pulling
↓
Loosening weasand
↓
Removing head
↓
Eviscerating
↓
Splitting carcass
(followed by steam vacuum spot cleaning)
↓
Final trimming
↓
Final inspecting
↓
Weighing
↓
Carcass washing
↓
Removing water
↓
Steam pasteurizing
— applying steam
— spraying cold water
↓
Chilling (24 h)

FIGURE 1. *Flow of slaughter operations in commercial testing facility.*

MATERIALS AND METHODS

Slaughter facility

Testing of the steam pasteurization equipment (Frigoscandia Food Process Systems, Bellevue, WA) *(20)* was conducted in a commercial beef slaughter/fabrication facility with a maximum slaughter capacity of 240 animals per hour. The facility was located at an altitude of 1,201 m above sea level and processed both fed cattle and cows. Fed cattle were classified as younger animals of beef breeds and Holstein steers that had been grain fed. Fed cattle carcasses had USDA maturity scores of A or B. Cows were older animals of both beef and dairy breeds with USDA maturity scores of C, D, or E. Approximately 70% of the facility's total production was cows, and the other 30% was fed cattle. In addition to knife trimming and final carcass washing, the facility used steam vacuum spot cleaning systems during slaughter to remove visible contamination per USDA specifications at two points (Fig. 1); after skinning over the outside round area and after splitting of the carcass. Dressed carcasses were chilled in a −0.5 to 0°C cooler with a spray chill system using intermittent sprays of water at 1.1 to 1.7°C containing 10 ppm chlorine. Approximately 24 h after slaughter carcasses were transferred from the holding coolers, sorted by grade, and fabricated.

Steam pasteurization treatment

A USDA-approved *(7)* steam pasteurization treatment was incorporated as the last step in the slaughter process (Fig. 1). Steam pasteurization as applied in this process, on which a patent is pending *(20)*, consisted of three distinct phases: removing surface water, pasteurizing, and surface cooling. The purpose of the water removal system was to remove from the carcass surface, after standard washing, pools of residual water that might have protected bacteria from the lethal effects of condensing steam. During the pasteurizing phase, the carcass surface was exposed to nearly saturated steam in an enclosed in-line moving chamber. Immediately after exposure to steam, the carcass surface was cooled with a cold water spray to remove the surface heat added during pasteurization.

The water-removal system employed a pair of vertical blowers each consisting of a fan housing and a pressure chamber. Each pressure chamber, or plenum, had seven openings 7.6 cm in diameter. Each fan, powered by a 3.5-hp (2.6-kW) motor, blew unfiltered air through the openings in the pressure chamber. The pair of blowers was situated so that air was blown from opposing sides, which resulted in total coverage of a carcass side as it passed between the blowers. The pressure of 7.0 cm of water column in each chamber created an air velocity of approximately 1,981 m/min (119 km/h). The blowers produced a total air volume of 170 m^3/min. Carcass sides passed through the water removal system about 20 s after exiting the carcass wash cabinet. After water removal, carcasses proceeded to the steam pasteurizing unit.

The pasteurization and chill phases of the process occurred within one piece of in-line equipment, which consisted of a long cabinet with a moving internal compartment (Fig. 2). The cabinet was a stainless steel sheet-metal tunnel (11.3 m long, 1.2 m wide, and 3.4 m tall) and housed both the steam chamber and the chilling system. The cabinet also prevented steam from escaping into the

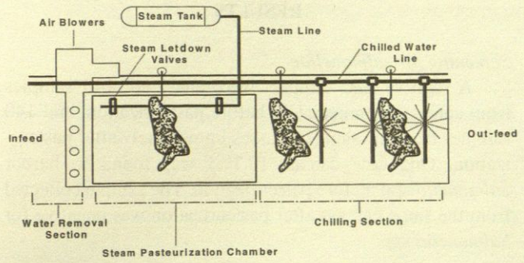

FIGURE 2. *Schematic diagram of commercial steam pasteurization unit.*

plant during treatment. Flexible seals at the top of the cabinet allowed trolleys that moved along the overhead production rail to pass through the equipment while preventing steam from escaping. The equipment's ventilation system exhausted air and steam from the cabinet to the roof of the plant.

