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Effects of peroxyacetic acid, acidified sodium chlorite or lactic acid solutions on the microflora of chilled beef carcasses☆

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Abstract

The effects of solutions of 0.02% peroxyacetic acid, acidified 0.16% sodium chlorite, 2% lactic acid and 4% lactic acid on the natural flora of the distal surfaces of pieces of brisket, from chilled beef carcass quarters delivered from two slaughtering plants to a processing plant, were investigated. Peroxyacetic acid and acidified sodium chlorite solutions had little effect on the numbers of aerobes, coliforms or *Escherichia coli* on meat from one plant, and were less effective than 4% lactic acid for reducing the numbers of bacteria on meat from the other plant. With meat from both plants, treatment of meat with 4% lactic acid and holding for 5 or 60 min at 7 ± 1 °C before sampling resulted in reductions of all three groups of bacteria by ≥ 1.5 log unit. Treatment with 2% lactic acid resulted in similar reductions when meat was sampled 5 min after the treatment, but reductions were about 1 log unit when meat was sampled 60 min after the treatment. Treatment of carcass quarters with 4% lactic acid resulted in reductions of bacterial numbers of ≥ 2 log units at distal surfaces, but ≤ 2 log units at medial surfaces. The findings indicate that the efficacies of antimicrobial solutions may be inconsistent when they are applied to chilled meat from different sources and to different types of meat surface, and that bacteria injured by application of an antimicrobial solution may recover during processing of meat at temperatures about 7 °C. However, 4% lactic acid may be generally useful as a decontaminant for chilled, raw meat.

Keywords: Beef; Carcasses; Decontamination; Lactic acid; Peroxyacetic acid; Sodium chlorite

1. Introduction

At beef packing plants in North America it is now the usual practice to subject carcasses to a variety of decontaminating treatments during the carcass dressing process (Bacon et al., 2000). Consequently, carcasses leaving the dressing processes at many plants may carry relatively few bacteria (Sofos et al., 1999). However, both mesophilic and psychrotrophic bacteria may grow on carcasses that are sprayed with water during cooling processes (Gill and Landers, 2003a), as is usual in North America; and further bacteria may be deposited on the meat during operations for dividing sides into quarters and loading quarters to trailers for transport to processing plants (Smeltzer et al., 1980). Moreover, some growth of bacteria on carcass quar-

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ters while they are in transit is likely. Such growth may be extensive if delivery is delayed or there is loss of control over the temperature of the air in a refrigerated trailer (Gill and Phillips, 1993). Thus, there is often uncertainty about the microbiological condition of the product that is received by processors of beef carcass quarters.

In such circumstances, it would seem desirable to apply some decontaminating treatment to carcass quarters received at processing plants, to better assure the microbiological condition of the incoming product. Although a pasteurizing treatment would likely be effective for that purpose (Bolton et al., 2001), the operation of equipment that produces large volumes of steam in facilities where cold air temperatures are maintained could result in problems from extensive condensation. Spraying of chilled carcass quarters with a solution of an antimicrobial agent would then likely be a preferred treatment.

A variety of antimicrobial solutions have been tested for their effects on warm carcasses or pieces of meat inoculated with bacterial cultures or fecal preparations, and most have been reported to reduce bacterial numbers under such experimental conditions (Belk, 2001). However, fewer antimicrobials have been tested against the natural flora of meat, and findings from such studies have been far from uniform (Dorsa, 1997). Moreover, of the antimicrobials that have been considered, only a few are used in commercial practice for the treatment of dressed beef carcass sides. Thus, current information does not allow the confident selection of an antimicrobial solution that would certainly be both effective and commercially acceptable for the treatment of chilled carcass quarters of disparate conditions. Therefore, for better understanding of the matter, a study was conducted to identify an appropriate antimicrobial solution for the treatment of the chilled carcass quarters delivered from two sources to a beef processing plant.

