

A Comparison of Three Commercial Beef Carcass Decontamination Systems

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SUMMARY

The objective of this study was to compare the efficacy of three beef carcass decontamination systems, when applied commercially, in reducing microbiological populations on the surfaces of beef carcasses. System A decontamination treatments included steam vacuuming, post-evisceration carcass washing, and post-evisceration acetic acid solution rinsing. System B decontamination treatments included steam vacuuming, pre-evisceration carcass washing, pre-evisceration acetic acid solution rinsing, post-evisceration carcass washing, and post-evisceration acetic acid solution rinsing. System C decontamination treatments included steam vacuuming, pre-evisceration carcass washing, pre-evisceration acetic acid solution rinsing, thermal pasteurizing, post-evisceration carcass washing, and post-evisceration acetic acid solution rinsing. In general, adjusted mean total plate counts (TPC), total coliform counts (TCC) and *Escherichia coli* counts (ECC) on carcasses exposed to system A were 8.5, 4.3 and 3.8 log CFU/100 cm², respectively, while corresponding counts on carcasses following exposure to system B were 6.4, 3.6 and 2.9 log CFU/100 cm², respectively. Additionally, carcasses exposed to system C possessed TPC, TCC and ECC of 6.3, 2.8 and 2.2 log CFU/100 cm², respectively.

Decontamination systems B and C, which employed additional decontamination treatments as compared to system A, produced carcasses with 2.1 and 2.2 log

CFU/100 cm² lower ($P < 0.05$) TPC, 0.8 and 1.5 log CFU/100 cm² lower TCC, and 0.9 and 1.6 log CFU/100 cm² lower ECC, respectively, thereby demonstrating that the efficacy of a decontamination system increases with the application of additional treatments.

INTRODUCTION

In 1996, the Food Safety and Inspection Service of the United States Department of Agriculture developed new regulations for meat and poultry inspection employing the concept of Hazard Analysis and Critical Control Point (HACCP) systems that included microbiological performance criteria for *Escherichia coli* and *Salmonella* to evaluate slaughter facilities as they operated under the new HACCP policies (FSIS-USDA, 1996). In order to comply with existing "zero tolerance" requirements and to meet the microbiological performance criteria set forth by the new "Pathogen Reduction: Hazard Analysis and Critical Control Points (HACCP) Systems; Final Rule" (FSIS-USDA, 1993; 1996), decontamination treatments have been identified and tested. These include the use of steam and/or hot water vacuuming and steam pasteurization, as well as pre- and post-evisceration carcass washing treatments using hot water and/or organic acid solution rinses (Dorsa, 1997; Hardin *et al.*, 1995; Sofos and Smith, 1998).

The objective of this study was to evaluate individual decontamination treatments--steam vacuuming, pre-evisceration carcass washing, hot water pasteurizing, post-evisceration carcass washing and acetic acid solution rinsing--for their additive and collective abilities to clean and decontaminate beef carcasses when applied in different combinations under commercial application.

MATERIALS AND METHODS

Microbiological samples ($N = 1,320$) were collected in each of three beef (steer-heifer) slaughtering facilities applying the same carcass decontamination system which consisted of: (a) steam vacuuming

(104-110°C, 138-345 kPa steam, negative 7 to 12 mm of Hg vacuum) of spot contamination, in a concentrated area of the slaughtering sequence, following hide removal; (b) pre-evisceration carcass washing (29-38°C water at 193-331 kPa, 6-8 sec), immediately following steam vacuuming; (c) pre-evisceration rinsing with an acetic acid solution (1.6-2.6% acetic acid solution, 43-60°C, 317-324 kPa, 2-4 sec), following pre-evisceration washing; (d) thermal pasteurizing (71-77°C water, 69-228 kPa, 10-14 sec), following "Zero Tolerance" final rail inspection; (e) post-evisceration carcass washing (16-32°C water, 483-897 kPa, 10-14 sec), following thermal pasteurizing; and (f) post-evisceration rinsing with an acetic acid solution (1.6-2.6% acetic acid solution, 43-60°C, 317-324 kPa, 2-4 sec), following post-evisceration carcass washing and immediately before carcass chilling. Plants 1,2 and 3 possessed slaughter chain speeds of 290-304, 325-350 and 330-345 head per hour, respectively, while cooler chain speeds were approximately 400 head per hour for all three plants.