Carcass sides were exposed to steam inside the moving internal compartment (car) which traveled back and forth inside the cabinet. Doors at each end of the car opened to allow carcass sides to move in and out and closed to entrap steam during treatment. At the beginning of each pasteurization cycle, the car was positioned at the in-feed end of the cabinet (Fig. 2). Four carcass sides per cycle entered the car, and the doors at both ends closed, enclosing the four sides. The car moved toward the out-feed end of the cabinet at the same speed that the trolleys moved along the overhead production rail. As the car doors closed, the car was filled with steam, and carcass sides were treated for either 6 or 8 s. At the end of the exposure time, the doors at both ends of the car opened, and the car quickly returned to the in-feed end of the cabinet. During steam treatment, the temperature inside the car was monitored by four thermocouple transmitters, two mounted near the floor and two mounted near the ceiling. Preliminary experiments showed that during steam application the surface temperature of the carcasses inside the car was equivalent to the atmospheric temperature inside the car. The system could be turned off, and carcass sides could pass through the tunnellike cabinet without being pasteurized. Under these circumstances, the car remained at the in-feed end of the tunnel with the doors open. No steam was released, but the cold water spray remained operational.

Steam for the system was generated by a pressure vessel that was charged from the boiler system of the plant. The pressure vessel stored steam between pasteurization cycles, releasing it rapidly to fill the car with steam and then more slowly to maintain the steam environment during pasteurization. Saturated steam was injected into the car through three letdown valves in the cabinet roof. As mentioned previously, a ventilation system exhausted air and steam from around the seals in the cabinet to prevent steam from escaping into the plant and causing condensation problems.

The chilling system consisted of 24 stainless steel cold-water spray nozzles (1/4 CW 11010SS 110°, Bete Fog, Greenfield, MA) mounted to the walls of the out-feed end of the cabinet (total system output 35 gal/min, 1.46 gal/min per nozzle [ca. 132 liter/min, 5.5 liter/min per nozzle]). As carcasses exited the moving steam chamber (car), they were sprayed with cold water (4.4°C) at approximately 40 lb/in^2 for at least 10 s. The distance from the spray nozzles to the centerline of the cabinet was 50.4 cm. Carcass sides exited the cabinet into the plant coolers (hot boxes) for chilling.

Sample collection and experimental design

On each of 10 consecutive production days, samples were excised from 14 carcasses treated with steam pasteurization for 8 s (8-s carcasses), two carcasses treated with steam pasteurization for 6 s (6-s carcasses), and two carcasses that received no steam pasteurization treatment (control carcasses). Over the 10-day testing period a total of 140 8-s carcasses (70 cow and 70 fed cattle), 20 6-s carcasses (9 cow and 11 fed cattle), and 20 control carcasses (10 cow and 10 fed cattle) were sampled and analyzed.

Samples were excised from each 8-s and 6-s carcass for enumeration of bacterial populations at three points in processing; immediately after exiting the water removal equipment and just before entering the steam pasteurization cabinet (BSP), immediately after exiting the steam pasteurization cabinet after the cold water shower to cool the surface (ASP), and 24 h after steam pasteurization treatment after a 24-h chill (AC). Samples were excised from each control carcass for enumeration of bacterial populations at BSP and AC. All samples for BSP and ASP were collected within 1 min of sides entering or exiting the pasteurization cabinet.

Samples from the selected carcasses were excised from the brisket/plate region (an area 30 by 30 cm area located 7 to 8 cm laterally from the juncture of the sternum and sixth and seventh ribs) of the carcasses. This site was chosen because it provided a sufficiently large surface area for obtaining samples at all three sampling times and this region was likely to be contaminated during the slaughter process *(9, 14)*. Also, it was easily accessible without stopping the production line or removing carcasses from the main production rail. The sampling technique of excising surface tissue from carcasses was chosen over swabbing or sponging of the carcass surface. Excised tissue samples have been shown to provide greater recovery of organisms than swab samples from washed beef carcass surfaces, especially when analyzing for *Enterobacteriaceae* and *E. coli (1)*.