2. Materials and methods

2.1. Processing and slaughtering plants

The processing plant involved in the study breaks beef carcasses at a rate of about 80 carcasses h^{-1}. Carcasses are delivered as chilled quarters transported by road from two beef slaughtering plants. Both beef cattle and culled cows are slaughtered at each of those plants, at rates of about 180 and 100 carcasses h^{-1} at plants A and B, respectively. Carcasses at plant B are pasteurized with hot water and sprayed with 2% lactic acid at the end of the dressing process, but carcasses at plant A are only sprayed with acid. Typically, carcass quarters from both slaughtering plants are delivered to the processing plant on the day after the completion of the carcass cooling processes.

2.2. Collection of meat pieces

On each of 10 days, 40 pieces of meat were obtained from forequarters delivered to the carcass breaking plant that day. The forequarters from which pieces were cut were selected at random from a consignment from each of plants A and B, with 20 pieces being obtained from product from each plant.

Each piece of meat was a portion of the brisket that measured approximately 20×20 cm. Pairs of meat pieces from forequarters from the same plant were placed side by side with the distal surface uppermost, on a plastic bag filled with ice, in a lidded box. The boxes were transported to a laboratory, for treatment within 3 h of being collected.

2.3. Treatment of meat pieces and carcass quarters

All pieces of meat were treated and held after treatment in a chiller with off-coil air delivered at a temperature of 7 ± 1 °C. All water and solutions used for treating meat pieces were of the same temperature.

On each of 5 days, five pieces of meat from each slaughtering plant were treated with distilled water or with a solution of 0.02% (w/v) peroxyacetic acid (Inspexx®; Ecolab, St. Paul, MN, USA), 0.16% (w/v) sodium chlorite supplemented with 2% (w/v) citric acid to obtain a solution of pH ≤ 3 (Sanova®; Alcide, Redmond, WA, USA) or 4% (w/v) L + lactic acid (Archer Daniels Midland, Decatur, IL, USA). For treatment, each piece of meat, with the distal surface outwards, was fixed to a block of polystyrene foam by means of a sterile skewer driven through the meat at the edge of one side. The meat was held in a vertical

position while it was sprayed with about 50 ml of water or one of the solutions delivered as a mist from a spray gun (Model L-280; Lemmer Spray Systems, Calgary, AB, Canada). The spray was applied from a distance of about 15 cm, to obtain complete coverage of the meat surface with little run-off. After being sprayed, the meat was removed from the polystyrene support and was placed on a stainless steel tray with the treated surface uppermost. The meat was then held in the chiller for 60 min before the treated surface was sampled.

On each of a further 5 days, 5 pieces of meat from each slaughtering plant were treated with water or 4% lactic acid, and 10 pieces of meat from each plant were treated with 2% (w/v) L + lactic acid. The water and solutions were applied, and the treated pieces were placed on trays as before, but the pieces treated with water or 4% lactic acid, and five of the pieces treated with 2% lactic acid were each sampled 5 min after the treatment was applied. The other five pieces that were sprayed with 2% lactic acid were held for 60 min before they were sampled.

In addition, on each of 5 days, 10 forequarters were selected at random from a consignment of carcass quarters delivered from each of the slaughtering plants. The selected quarters were moved to a detaining rail in the chilled area used for the reception of carcass quarters at the processing plant. Five of the carcass quarters from each slaughtering plant were sprayed with 4% lactic acid, using the same equipment as had been used for treating meat pieces. Each quarter was sprayed over both distal and medial surfaces, with about 500 ml of water or lactic acid solution, to obtain complete coverage of all surfaces. Treated quarters were held for 60 min before they were sampled.

2.4. Sampling of meat pieces and forequarters, and enumeration of bacteria

Each piece of treated meat was swabbed over all the treated surface with a cellulose acetate sponge (speci sponge; VWR Canlab, Mississauga, ON, Canada) that had been moistened with 5 ml of neutralizing buffer (Difco Laboratories, Detroit, MI, USA) or buffered peptone water (Difco Laboratories). Each treated forequarter was swabbed with two sponges, with one sponge being used to swab all of the distal surface and the other being used to swab the medial and cut surfaces. Neutralizing buffer, which contains the reducing agent thiosulphate, was used for sponge moistening and subsequent dilution of samples when meat pieces were treated with the oxidizing agents peroxyacetic acid or acidified sodium chlorite, or with water when those treatments were applied. Buffered peptone water was used in all other sampling and diluting, when meat had been treated with lactic acid only. Samples were stored on ice until processed within 3 h of being collected.

