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Assessment of the hygienic performances of an air-cooling process for lamb carcasses and a spray-cooling process for pig carcasses[1]

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Abstract

The air-cooling process for carcasses at a lamb slaughtering plant and the blast-plus-spray-cooling process for carcasses at a pig slaughtering plant were examined. Temperature histories were collected from the deep leg, the aitch bone pocket surface and randomly selected surface sites of carcasses passing through each process. For each process, sets of 25 temperature histories were collected for each type of site, with a single history being collected from each of 75 randomly selected carcasses. A swab sample was obtained from a randomly selected site on each of 25 randomly selected carcasses entering and 25 leaving each process. Total aerobic counts, coliforms and *Escherichia coli* were enumerated in each sample. Lamb carcasses resided in the chiller for between 17.5 and 66.8 h, and pig carcasses for between 14.8 and 24.5 h. All the lamb carcasses attained deep leg and aitch bone pocket surface temperatures $<7°C$ as did most pig carcasses. However, those temperatures remained $>13°C$ in 8% of pig carcasses. Such inadequate cooling of pig carcasses was not apparent in temperature histories from randomly selected surface sites as such sites on both pig and lamb carcasses all attained temperatures $<7°C$. Proliferation values for *E. coli* and psychrotrophic pseudomonads calculated for the temperature history from each randomly selected surface site indicated that growth of *E. coli* on either lamb or pig carcasses would be undetectable, but that increases in the log numbers of total aerobic counts of >1 and <1 during the cooling processes could be expected for lamb and pig carcasses respectively. Enumerations of bacteria showed that bacteria on pig carcasses behaved much as would be expected from the temperature histories from randomly selected sites. However, on lamb carcasses the log numbers of bacteria were reduced by about 0.5, 1.5 and 2 for total aerobic counts, coliforms, and *E. coli*, respectively. The findings indicate that microbiological data are required to properly assess the microbiological effects of carcass cooling processes because, in some, factors other than temperature determine the behavior of the microflora. © 1997 Elsevier Science B.V.

Keywords: Pig; Lamb; Carcasses; Cooling processes

1. Introduction

Carcass cooling processes must be well controlled, to contain the possibly rapid proliferation of both pathogenic and spoilage bacteria on the meat while it

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remains warm. Proposed criteria against which to assess the hygienic adequacy of carcass cooling processes have been based on product temperature data. Such criteria have included the specification of times to reach a stipulated deep or surface temperature, usually 7°C; the specification of acceptable cooling curves for deep or surface temperatures; and the specification of acceptable proliferation of *Escherichia coli* estimated from appropriate temperature histories of product surfaces (Bailey, 1986; Gill et al., 1991; USDA, 1995).

It has long been known that factors other than temperature can affect the growth of bacteria on cooling carcasses. Traditional carcass cooling involves the exposure of carcasses to a flow of cool air which can dry the carcass surface and so inhibit the growth of bacteria (Scott and Vickery, 1939). Adjustments of the humidity and speed as well as the temperature of the air applied to cooling carcasses can then variously result in increases, decreases or no change in the numbers of the aerobic flora (Nottingham, 1982). However, traditional cooling inevitably results in loss of carcass weight (James and Bailey, 1989). Consequently, the practice of spraying carcasses with water during the first part of the cooling process has been widely adopted in North America. Despite surface drying being prevented by the spraying, the numbers of aerobic bacteria on spray-cooled carcasses can apparently also be increased, decreased or maintained by adjustments of air speeds and temperatures and the frequencies and durations of spraying events, although there appears to have been no explanations offered for those effects (Greer et al., 1990; Strydom and Buys, 1995).

Such experimental findings obviously suggest that product temperature data alone may be inadequate for assessing the hygienic performances of some carcass cooling processes. That perception was seemingly confirmed in a recent study of two spray-cooling processes for beef carcasses, which differed considerably in their microbiological effects despite the similar cooling of product in the two processes (Gill and Bryant, 1997). To determine if assessments of other types of carcass cooling processes from temperature or microbiological data could also differ substantially, a process for air-cooling lamb carcasses, and a blast-plus-spray-cooling process for pig carcasses were each assessed by both temperature monitoring and microbiological techniques.