Samples for microbiological enumerations consisted of two 11.4-cm^2 cores approximately 2 mm in depth (total external surface area 22.8 cm^2). Core samples were obtained by cutting the carcass surface with a sterile steel coring device and excising the core with sterile scalpel and forceps. All utensils were sterilized by dipping in 95% ethanol and flaming. Depending on carcass type and amount of fat cover, cores consisted of adipose tissue, lean (cutaneus trunci) tissue, or both. Core samples always were excised from the leading (right-hand) carcass side. Samples collected immediately after treatment (ASP) were removed from an area above that from which BSP samples were collected. The two excised cores were placed into one sterile filter stomacher bag and held at 1.1°C until plating (<2 h).

For screening of 8-s carcasses for *Salmonella* spp., one 11.4-cm^2 core (ca. 2 mm in depth), excised as previously described, was obtained before pasteurization (BSP) and immediately after pasteurization (ASP). Each core sample was placed into a sterile filter stomacher bag and held at 1.1°C. At the end of each production day, all samples to be screened for *Salmonella* spp. were packed into insulated containers with cold packs and shipped by next-day delivery to the food microbiology lab at Kansas State University. All other microbial analyses were performed at the commercial testing site.

Temperature monitoring of carcasses during 24-h chilling

After exiting the steam pasteurization cabinet, test carcasses were positioned on a designated rail in the cooler so as to avoid cross-contamination among test carcasses. Once positioned in the cooler, temperature-monitoring devices were attached to the surface of selected 8-s carcasses. Carcass surface temperature over the

sirloin area was recorded every 10 min for 24 h using Sapac Temprecord Scientific Model temperature recorders (Monitor Co., Modesto, CA). The probe of the recorders was inserted just under the surface of the adipose tissue (about 1 mm deep).

Microbiological analyses

Samples for enumeration of bacterial populations (consisting of two cores) were stomached for 2 minutes with 90 ml 0.1% peptone water diluent (Fisher Scientific, Pittsburgh, PA) in a Stomacher Lab Blender 400 (Tekmar, Cincinatti, OH). Serial dilutions were prepared using 0.1% peptone water diluent. One milliliter of appropriate dilutions was plated in duplicate onto Petrifilm® aerobic count plates for the enumeration of aerobic bacterial populations, *E. coli* count plates for enumeration of *E. coli* and total coliform populations, and *Enterobacteriaceae* count plates (3M, St. Paul, MN) for the enumeration of *Enterobacteriaceae* populations. All Petrifilm plates were incubated at 35°C for 48 h. Colonies were enumerated according to manufacturer's guidelines. All blue colonies with or without gas on *E. coli* count plates were enumerated as *E. coli.* The minimum detectable count for Petrifilm was 0.6 log CFU/cm^2; all counts less than 1.99 log CFU/cm^2 for APCs and 1.77 log CFU/cm^2 for other populations (25 colonies on APC plates or 15 colonies on other Petrifilm plates from the lowest dilution) should be considered estimates. For statistical analyses, counts from plates having no detectable colonies were entered as 0.01 log CFU/cm^2 *(19).*

Samples for qualitative *Salmonella* spp. screening were analyzed at Kansas State University within 30 h of collection according to USDA-FSIS procedures *(14).* Samples were preenriched for 24 h at 35°C in 100 ml buffered peptone water (Difco, Detroit, MI). Aliquots (0.5 ml) of the preenriched sample were transferred to 9 ml of selenite cystine (SC) broth (Difco) and 9 ml of Hajna and Damon tetrathionate (TT) broth (Difco). The SC and TT broths were incubated at 35 and 42°C, respectively, for 24 h. One loopful of sample from each selective enrichment was streaked onto lysine iron agar (LIA; Oxoid) and brilliant green sulfapyridine agar (BGS; Difco) plates and incubated for 24 h at 35°C. BGS plates with no presumptive colonies were incubated for an additional 24 h. Suspect colonies on BGS and LIA plates were tested with *Salmonella* O antiserum poly A-I, Vi (Difco) and *Salmonella* H (A-Z) (Difco) antisera. All colonies showing positive agglutination were further confirmed as *Salmonella* spp. using API 20E test kits (bioMerieux, Hazelwood, MO).