Each sponge was placed in a stomacher bag and was pummeled for 2 min with an additional 10 ml of diluent. A 1 ml portion of the stomacher fluid was used to prepare dilutions of the fluid. The dilutions were to 10^{-1} and 10^{-2} for fluids from sponges used on meat pieces, but additional dilutions to 10^{-3} and 10^{-4} were prepared for fluids from sponges used on forequarters.

One milliliter of the stomacher fluid and 1 ml of each dilution were each filtered through a separate hydrophobic grid membrane filter (HGMF; QA Life Sciences, San Diego, CA, USA). Each filter was placed on a plate of tryptone soy fast green agar (TSFG; QA Life Sciences) which was incubated at 25 °C for 3 days. Squares containing green or blue-green colonies on filters preferably bearing between 20 and 200 colonies were counted, and a most probable number (MPN) for aerobic counts was obtained by application of the formula: $\mathrm{MPN} = N \times \ln(N/N - X)$, where N is the total number of squares on the filter and X is the count of squares containing green or blue green colonies.

A 10 ml portion of each stomacher fluid was filtered through an HGMF which was then placed on a plate of lactose monensin glucuronate agar (LMG; QA Life Sciences). After incubation at 35 °C for 24 h, squares containing blue colonies were counted, and an MPN value for coliforms was obtained by the same calculation as was used for total counts. The filter was then placed on a plate of buffered 4-methyumbelliferyl-β-D-glucuronide agar (BMA; QA Life Sciences) which was incubated at 35 °C for 3 h. The filter was illuminated with long wavelength UV light, and squares containing blue-white fluorescent colonies were counted. A MPN value for *Escherichia coli* was obtained from that count.

2.5. Analysis of data

All bacterial counts were transformed to log values. When bacteria of a group were recovered from ≥ 20 of 25 samples, values for the mean log ($\bar{x}$) and standard deviation (s) of the set of counts were calculated on the assumption that the counts were log normally distributed. A Shapiro–Wilk test for normal distribution was applied to each of those sets of counts. In the calculation of $\bar{x}$ and s, a log value of -0.5 40, 400 or 8000 cm^{-2} was assumed for samples in which aerobes from meat pieces, coliforms or *E. coli* from meat pieces, or coliforms or *E. coli* from carcass quarters, respectively, were not detected (Marks and Coleman, 1998). A value for the log of the arithmetic mean (log A) was calculated for each set of counts for which values for $\bar{x}$ and s were available, using the formula $\log A = \bar{x} + \log_n 10(s^2/2)$. A value for the log of the total number of bacteria recovered (N) was calculated for each set of counts by summing the counts in each set and obtaining the log of the sum. Those calculations were performed with Microsoft Excel, version 4 statistical functions (Microsoft, Redmond, WA, USA). Values for $\bar{x}$ were separated using the Tukey option of the general linear model procedure in Statistical Analysis Systems, version 8 (SAS Institute, Cary, NC, USA). For convenient comparison of data with data from other studies, values for $\bar{x}$, log A and N are reported as log cfu cm^{-2} or 25 cm^{-2} for aerobes, or log cfu 100 cm^{-2} or 2500 cm^{-2} for coliforms or *E. coli*, with values per sample being converted on the assumptions that the surface area of each meat pieces was 400 cm^2, and the forequarter surface area swabbed with each sponge was 8000 cm^2.

3. Results

The microbiological conditions of meat surfaces before and after decontaminating treatments can be compared by reference to values for log A and/or N (Gill, 2000). For pieces of meat from plant A, the log mean numbers of aerobes recovered from pieces treated with peroxyacetic acid or acidified sodium chlorite solutions were <0.5 log unit less, but the numbers recovered from pieces treated with 4% lactic acid were >1 log unit less than the numbers recovered from pieces treated with water (Table 1). For pieces of meat from plant B, the log mean numbers of aerobes recovered from pieces treated with peroxyacetic acid or acidified sodium chlorite solutions were about 1 log unit less, and the numbers recovered from pieces treated with 4% lactic acid were >2 log unit less than the numbers recovered from pieces treated with water.