2. Materials and methods

2.1. The cooling processes

The carcass cooling process at a plant which slaughters a maximum of 1000 lambs per day was examined. At that plant, the washed carcasses are transferred for cooling from the dressing line to a rectangular frame from which four carcasses are suspended on each of the longer sides. Throughout the cooling process, air is blown from the refrigeration coils at a temperature of about 0°C.

The carcass cooling process at a plant which slaughters a maximum of 8000 pigs per day was also examined. At that plant, the washed carcasses which leave the dressing process enter a tunnel where they are subjected to a blast of air at −20°C for about 60 min. The carcasses then enter a chiller in which they are sprayed with water of about 5°C, for 20 s at intervals of 10 min, until unloading of the chiller commences. Air at −2°C is blown from the coils of the chiller refrigeration equipment.

2.2. Collection of temperature histories

Temperature histories were collected using MIRINZ-Delphi temperature data loggers (True-Test, Auckland, New Zealand), each fitted with an external thermistor probe encased in a tapered teflon sheath. The loggers were set to record temperatures between +40 and −20°C, with an accuracy of ±0.25°C and resolution of 0.25°C, at intervals of 1.875 min.

For recording deep temperatures, the probe was inserted at the thickest point of the hind leg until the tip lay at the center of the tissue in that region.

For recording surface temperatures, a disc of stainless steel, of diameter 25 mm, was held against the carcass surface by means of a plastic staple passed through holes at opposite sides of the disc. The probe was then inserted into a cone-shaped slot running across the diameter of the disc between the two holes for the retaining staple. The dimensions of the slot are such that its inner surface fits tightly to the probe sheath when the temperature-sensitive probe tip lies at the center of the disc. The discs for probe retention at meat surfaces are manufactured by the Meat Industry Research Institute of New Zealand, Hamilton, New Zealand.

For the collection of a temperature history from

the slowest cooling area of the carcass surface, a disc was placed within the aitch-bone pocket, on the psoas major/minor complex, as caudally and medially as possible. That region has previously been identified as the slowest cooling area of carcass surfaces (Scott and Vickery, 1939), and the procedure for collecting the temperature history of that area has been fully described (Gill et al., 1991). For the collection of temperature histories from other areas of the carcass surface, discs were placed at sites selected at random from grids which specify 43 areas of the lamb carcass surfaces or 83 areas of the pig carcass surface (Gill and Jones, 1997; Gill and Baker, 1997). After placement of each probe, the logger was attached to a convenient point on the carcass by means of a skewer passed through the unsealed lip of the plastic pouch in which each logger had been sealed.

At each plant, on each of five days, loggers were placed to record five deep, five slowest cooling surface and five random surface site temperature histories. A single logger was placed with each of 15 carcasses which were selected at random from lamb carcasses leaving the dressing line or pig carcasses leaving the blast-cooling tunnel. Each logger was recovered within ten minutes of the monitored carcass exiting the chiller.

2.3. Integration of surface temperature histories with respect to the growths of E. coli and pseudomonads

Each surface temperature history was integrated with respect to a model which describes the relationship between temperature and the rate of aerobic growth of *E. coli*. The model has the form:

$$y = (0.0513x - 0.17)^2$$

when x is between 7 and 30

$$y = (0.027x + 0.55)^2$$

when x is between 30 and 40

$y = 2.66$ when x is between 40 and 47 and

$y = 0$ when x is <7 or >47

where y is the growth rate expressed as generations h^{-1} and x is the temperature in °C (Gill et al., 1991).

Each temperature history from a randomly selected surface site was also integrated with respect to a model which describes the relationship between temperature and the rate of growth of psychrotrophic pseudomonads. The model has the form:

$$y = (0.033x + 0.27)^2$$

when x is between -2 and 25;

$y = 1$ when x is between 25 and 35; and

$y = 0$ when $x < -2$ or >35;

when y and x are as for the *E. coli* model (Gill and Jones, 1992).

2.4. Microbiological sampling and analysis

At each plant, on each of five days, five samples were collected from carcasses selected at random from those leaving the dressing process and, similarly, from those exiting the chiller. The site for sampling each carcass was selected at random from the appropriate grid used also for the selection of random sites from which to collect surface temperature histories.