Sample Collection and Enumeration.

In each plant, sampling was conducted to evaluate three intervention systems (A, B and C), each employing different treatment combinations, in an attempt to determine the system's collective, decontamination ability. During application of system A, carcasses were not exposed to pre-evisceration carcass washing, pre-evisceration acetic acid solution rinsing, or thermal pasteurizing. Data from system A reflected the efficacy of using a combination of two decontamination treatments: steam vacuuming and post-evisceration carcass washing plus acetic acid solution rinsing. Sponge sampling for system A occurred during the slaughtering/dressing process at four in-plant locations, which were: (1) hide-off, following dehiding but before the application of steam vacuuming; (2) after steam vacuuming, immediately following application of the last steam vacuum; (3) immediately before post-

evisceration carcass washing plus acetic acid solution rinsing, and; (4) immediately after post-evisceration carcass washing and acetic acid solution rinsing. Differences in contamination levels between sampling locations 1 and 2 could be attributed to the individual effect of steam vacuuming. The contamination level at site 3 not only included the individual effects of steam vacuuming, but any further contamination of the carcass occurring during subsequent dressing processes (evisceration, splitting, etc). Differences in contamination levels between sampling locations 3 and 4 could be attributed to the individual effect of post-evisceration carcass washing plus acetic acid solution rinsing when the only previously applied treatment was steam vacuuming.

During testing of system B, carcasses were not exposed to thermal pasteurizing, therefore, data from deployment of system B indicated the decontaminating ability of a combination of three interventions: steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing, and post-evisceration carcass washing plus acetic acid solution rinsing. System B sponge sampling occurred during the slaughtering/dressing process at four in-plant locations which were: (1) hide-off, following dehiding but before the application of steam vacuuming; (2) immediately after pre-evisceration carcass washing plus acetic acid solution rinsing; (3) immediately before post-evisceration carcass washing plus acetic acid solution rinsing, and; (4) immediately following post-evisceration carcass washing and acetic acid solution rinsing. Differences in contamination levels between sampling locations 1 and 2 could be attributed to the collective effects of steam vacuuming and pre-evisceration carcass washing plus acetic acid solution rinsing. Contamination at

sampling location 3 not only included the collective decontamination effects of steam vacuuming and pre-evisceration carcass washing plus acetic acid solution rinsing, but any further contamination of the carcass occurring during subsequent dressing processes (evisceration, splitting, etc). Differences in contamination levels between sampling locations 3 and 4 could be attributed to the individual effect of post-evisceration carcass washing plus acetic acid solution rinsing when steam vacuuming and pre-evisceration carcass washing plus acetic acid solution rinsing treatments were applied in the system.

During testing of system C, carcasses were exposed to all of the decontamination treatments. Consequently, data from samples exposed to system C reflect the decontamination ability of a combination of four interventions: steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing, thermal pasteurizing, and post-evisceration carcass washing plus acetic acid solution rinsing. Sponge sampling occurred during the slaughtering/dressing process at three in-plant locations, which were: (1) hide-off, following dehiding but before the application of steam vacuuming; (2) immediately before final carcass washing plus acetic acid solution rinsing, and; (3) immediately following post-evisceration carcass washing plus acetic acid solution rinsing. Microbiological populations at location 2 reflected the collective decontamination effects of steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing and thermal pasteurizing, in addition to any further contamination occurring as a result of the dressing processes

(evisceration, splitting, etc). Furthermore, differences in site 2 microbiological populations, when compared to those at site 3 in the other systems, could be a result of the thermal pasteurizing treatment. For system C, population differences between sampling locations 2 and 3 could be attributed to the individual effects of post-evisceration carcass washing plus acetic acid solution rinsing when steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing and thermal pasteurizing treatments were previously applied in the system.