Table 1
Statistics for sets of 25 total aerobic counts (cfu cm^{-2}) recovered from the distal surfaces of pieces of briskets from beef carcass quarters delivered to a breaking plant from two slaughtering plants, after pieces were sprayed with water or an antimicrobial solution then held at 7 °C for 60 min before sampling

Slaughtering plant	Spray	Statistics				
		$\bar{x}$	s	no	log A	N
A	Water	1.74a	0.62	0	2.18[a]	3.48
	Peroxyacetic acid[b]	1.39ab	0.70	0	1.95[a]	3.52
	Acidified sodium chlorite[c]	1.04b	0.81	0	1.80	3.07
	4% Lactic acid	0.13c	0.69	0	0.68[a]	2.29
B	Water	1.70a	0.79	0	2.41[a]	3.97
	Peroxyacetic acid	1.00b	0.71	0	1.57[a]	2.85
	Acidified sodium chlorite	0.70b	0.92	1	1.68	2.82
	4% Lactic acid	−0.60c	0.67	2	−0.08	1.15

$\bar{x}$, mean log; s, standard deviation; no, number of samples from which bacteria were not recovered; log A, log mean; N, log of the total number recovered from 25 samples.
Mean logs for sets of counts from the same plant with the same letter are not significantly different ($P>0.05$).
[a] Set of log counts is normally distributed.
[b] 0.02% (w/v) peroxyacetic acid.
[c] 0.16% (w/v) sodium chlorite plus 2% (w/v) citric acid, pH < 3.

The coliforms recovered from pieces of meat from both plants A and B were mostly *E. coli* (Table 2). For pieces of meat from plant A, the log total numbers of those bacteria recovered from pieces treated with peroxyacetic acid or acidified sodium chlorite solutions were similar to the numbers recovered from pieces treated with water, but the numbers recovered from pieces treated with 4% lactic acid were >1.5 log unit less. For pieces of meat from plant B, the log total numbers of coliforms and *E. coli* recovered from pieces treated with peroxyacetic acid or acidified sodium chlorite solutions were about 1 log unit less,

Table 2
Statistics for sets of 25 coliform or *E. coli* counts (cfu 100 cm^{-2}) recovered from distal surfaces of pieces of brisket from beef carcass quarters delivered to a breaking plant from two slaughtering plants, after pieces were sprayed with water or an antimicrobial solution then held at 7 °C for 60 min before sampling

Slaughtering plant	Spray	Statistics			
		Coliforms		*E. coli*	
		no	*N*	no	*N*
A	Water	3	2.78	5	2.55
	Peroxyacetic acid[a]	6	3.23	8	2.10
	Acidified sodium chlorite[b]	6	2.85	6	2.85
	4% Lactic acid	14	1.09	16	0.76
B	Water	8	2.37	9	1.90
	Peroxyacetic acid	9	1.37	13	1.01
	Acidified sodium chlorite	14	1.16	15	0.74
	4% Lactic acid	18	0.85	21	0.48

no, number of samples from which bacteria were not recovered; *N*, log of the total number recovered from 25 samples.
[a] 0.02% (w/v) peroxyacetic acid.
[b] 0.16% (w/v) sodium chlorite plus 2% (w/v) citric acid, pH < 3.