Statistical analyses

Microbiological data were converted to log CFU/cm^2 for analyses. The main plot design was a two (cow or fed cattle) by three (8-s, 6-s, or 0-s exposure time) factorial design. The subplot treatment, measured on each animal, consisted of the three sampling times (BSP, ASP, and AC). The data were analyzed using the General Linear Models (GLM) procedure of SAS. Because significant interactions were present, separate analyses were performed for each sampling time, with comparisons across carcass types and exposure time made for each.

Because the bulk of the experiment focused on carcasses exposed for 8 s, a separate analyses also was done on these data alone. This portion of the experiment was a split plot, with carcass type as the main plot treatment and sampling time as the subplot treatment. Comparison of carcass type and sampling time combination also was made for these data using the GLM procedure. The level of significance for all statistical analyses was set at $P \leq 0.01$.

RESULTS

Screening for salmonellae

A total of 280 samples were analyzed; 140 samples from carcasses immediately before pasteurization, and 140 samples from the same carcasses immediately after pasteurization. One cow carcass (0.7%) was found to harbor *Salmonella* spp. before pasteurization. The sample collected from the same carcass after pasteurization was negative for *Salmonella* spp.

Temperature monitoring

The Frigoscandia steam pasteurization system automatically recorded the atmospheric temperature inside the steam chamber (car) during steam treatment. The temperature ranged from 90.5 to 94.0°C. Surface temperatures of pasteurized 8-s carcasses upon entering the coolers (hot boxes) ranged from 17.5 to 22.4°C with an average of 19.4°C (Fig. 3). The average surface temperature reached 10°C approximately 5 h after carcasses entered the coolers. At the end of the 24-h chilling period, surface temperatures were 2.2 to 2.8°C.

Microbiological analyses

Effectiveness on cow versus fed cattle carcasses. For controls and both steam exposure times, no differences ($P > 0.01$) were found in the microbial populations of fed cattle carcasses compared to cow carcasses before or immediately after pasteurization (Table 1, statistical comparisons not indicated). These results show that, in this processing facility, cow carcasses and fed cattle carcasses had similar microbial populations, and steam pasteurization was equally effective at reducing the microbial populations on both types of carcasses. After a 24-h chill, the microbial populations were similar for cow carcasses and fed cattle carcasses for the control and the 8-s exposure time. However, at the 6-s exposure time, cow carcasses had lower APCs ($P \leq 0.01$) than fed cattle carcasses.

Control carcasses. The mean APC on control carcasses immediately after slaughter was 2.05 log CFU/cm^2 for cows and 2.20 log CFU/cm^2 for fed cattle (Table 1). After the 24-h chill cycle, APCs on cow carcasses and fed cattle carcasses were 1.85 and 2.13 log CFU/cm^2, respectively. For both carcass types, the APCs immediately after slaughter were the same ($P > 0.01$) as APCs after chilling for 24 h (Table 1). For both control carcass types, the *E. coli,* total coliform, and *Enterobacteriaceae* populations tended to be low both immediately after slaughter and after chilling (Tables 2–4). No significant differences ($P > 0.01$) were found in these populations at the two sampling times (BSP and AC).

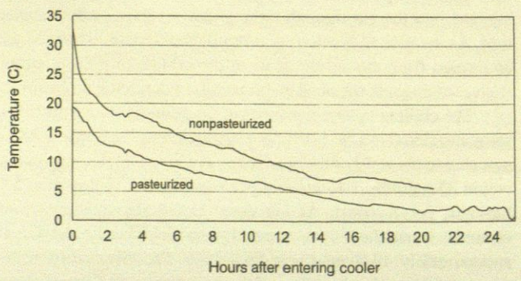

FIGURE 3. *Average surface temperatures of pasteurized and nonpasteurized carcasses during the 24-h chilling period.*

TABLE 1. *Mean total aerobic bacterial populations on beef carcasses before, immediately after, and 24 h after steam pasteurization treatments*