At each in-plant sampling location, for each system evaluated, 40 carcass sides were sampled and tested for total plate counts (TPC), total coliform counts (TCC) and *Escherichia coli* counts (ECC). Sampled carcasses, from sites 1 and 2, were tracked through the entire slaughtering/dressing process and tag transfer was documented in order to prevent re-sampling and to ensure that site 3, and site 4 samples when needed, were collected from adjacent, same-lot carcasses as those previously sampled at sites 1 and 2. For all systems, initial carcass evaluation (site 1) occurred following the dehiding process, but before the application of any interventions, to establish the microbiological loads carried on the carcasses as a result of the dehiding process. It was this contamination of the otherwise sterile carcass surface that the intervention systems targeted for subsequent removal.

Sponge swab sampling followed the procedures described in the FSIS/USDA (1996) Meat and Poultry Inspection regulations. Immediately before sampling, sterile sponges (BioPro Enviro-Sponge Bags, International BioProducts, Redmond, WA) were hydrated with 10 ml of 0.1% sterile, buffered peptone water (BioPro, International BioProducts). Sampling of each carcass side was achieved using a 100 cm² disposable,

sterile template (USDA Template, International BioProducts) at each of three anatomical locations for a total sampling area of 300 cm². Sponging at each anatomical carcass site, within the 100 cm² template area, consisted of 10 passes vertically (up-and-down being considered as 1 pass) and 10 passes horizontally (side-to-side being considered as 1 pass) with a pressure equivalent to that which would be used to remove dried blood from the carcass.

The three anatomical carcass sites included: (a) flank, at a point where the medial border of the cutaneous flank muscle came within 7.62 cm of the midline, (b) brisket, at a point on the midline that was level with the elbow and (c) rump, at a point where a line from the posterior aspect of the aitch bone to the achilles tendon intersected the cut surface of the round (FSIS-USDA, 1996).

Samples were collected aseptically using sterile, latex gloves (International BioProducts) which, in addition to the template, were changed between each carcass side sampled. An additional 15 ml of refrigerated 0.1% sterile, buffered peptone water (Difco Laboratories, Detroit, MI) was added to the sponge after sampling to bring the total volume of buffer to 25 ml. After excess air was expelled and the sponge bags were folded down, the samples were packed with icepacks and a cardboard pad, to prevent direct contact with the samples, into shipping coolers for overnight delivery to the laboratory (Warren Analytical Laboratory, Greeley, CO) for analysis.

Following arrival of samples at the laboratory, the sponges and associated buffer were pummeled in a stomacher (Seward Model 400, Tekmar Company, Cincinnati, OH) for 1 min and appropriate serial dilutions were made based on past test and background sample results. Appropriate dilutions were plated on Plate Count Agar (Difco Laboratories) using a spiral plating system (Spiral Systems Instruments, Inc., Cincinnati, OH). Plates were incubated at 35°C

+/- 2°C for 48 h at which point colonies were counted using a laser bacteria colony counter (Model 500A, Spiral Systems Instruments, Inc.) and a computer assisted spiral bio-assay (CASBA) data processor with Bacterial Enumeration Program E20 (Spiral Systems, Inc.). Additionally, appropriate dilutions were placed on Petrifilm™ *E. coli* count plates (3M™ Health Care, St. Paul, MN), and following a 24 +/- 2 h incubation period at 35°C +/- 2°C, colonies associated with trapped gas and possessing a dark red or blue color were counted as coliforms, while dark blue colonies associated with trapped gas were counted separately as *E. coli* biotype I.