Table 3
Statistics for sets of 25 total aerobic counts (cfu cm^{-2}) recovered from distal surfaces of pieces of briskets from beef carcass quarters delivered to a breaking plant from two slaughtering plants, after pieces were sprayed with water or a lactic acid solution then held at 7 °C for 5 or 60 min before sampling

Slaughtering plant	Spray	Time before sampling	Statistics				
			$\bar{x}$	*s*	no	log *A*	*N*
A	Water	5	3.82a	0.53	0	4.14[a]	5.57
	2% Lactic acid	5	1.86bc	0.58	0	2.26[a]	3.55
	2% Lactic acid	60	2.28b	0.82	0	3.05[a]	4.30
	4% Lactic acid	5	1.31c	1.02	1	2.52	3.65
B	Water	5	3.34a	0.63	0	3.80[a]	5.14
	2% Lactic acid	5	1.56b	0.51	0	1.85[a]	3.24
	2% Lactic acid	60	1.74b	0.76	0	2.61[a]	3.71
	4% Lactic acid	5	1.01c	0.81	1	1.77	2.81

$\bar{x}$, mean log; *s*, standard deviation; no, number of samples from which bacteria were not recovered; log *A*, log mean; *N*, log of the total number recovered from 25 samples.
Mean logs for sets of counts from the same plant with the same letter are not significantly different ($P > 0.05$).
[a] Set of log counts is normally distributed.

and the numbers recovered from pieces treated with 4% lactic acid were about 1.5 log unit less than the numbers recovered from pieces treated with water.

When pieces of meat were treated with 2% or 4% lactic acid, for pieces from both plant A and B, the log mean numbers of aerobes recovered from pieces treated with 2% or 4% lactic acid and sampled after 5 min were about 2 log units less, but the numbers recovered from pieces treated with 2% lactic acid and sampled after 60 min were about 1 log unit less than the numbers recovered from pieces treated with water (Table 3).

For pieces of meat from plant A, the log total numbers of coliforms and *E. coli* recovered from pieces treated with 2% or 4% lactic acid and sampled after 5 min were >1.5 log units less, but the numbers recovered from pieces treated with 2% lactic acid and sampled after 60 min were < 1 log unit less than the numbers recovered from pieces treated with water (Table 4). For pieces of meat from plant B, the log total numbers of coliforms and *E. coli* recovered from pieces sampled 5 min after being treated with 2% or 4% lactic acid were about 1 or 1.5 log units less,

Table 4
Statistics for sets of 25 coliform or *E. coli* counts (cfu 100 cm^{-2}), recovered from the distal surfaces of pieces of brisket from two slaughtering plants, after pieces were sprayed with water or with a lactic acid solution then held at 7 °C for 5 or 60 min before sampling

Slaughtering plant	Spray	Time before sampling (min)	Statistics			
			Coliforms		*E. coli*	
			no	*N*	no	*N*
A	Water	5	0	2.70	0	2.68
	2% Lactic acid	5	9	1.21	18	0.78
	2% Lactic acid	60	6	1.89	10	1.71
	4% Lactic acid	5	18	0.80	21	0.55
B	Water	5	3	2.38	12	1.58
	2% Lactic acid	5	11	1.30	22	0.76
	2% Lactic acid	60	10	2.28	19	1.12
	4% Lactic acid	5	17	0.58	24	−0.60

no, number of samples from which bacteria were not recovered; *N*, log of the total number recovered from 25 samples.

respectively, than the numbers recovered from pieces treated with water, but the numbers recovered from pieces treated with 2% lactic acid and sampled after 60 min were <0.5 log unit less than the numbers recovered from pieces treated with water.

Aerobes were recovered from all carcass quarters before or after treatment with 4% lactic acid (Table 5). For quarters from both plants A and B, the log mean numbers of aerobes recovered from distal and medial surfaces were, respectively, >2 log units less and about 1 log unit less after than before treatment with 4% lactic acid.

Coliforms recovered from carcass quarters were mainly *E. coli*, and data for the two groups of organisms were little different. Therefore, data from only *E. coli* are presented (Table 6). For quarters from plant A, the log mean numbers of *E. coli* recovered from distal and medial surfaces were, respectively, >3 and <2 log units less after than before treatment with 4% lactic acid. For quarters from plant B the number of samples from treated carcasses that yielded *E. coli* were too few for estimation of log mean numbers, but the log total numbers of *E. coli* recovered from distal and medial surfaces were both about 2 log units less after than before treatment with 4% lactic acid.