Each sample was obtained by swabbing an undelimited area of approximately 100 cm^2 with a 5×5cm, 8 ply, sterile gauze swab (Curity gauze sponge; Kendall Canada Inc. Peterbororough, ON, Canada) which had been moistened with 0.1% w/v peptone water (Gill and Bryant, 1993). Each swab was placed in a separate stomacher bag, which was then immersed in slush ice until each swab was processed within 3 h of being collected.

Each swab was macerated for 2 min, with 10 ml 0.1% w/v peptone water, using a Colworth Stomacher 400 (Baxter Diagnostics Corp., Edmonton, AB., Canada). A 1 ml portion of each homogenate was used to prepare 10-fold dilutions to 10^{-3}, in 0.1% w/v peptone water. Portions of 0.1 ml of the homogenate and each dilution were spread on duplicate plates of plate count agar (PCA; Difco). The plates were incubated for 2 days at 25°C. The numbers of the aerobic flora were preferably determined from plates bearing 20 to 200 colonies, when such numbers were available.

After the preparation of the spread plates, a 0.1 ml portion of each homogenate was diluted in 10 ml of ice-cold peptone water then stored on ice in a refrigerator. The remaining homogenate was filtered

through the prefilter of an Iso-Grid filtration unit (QA Laboratories, Toronto, ON, Canada) and a hydrophobic-grid membrane filter (QA Laboratories) clamped in the unit. The swab within the stomacher bag was squeezed to expel the homogenate that it otherwise retained. Each membrane filter was removed from the filtration unit and was placed on a plate of lactose monensin gluconurate agar (LMGA, QA laboratories). The LMGA plates were incubated at 35°C for 24 h. The filters were examined under 5× magnification using a Model 101 Iso-Grid Line Counter (QA Laboratories), and the squares containing blue colonies were counted. The counts were converted to a most probable number (MPN) of coliforms by application of the formula $MPN = N \times \ln(N/(N-X))$, where N is the total number of squares on a filter, and X is the count of squares containing blue colonies (Entis and Boleszczuk, 1990). Each filter was then transferred to a plate of buffered 4-methylumbelliferyl-β-D-glucuronide agar (BMA; QA Laboratories). The BMA plates were incubated at 35°C for 3 h before being examined under magnification as for the LMGA plates, but with the BMA plates illuminated with long wavelength ultraviolet light from a UVL-56 Blak-Ray® lamp (UVP Inc. San Gabriel, CA, USA). Squares containing large, blue-white, fluorescent colonies were counted, and MPN values for *E. coli* numbers were calculated as in the estimation of coliforms numbers.

When *E. coli* and/or coliform numbers in the undiluted homogenate were too numerous to count (log number > 4/100 cm^2), the stored, diluted portion of the homogenate was treated as was the undiluted homogenate to obtain coliform and *E. coli* counts.

2.5. Analysis of microbiological data

All bacterial counts were transformed to $\log_{10}$ values. Values for the mean log ($\bar{x}$) and standard deviation (s) of each set of $\log_{10}$ values were calculated on the assumption that the $\log_{10}$ values were normally distributed (Brown and Baird-Parker, 1982). In the calculation of $\bar{x}$ and s for sets of $\log_{10}$ coliform and *E. coli* counts, values of $-0.5/100\ cm^2$ were assumed for samples in which coliforms or *E. coli* were not detected at the level of 1 coliform or *E. coli*/100 cm^2. A value for the $\log_{10}$ of the arithmetic mean (log A) was calculated from the formula, $\log A = \bar{x} + \ln 10^2/2$ (Kilsby and Pugh, 1981). All calculations were performed with Microsoft Excel (Version 4, statistical functions, Microsoft Corp., Redmond WA, USA).

3. Results

At the lamb slaughtering plant, 27% of the carcasses remained in the chiller for between 40 and 67 h (Fig. 1). For the carcasses which were removed from the chiller after overnight cooling, the residence times in the chiller ranged from 17.5 to 27.3 h, and averaged 21.5 h. At the pig slaughtering plant, the residence time in the chiller ranged from 14.8 to 24.5 h, and averaged 20.5 h.