Statistical Analysis. The data (TPC, TCC and ECC) were transformed to log₁₀ CFU/100 cm² for statistical analyses. Minimum detection limits for TPC, TCC and ECC were 2.2, 0.9 and 0.9 log CFU/100 cm², respectively, based on the maximum sensitivity of the tests with no further dilution of the samples beyond the original buffer volume of 25 ml. TPC, TCC and ECC falling below the minimum detection limit were entered as 2.2, 0.9, and 0.9 log CFU/100 cm², respectively, so that statistical analysis could be performed. Values for the mean log (\bar{x}) and standard deviation of each set of bacterial counts were calculated on the assumption of a log-normal distribution of microorganisms (Brown and Baird-Parker, 1982; Gill *et al.*, 1996; Gill and Bryant, 1997; Kilsby and Pugh, 1981). A value for the log mean (log α) for each set of bacterial counts was calculated from the formula $\text{Log } \alpha = \mu + \ln 10 \sigma^2 2^{-1}$ in an attempt to estimate the true log average count (Gill *et al.*, 1996; Gill and Bryant, 1997; Kilsby and Pugh, 1981). For comparisons involving systems A, B, and C (Tables 1-3), data taken following dehid, before post-evisceration carcass washing plus acetic acid solution rinsing, and after post-evisceration carcass washing plus acetic acid solution rinsing were evaluated with AOV using the model $y = a + x_1 + x_2 + x_1x_2$ and least squares means were computed and adjusted using sampling location 1 as a

covariate for TPC, TCC and ECC by system, sampling location, and system x sampling location effects using the Mixed Procedure of SAS® (SAS, 1995).

For system A and B comparisons (Tables 4-6), data taken following dehid, steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing, before post-evisceration carcass washing plus acetic acid solution rinsing, and after post-evisceration carcass washing plus acetic acid solution rinsing were evaluated with AOV using the model $y = a + x_1 + x_2 + x_1x_2$ and least squares means were computed and adjusted using sampling location 1 as a covariate for TPC, TCC and ECC by system, sampling location, and system x sampling location effects using the Mixed Procedure of SAS® (SAS, 1995). Due to the significant System x Sampling Location interaction (P = 0.0001), only interaction subclass least-squares means are reported (Tables 1-6). When AOV detected effects (P < 0.05), least-squares means were separated using a paired t-test in the Mixed Procedure of SAS® (SAS, 1995). In both models, ABC and AB system comparisons, carcass side sampled was included in the programs as a random effect.

RESULTS AND APPLICATION

The three intervention systems tested were: 1. system A: steam vacuuming and post-evisceration carcass washing plus acetic acid solution rinsing; 2. system B: steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing and post-evisceration carcass washing plus acetic acid solution rinsing, and; 3. system C: steam vacuuming, pre-evisceration carcass washing plus acetic acid solution rinsing, thermal pasteurizing and post-evisceration carcass washing plus acetic acid solution rinsing. For the systems as a whole, use of system A resulted in carcasses possessing TPC, TCC and ECC of 8.5, 4.3 and 3.8 log CFU/100 cm² before to entering the cooler (Tables 1-3). Corresponding counts for carcasses processed through system B were 6.4, 3.6 and 2.9 while

carcasses processed through system C had counts of 6.3, 2.8 and 2.2 log CFU/100 cm², respectively (Tables 1-3). Despite numerical differences in counts between systems A, B and C, the only statistically significant difference was for TPC as carcasses from system A had higher ($P \leq 0.05$) counts at the final sampling site than did carcasses from either system B or C (Table 1).

The efficacy of steam vacuuming and pre-evisceration carcass washing plus acetic acid solution rinsing was evident when TPC, TCC and ECC on carcasses following application of the microbiological interventions included in system B were compared to TPC, TCC and ECC on carcasses at the same location following deployment of system A which did not include pre-evisceration carcass washing plus acetic acid solution rinsing. TPC, TCC and ECC in system B were 5.5, 2.2 and 2.0 log CFU/100 cm², respectively, as compared to corresponding counts in system A which were 7.7, 5.2 and 5.0 log CFU/100 cm², respectively (Tables 4-6). It is important to note that the significantly higher ($P < 0.05$) TPC, TCC and ECC obtained using system A could not be attributed to inadequate decontamination via steam vacuuming because steam vacuuming is simply a spot decontamination treatment used in lieu of knife-trimming to meet "Zero Tolerance" requirements. Differences in TPC, TCC and ECC between systems A and B as seen following the application of steam vacuuming and pre-evisceration carcass washing plus acetic acid solution rinsing, were reduced following the evisceration and splitting process which yielded similar TPC, TCC and ECC at the third sampling site for both systems (Tables 4-6). Despite the similarities in TPC, TCC and ECC at the third sampling site, when comparing systems A and B, the addition of pre-evisceration carcass washing plus acetic acid solution rinsing might contribute to the efficacy of post-evisceration carcass washing plus acetic acid

solution rinsing by reducing the time allowed for attachment of initial carcass surface contamination. Under system A, TPC and ECC before and after final washing plus acetic acid solution rinsing are similar ($P > 0.05$), while corresponding counts under the application of system B were different ($P < 0.05$) (Tables 1-3).