Table 5
Statistics for sets of 25 total aerobic counts (cfu cm^{-2}), recovered from distal or medial surfaces of beef carcass quarters delivered to a breaking plant from two slaughtering plants, after quarters were sprayed with water or 4% (w/v) lactic acid then held at about 7 °C for 60 min before sampling

Slaughtering plant	Surface	Spray	Statistics			
			$\bar{x}$	s	log A	N
A	Distal	Water	1.51ab	1.28	3.39[a]	4.78
		4% Lactic acid	−0.46c	0.97	0.63[a]	2.37
	Medial	Water	1.47ab	1.10	2.87[a]	3.91
		4% Lactic acid	−0.21c	1.23	1.52	3.09
B	Distal	Water	2.01a	0.68	2.54[a]	3.86
		4% Lactic acid	−0.37c	0.54	−0.03[a]	1.46
	Medial	Water	0.96b	0.89	1.86[a]	3.61
		4% Lactic acid	−0.38c	1.06	0.90[a]	1.92

$\bar{x}$, mean log; s, standard deviation; log A, log mean; N, log of the total number recovered from 25 samples (25 cm^2).
Mean logs with the same letter are not significantly different ($P>0.05$).
[a] Set of log counts is normally distributed ($P>0.05$).

Table 6
Statistics for sets of 25 *E. coli* counts (cfu 100 cm^{-2}), recovered from the distal or medial surfaces of beef carcass quarters delivered to a breaking plant from two slaughtering plants, after quarters were sprayed with water or with 4% (w/v) lactic acid then held at 7 °C for 60 min before sampling

Slaughtering plant	Surface	Spray	Statistics				
			$\bar{x}$	s	no	log A	N
A	Distal	Water	1.35a	1.45	0	3.78[a]	4.52
		4% Lactic acid	−1.06c	1.03	4	0.17[a]	1.45
	Medial	Water	0.89a	1.59	0	3.81[a]	4.45
		4% Lactic acid	−0.45bc	1.54	2	2.27	4.12
B	Distal	Water	0.30ab	1.51	2	2.91[a]	3.34
		4% Lactic acid	–[b]	–	17	–	1.30
	Medial	Water	−0.94c	1.26	5	0.90	2.42
		4% Lactic acid	–	–	15	–	0.45

$\bar{x}$, mean log; s, standard deviation; no, number of samples from which *E. coli* were not recovered; log A, log mean; N, log of the total number recovered from 25 samples (2500 cm^2).
Mean logs with the same letter are not significantly different ($P>0.05$).
[a] Set of log counts is normally distributed ($P>0.05$).
[b] Insufficient data for calculation of the statistic.

4. Discussion

Although both peroxyacetic acid and acidified sodium chlorite solutions are applied to warm beef carcasses at some packing plants (Bjerklie, 2001), the antimicrobial solution most widely used on beef carcasses is 2% lactic acid (Longman and Bacon, 1999). However, it has been reported that 2% lactic acid was relatively ineffective when applied to cooled carcasses, but that substantial reductions in numbers were obtained with a 4% solution (Castillo et al., 2001b). Therefore, for this study, spraying with 4% lactic acid was adopted as a likely effective treatment against which others could be assessed. Although the effects of antimicrobial solutions have been reported to increase with time after treatment (Dorsa et al., 1998), the time for which antimicrobial solutions remain on meat surfaces may be limited by regulatory requirements that carcasses be rinsed to remove re-

sidual antimicrobials before further processing of the meat (CFIA, 2000). In most commercial circumstances a delay of about 1 h between treatment and further processing would likely be the maximum practicable time. Therefore, in the first instance, treated meat was held for 60 min before sampling.

With a holding time of 60 min, treatment with 4% lactic acid resulted in substantial reductions in the numbers of aerobes and *E. coli* on meat from both plants A and B. The reductions in the numbers of aerobes, of 1.5 to 2 log units, were of the order commonly reported for meat treated with dilute solutions of lactic acid; but the similar reductions in the numbers of *E. coli* were somewhat greater than might be expected (Smulders and Greer, 1998). In contrast, the smaller reductions obtained with peroxyacetic acid and acidified sodium chlorite solutions applied to meat from plant B were less than might be expected (Castillo et al., 1999; Belk, 2001); while with meat from plant A, both solutions were largely ineffective against the aerobic flora, and wholly ineffective against *E. coli*.