		Steam exposure time (s)					
		0		6		8	
Carcass type	Sampling time[a]	Mean[b]	SEM	Mean	SEM	Mean	SEM
Cows	BSP	2.05^{cx}	0.18	2.12^{cx}	0.14	2.19^{cx}	0.06
	ASP	NA	NA	0.56^{dx}	0.14	0.84^{dx}	0.06
	AC	1.85^{cx}	0.18	0.77^{dy}	0.14	0.94^{dy}	0.06
Fed cattle	BSP	2.20^{cx}	0.15	2.38^{cx}	0.15	2.14^{cx}	0.07
	ASP	NA	NA	0.90^{dx}	0.15	1.03^{dx}	0.07
	AC	2.13^{cx}	0.15	1.38^{dxy}	0.15	1.09^{dy}	0.07

[a] BSP = immediately before steam pasteurization treatment; ASP = immediately after steam pasteurization treatment; AC = 24 h after steam pasteurization treatment, after a 24-h chill.
[b] Mean bacterial counts (log CFU/cm^2) are averages of 70 replications for the 8-s steam exposure, 10 replications for the 6-s steam exposure, and 9 replications for cows and 11 replications for fed cattle for the 0-s steam exposure.
[c,d] Means within columns (steam exposure times) and carcass type with different superscripts are different ($P \leq 0.01$).
[x,y] Means within rows (sampling times) and carcass type with different superscripts are different ($P \leq 0.01$).

Eight-second exposure time. The APCs for cow and fed cattle carcasses before pasteurization were 2.19 and 2.14 log CFU/cm^2, respectively (Table 1). Immediately after pasteurization, APCs were reduced ($P \leq 0.01$) by 1.35 and 1.11 log CFU/cm^2, respectively. No differences ($P > 0.01$) were found between mean APCs immediately after pasteurization and after chilling for 24 h, indicating no resuscitation of thermally injured cells or contamination in the cooler.

E. coli was detected on 16.4% of the 140 carcasses sampled before pasteurization (population levels of 0.60 to 1.53 log CFU/cm^2). All carcasses were negative for *E. coli* after treatment and after chilling (Table 2). Coliforms were present on 37.9% of carcasses before pasteurization (levels of 0.60 to 2.26 log CFU/cm^2). After pasteurization, only two of 140 carcasses were positive (level of 0.60 to 1.53 log CFU/cm^2; Table 3). *Enterobacteriaceae* populations were detected on 46.4% of carcasses before treatment (level of 0.60 to 2.25 log CFU/cm^2) and only four of 140 carcasses after pasteurization (level of 0.60 to 1.99 log CFU/cm^2; Table 4).

Six-second exposure time. Reductions in bacterial populations after a 6-s steam exposure time were very similar to those obtained with an 8-s exposure time (Tables 1–4). The 6-s steam pasteurization treatment reduced mean APCs ($P \leq 0.01$) on cow and fed cattle carcasses from initial levels of 2.12 and 2.38 log CFU/cm^2 immediately prior to pasteurization to 0.56 and 0.90 log CFU/cm^2 immediately after pasteurization, respectively (Table 1). No significant differences occurred between APCs immediately after pasteurization and after a 24-h chill ($P > 0.01$). Reductions in *E. coli,* total coliform, and *Enterobactericeae* populations were very similar to those found with an 8-s pasteurization treatment (Tables 2–4) with 0 of 20 carcasses being positive

TABLE 2. *Mean* E. coli *(generic) populations on beef carcasses before, immediately after, and 24 h after steam pasteurization treatments*

		Steam exposure time (s)					
		8		6		0	
Carcass type	Sampling time[a]	*N*, carcasses[b]	Range[c] (log CFU/cm^2)	*N*, carcasses	Range (log CFU/cm^2)	*N*, carcasses	Range (log CFU/cm^2)
Cows	BSP	13 of 70	0.60–1.53	2 of 9	0.60–0.99	1 of 10	0.60
	ASP	0 of 70	<0.60	0 of 9	<0.60	NA	NA
	AC	0 of 70	<0.60	0 of 9	<0.60	0 of 10	<0.60
Fed cattle	BSP	10 of 70	0.60–1.20	1 of 11	0.60	2 of 10	0.60–0.77
	ASP	0 of 70	<0.60	0 of 11	<0.60	NA	NA
	AC	0 of 70	<0.60	0 of 11	<0.60	0 of 10	<0.60

[a] BSP = immediately before steam pasteurization treatment; ASP = immediately after steam pasteurization treatment; AC = 24 h after steam pasteurization treatment, after a 24-h chill.
[b] *N*, carcasses = number of carcasses on which *E. coli* (generic) was detected (detection limit of 0.6 log CFU/cm^2) out of the total number of carcasses sampled.
[c] Range = the range of *E. coli* populations on the carcasses on which *E. coli* was detected.