Results of this study indicate that the application of a combination of steam vacuuming and pre-evisceration carcass washing plus acetic acid solution rinsing is an effective means for reducing microbiological contamination transferred to the carcass during the dehiding process inasmuch as TPC, TCC and ECC were all lower ($P < 0.05$) following sequential application. Furthermore, the application of pre-evisceration carcass washing plus acetic acid solution rinsing could potentially add to the efficacy of the final washing plus acetic acid solution rinsing. During the evisceration and splitting processes, carcasses were recontaminated to a level that was comparable to that of the carcasses produced using system A, which did not include the application of pre-evisceration carcass washing plus acetic acid solution rinsing. Comparisons of the efficacy of using decontamination systems that combined 2, 3 or 4 microbiological interventions revealed that TPC on carcasses were lower following post-evisceration carcass washing plus acetic acid solution rinsing in the systems combining 3 or 4 interventions. Despite numerical differences, there were no statistical differences in TCC or ECC on carcasses processed using 2, 3 or 4 microbiological interventions (systems A, B or C, respectively).

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Table 1. Adjusted least squares means (\bar{x}) and standard deviations (s) for the \log_{10} values of total plate counts (CFU/100 cm²) and estimated logs for the arithmetic means ($\log \alpha$) of total plate counts on beef carcasses for each of three decontamination systems and in-plant sampling locations in the harvesting sequence.

System	In-Plant Location in the Harvesting Sequence								
	Hide-Off			Before Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			After Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing		
	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$
A	8.1	1.51	10.7	8.0	1.49	10.6	8.5 ^y	1.74	12.0
B	8.1	1.55	10.9	7.2 ^a	1.89	11.3	6.4 ^{bz}	1.90	10.6
C	8.1	2.14	13.4	7.3 ^a	1.73	10.7	6.3 ^{bz}	1.56	9.1

Number of samples analyzed at each location in each system: 120.

$\log \alpha = \bar{x} + \ln 10 s^2 2^{-1}$.

^{ab} Means in the same row with different superscript letters are different (P < 0.05).

^{yz} Means in the same column with different superscript letters are different (P < 0.05).

Table 2. Adjusted least squares means (\bar{x}) and standard deviations (s) for the \log_{10} values of total coliform counts (CFU/100 cm²) and estimated logs for the arithmetic means ($\log \alpha$) of total coliform counts on beef carcasses for each of three decontamination systems and in-plant sampling locations in the harvesting sequence.

System	In-Plant Location in the Harvesting Sequence								
	Hide-Off			Before Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			After Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing		
	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$
A	5.2	1.59	8.1	4.8 ^a	1.96	9.2	4.3 ^b	2.01	9.0
B	5.2	2.01	9.9	4.3 ^a	2.21	9.9	3.6 ^b	2.02	8.3
C	5.2	1.36	7.3	3.1	1.93	7.4	2.8	1.17	4.4

Number of samples analyzed at each location in each system: 120.

$\log \alpha = \bar{x} + \ln 10 s^2 2^{-1}$.

^{ab} Means in the same row with different superscript letters are different (P < 0.05).

Table 3. Adjusted least squares means (\bar{x}) and standard deviations (s) for the \log_{10} values of *Escherichia coli* counts (CFU/100 cm²) and estimated logs for the arithmetic means ($\log \alpha$) of *Escherichia coli* counts on beef carcasses for each of three decontamination systems and in-plant sampling locations in the harvesting sequence.