As carcasses are subjected to pasteurizing at plant B but not at plant A, the different effects of peroxyacetic acid and sodium chlorite solutions on the aerobic flora might be due to differences in the compositions of the flora on the carcasses from the two plants (Gill and Badoni, 2002). However, the different effects of those solutions on the numbers of *E. coli* would seem to indicate that those organisms on carcasses from the two plants were in different physiological states, with *E. coli* from plant A but not plant B having induce resistance to oxidative stress (Yamanaka et al., 1998). That matter obviously requires further investigation. Nonetheless, it is apparent that identical effects of an antimicrobial solution on the microflora of raw meat from different sources cannot be safely assumed.

As the reductions in bacterial numbers after treatment with 4% lactic acid and holding for 60 min were similar to those reportedly obtained with milder treatments (Smulders and Greer, 1998), it seemed appropriate to examine the effects of treatment with a weaker solution of lactic acid, and holding for a short time. With product from both plants, after treatments with 2% or 4% lactic acid and holding for 5 min, the reductions in the numbers of bacteria recovered were similar to those obtained previously with 4% lactic acid and holding for 60 min. However, after treatment with 2% lactic acid and holding for 60 min, more bacteria were recovered than after holding for 5 min. Those findings indicate that organisms injured by 2% lactic acid can recover within 60 min at temperatures usual in meat cutting facilities. Sampling after 5 min and storage of samples at 0 °C would delay or prevent recovery. The similar findings for holding for 5 or 60 min after treatment with 4% lactic acid indicate that injury with that concentration of acid in largely irreparable. Therefore, those findings seemingly confirm that 4% rather than 2% lactic acid should be used for decontaminating cooled carcasses, as has been previously suggested (Castillo et al., 2001a).

As the time of holding after treatment with 4% lactic acid appeared to be of little importance, carcass quarters treated with 4% lactic acid were held for 60 min before sampling, which allowed for convenient separation of treating and sampling activities. The reductions in the numbers of bacteria on distal surfaces were similar to those that were found when pieces of brisket were treated with 4% lactic acid, but the reductions in numbers on medial surfaces were generally an order of magnitude less. The lesser effect of the acid solution on the serous surface flora may be ascribable to absorption of the solution by serous membrane covered and exposed muscle surfaces and buffering by soluble component of muscle; whereas at the mostly fat distal surfaces of the carcass quarters and meat pieces used in this study, the solution would tend to persist and maintain a low pH (Cutter and Siragusa, 1994).

Despite the reduced effect of 4% lactic acid on medial surface flora, that solution would be expected to give reductions in the numbers of *E. coli* and other bacteria of between 1 and 2 log units if it were applied routinely to carcass quarters delivered to the breaking plant involved in this study. However, such reductions would be consistently achieved only if the solution was applied to give uniform wetting of all surfaces, as in this study. Whether such wetting is achieved with current, commercial, automatic spraying equipment used in the beef industry is not known, but some findings suggest that the coverage achieved in practice may not always be adequate (Gill and Landers, 2003b).

Whether or not treatment of chilled meat with 4% lactic acid would always be effective is uncertain, in view of the various factors that obviously can influ-

ence the antimicrobial actions of organic acid solutions applied to meat, and the disparate findings from treatments of chilled meats with weaker solutions of lactic acid (Bacon et al., 2001). Determination of the effects of otherwise suitable antimicrobial solutions against the natural flora of product that will be treated, before implementation of a routine treatment for commercial product, can then be recommended. However, the findings of this study suggest that 4% lactic acid may be more consistently effective than some other antimicrobiological solutions. Therefore, inclusion of 4% lactic acid among candidate solutions would probably be appropriate when decontaminating treatments of commercial chilled product are being investigated.

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