TABLE 3. *Mean total coliform populations on beef carcasses before, immediately after, and 24 h after steam pasteurization treatments*

		Steam exposure time (s)					
		8		6		0	
Carcass type	Sampling time[a]	*N*, carcasses[b]	Range[c] (log CFU/cm^2)	*N*, carcasses	Range (log CFU/cm^2)	*N*, carcasses	Range (log CFU/cm^2)
Cows	BSP	28 of 70	0.60–2.26	3 of 9	0.60–1.55	1 of 10	1.25
	ASP	0 of 70	<0.60	0 of 9	<0.60	NA	NA
	AC	1 of 70	0.60	0 of 9	<0.60	2 of 10	0.60–1.25
Fed cattle	BSP	25 of 70	0.60–2.18	3 of 11	0.60–2.18	2 of 10	1.07–1.34
	ASP	2 of 70	0.60–1.53	0 of 11	<0.60	NA	NA
	AC	6 of 70	0.60–1.41	0 of 11	<0.60	1 of 10	0.60

[a] BSP = immediately before steam pasteurization treatment; ASP = immediately after steam pasteurization treatment; AC = 24 h after steam pasteurization treatment, after a 24-h chill.
[b] *N*, carcasses = number of carcasses on which coliforms were detected (detection limit of 0.6 log CFU/cm^2) out of the total number of carcasses sampled.
[c] Range = the range of total coliform populations on the carcasses on which coliforms were detected.

for *E. coli,* coliforms, or *Enterobacteriaceae* populations immediately after pasteurization.

Exposure time comparisons. Fed cattle carcasses showed no differences in APCs ($P > 0.01$) immediately before pasteurization among controls and those treated for 6 and 8 s (Table 1). Immediately after treatment, no differences occurred in APCs between carcasses treated for 6 or 8 s ($P > 0.01$). This indicates that the 8-s and 6-s steam pasteurization treatments were equally effective at reducing APCs. After a 24-h chill, APCs were significantly lower on the fed cattle carcasses treated for 8 s compared to control and 6-s carcasses. For *E. coli,* total coliform, and *Enterobacteriaceae* populations, no significant differences occurred at any sampling time (BSP, ASP, or AC) among control carcasses and those treated for 6 and 8 s. As stated previously, these populations were very low or undetectable.

For cow carcasses, no differences ($P > 0.01$) occurred in APCs between the 8-s and 6-s treatments at any sampling time (BSP, ASP, or AC) (Table 1), indicating that both treatments were equally effective at reducing APC populations. No differences ($P > 0.01$) were observed in APCs between control and treated (8- and 6-s) carcasses before pasteurization. After a 24-h chill, the treated carcasses (8 and 6 s) had lower APCs than control carcasses ($P \leq 0.01$) (Table 1). Before pasteurization, no differences ($P > 0.01$) occurred in total coliform counts between treated (8- or 6-s) and control carcasses. After a 24-h chill, treated (8- and 6-s) carcasses had significantly ($P \leq 0.01$) lower total coliform populations than control carcasses (0 s). No differences ($P > 0.01$) occurred in *E. coli* or *Enterobacteriaceae* populations among control carcasses and those treated for 6 and 8 s at any sampling time.