System	In-Plant Location in the Harvesting Sequence								
	Hide-Off			Before Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			After Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing		
	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$
A	4.9	1.51	7.5	3.9	2.17	9.3	3.8	2.22	9.5
B	4.9	2.05	9.7	3.6 ^a	2.09	8.6	2.9 ^b	1.99	7.5
C	4.9	1.29	6.8	2.6	1.88	6.7	2.2	1.17	3.8

Number of samples analyzed at each location in each system: 120.

$$\log \alpha = \bar{x} + \ln 10 s^2 2^{-1}$$

^{ab} Means in the same row with different superscript letters are different (P < 0.05).

Table 4. Adjusted least squares means (\bar{x}) and standard deviations (s) for the \log_{10} values of total plate counts (CFU/100 cm²) and estimated logs for the arithmetic means ($\log \alpha$) of total plate counts on beef carcasses for each of two decontamination systems and in-plant sampling locations in the harvesting sequence.

System	In-Plant Location in the Harvesting Sequence											
	Hide-Off			After Pre-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			Before Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			After Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing		
	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$	\bar{x}	s	$\log \alpha$
A	7.9	1.51	10.5	7.7 ^z	1.36	9.8	8.0	1.49	10.6	8.5 ^z	1.74	12.0
B	7.9	1.55	10.7	5.5 ^{cy}	1.78	9.1	7.2 ^a	1.89	11.3	6.4 ^{by}	1.90	10.6

Number of samples analyzed at each location in each system: 120.

$$\log \alpha = \bar{x} + \ln 10 s^2 2^{-1}$$

^{abc} Means in the same row with different superscript letters are different (P < 0.05).

^{yz} Means in the same column with different superscript letters are different (P < 0.05).

Table 5. Adjusted least squares means (\bar{X}) and standard deviations (s) for the \log_{10} values of total coliform counts (CFU/100 cm²) and estimated logs for the arithmetic means ($\log \alpha$) of total coliform counts on beef carcasses for each of two decontamination systems and in-plant sampling locations in the harvesting sequence.

System	In-Plant Location in the Harvesting Sequence											
	Hide-Off			After Pre-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			Before Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			After Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing		
	\bar{X}	s	$\log \alpha$	\bar{X}	s	$\log \alpha$	\bar{X}	s	$\log \alpha$	\bar{X}	s	$\log \alpha$
A	5.0	1.59	7.9	5.2 ^z	1.51	7.8	4.7	1.96	9.1	4.2 ^z	2.01	8.9
B	5.0	2.01	9.7	2.2 ^{by}	1.63	5.3	4.3 ^a	2.21	9.9	3.6 ^{ay}	2.02	8.3

Number of samples analyzed at each location in each system: 120.

$$\log \alpha = \bar{X} + \ln 10 s^2 2^{-1}$$

^{ab} Means in the same row with different superscript letters are different (P < 0.05).

^{yz} Means in the same column with different superscript letters are different (P < 0.05).

Table 6. Adjusted least squares means (\bar{X}) and standard deviations (s) for the \log_{10} values of *Escherichia coli* counts (CFU/100 cm²) and estimated logs for the arithmetic means ($\log \alpha$) of *Escherichia coli* counts on beef carcasses for each of two decontamination systems and in-plant sampling locations in the harvesting sequence.

System	In-Plant Location in the Harvesting Sequence											
	Hide-Off			After Pre-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			Before Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing			After Post-Evisceration Carcass Washing plus Acetic Acid Solution Rinsing		
	\bar{X}	s	$\log \alpha$	\bar{X}	s	$\log \alpha$	\bar{X}	s	$\log \alpha$	\bar{X}	s	$\log \alpha$
A	4.7	1.51	7.3	5.0 ^{az}	1.54	7.7	3.9 ^b	2.17	9.3	3.8 ^b	2.22	9.5
B	4.7	2.05	9.5	2.0 ^{by}	1.61	5.0	3.6 ^a	2.09	8.6	2.9 ^{ab}	1.99	7.5

Number of samples analyzed at each location in each system: 120.

$$\log \alpha = \bar{X} + \ln 10 s^2 2^{-1}$$

^{ab} Means in the same row with different superscript letters are different (P < 0.05).

^{yz} Means in the same column with different superscript letters are different (P < 0.05).