DISCUSSION

In laboratory validation studies, steam pasteurization effectively reduced high levels of pathogenic bacterial populations inoculated onto freshly slaughtered beef tissue *(15).* The current study verified that the scaled-up commercial pasteurization system is very effective in reducing the levels of natural mixed flora on surfaces of commercially slaughtered beef carcasses. After chilling for 24 h after slaughter, carcasses subjected to steam pasteurization had APCs more than 1 log CFU/cm^2 lower than those of untreated carcasses (ca. 2.0 log CFU/cm^2). In most cases, the enteric bacterial populations after pasteurization were undetectable. When viewed in terms of the documented very low infectious dose level of *E. coli* O157:H7 *(13)* and certain other pathogens, these statistically significant reductions in enteric bacterial populations likely offer positive effects in terms of meat safety. No significant differences were apparent in the effectiveness of the system on cow carcasses compared to fed cattle carcasses. Because the cow carcasses sampled during this study often had very little, if any, fat cover in the sampling region (brisket/plate junction) and fed cattle carcasses generally had thick fat cover, this observation can be interpreted to mean that the lethal effects of the steam application are equally effective on lean tissue and adipose tissue. Additionally, the commercially designed system operated equally well with both carcass types despite considerable variations in carcass size and shape.

Steam pasteurization does not require the use of chemicals, does not require specialized waste water treatment systems, and, when used properly with commercially installed safeguards, is not hazardous to plant personnel and equipment. Contamination need not be visible to be treated, because the uniform condensation of steam over the entire carcass surface area theoretically provides total and complete carcass decontamination. A distinct advantage of steam pasteurization, in which carcass surface temperatures instantaneously reach levels above 90.5°C, is the likely reduced potential for selecting resistant bacterial populations. The documented acid resistance of *E. coli* O157:H7 *(3, 5),* might reduce the efficacy of organic acids as carcass interventions.

TABLE 4. *Mean* Enterobacteriaceae *populations on beef carcasses before, immediately after, and 24 h after steam pasteurization treatments*

		Steam exposure time (s)					
		8		6		0	
Carcass type	Sampling time[a]	*N*, carcasses[b]	Range[c] (log CFU/cm^2)	*N*, carcasses	Range (log CFU/cm^2)	*N*, carcasses	Range (log CFU/cm^2)
Cows	BSP	36 of 70	0.60–2.23	4 of 9	0.60–0.99	2 of 10	0.60–0.77
	ASP	1 of 70	0.60	0 of 9	<0.60	NA	NA
	AC	2 of 70	0.60	1 of 9	0.60	1 of 10	1.86
Fed cattle	BSP	29 of 70	0.60–2.25	4 of 11	0.60–2.35	3 of 10	0.60–1.37
	ASP	3 of 70	0.60–1.99	0 of 11	<0.60	NA	NA
	AC	6 of 70	0.60–1.44	1 of 11	1.25	2 of 10	0.60

[a] BSP = immediately before steam pasteurization treatment; ASP = immediately after steam pasteurization treatment; AC = 24 h after steam pasteurization treatment, after a 24-h chill.
[b] *N*, carcasses = number of carcasses on which *Enterobacteriaceae* were detected (detection limit of 0.6 log CFU/cm^2) out of the total number of carcasses sampled.
[c] Range = the range of *Enterobacteriaceae* populations on the carcasses on which *Enterobacteriaceae* were detected.

CONCLUSIONS

HACCP programs for beef slaughter and processing recently have been mandated by the USDA, including *E. coli* and *Salmonella* spp. standards *(8).* Comparing *E. coli* population levels in this study before pasteurization and after pasteurization, steam pasteurization likely can assist companies in meeting regulatory standards consistently. The commercial steam pasteurization system provides a true critical control point for pathogens in the slaughter phase. Records, including steam chamber/carcass surface temperature, carcass identification, exposure time, and deviations, are computer logged automatically by the equipment for regulatory review. Carcasses not receiving the specified steam treatment can be automatically railed out and redirected through the unit if such rail-out systems are installed. Steam pasteurization, when combined with well-defined standard operating procedures for slaughter, good manufacturing practices, and regulatory oversight, likely will provide a microbiologically safer carcass entering the cooler. However, the potential still exists for recontamination of meat products at any point postpasteurization, including cooler sorting of carcasses, USDA grading, and fabrication. Companies should continue to monitor conditions and practices in these areas, and customers should continue to use proper handling and cooling methods to ensure meat safety.

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