For lamb carcasses, deep leg cooling curves were typically smooth with initial temperatures between 33 and 40°C. All the deep leg temperatures were <5°C at the times the carcasses were removed from the chiller (Fig. 2). For pig carcasses deep leg cooling curves were also typically smooth, with an initial temperature of 40°C. The minimum deep leg

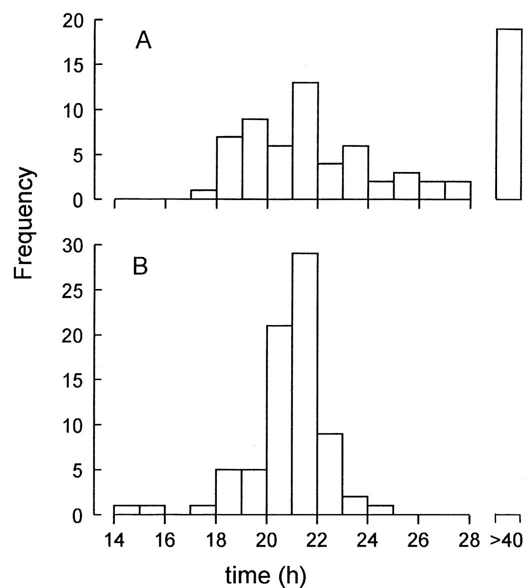

Fig. 1. The frequency distributions of the times of residence of 75 carcasses in the chiller at each of (A) a lamb slaughtering and (B) a pig slaughtering plant.

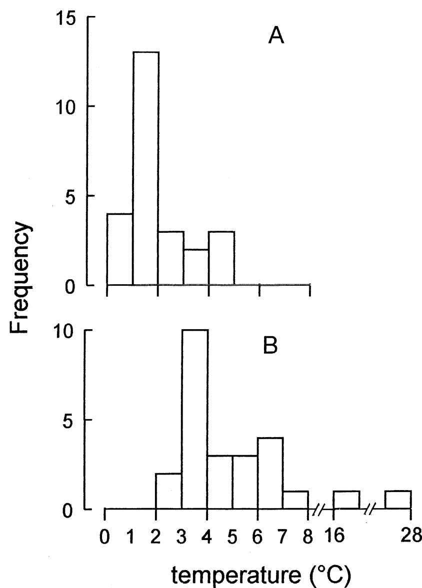

Fig. 2. The frequency distributions of the minimum temperatures attained in the deep legs of 25 carcasses on their exit from the chiller at each of (A) a lamb slaughtering or (b) a pig slaughtering plant.

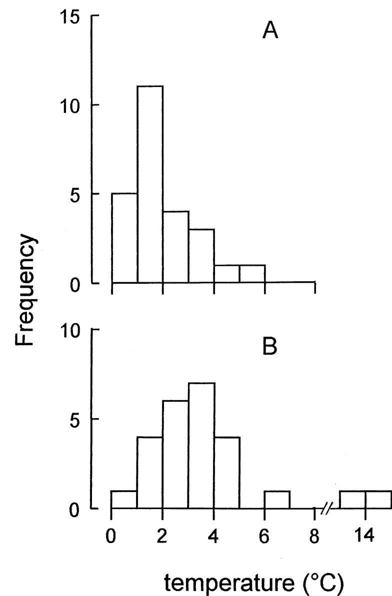

Fig. 3. The frequency distributions of the minimum temperatures attained at the aitch bone pocket surface site of 25 carcasses on their exit from the chiller at each of (A) a lamb slaughtering or (B) a pig slaughtering plant.

temperatures attained by 23 of the 25 pig carcasses ranged from 3.3 to 7.3°C, with the two remaining carcasses attaining minimum deep leg temperatures of 16.5 and 27.3°C.

For the lamb carcasses, cooling curves for surface temperatures within the aitch bone pocket were typically smooth with initial temperatures between 18 and 28°C. All aitch bone pocket surface temperatures were <5°C at the times that lamb carcasses were removed from the chiller (Fig. 3). For the pig carcasses, cooling curves for surface temperatures within the aitch bone pocket were typically smooth, with initial temperatures between 16 and 20°C. The minimum temperatures attained at the aitch bone pocket site for 23 of the 25 carcasses were <7°C, with the two remain carcasses attaining temperatures at that site of 13.8 and 14.5°C. The *E. coli* proliferation values calculated from the lamb carcass aitch bone pocket temperature histories were between 0.2 and 7.1 generations, with a mean value of 2.0 generations (Fig. 4). The *E. coli* proliferation values calculated from the pig carcasses aitch bone pocket temperature histories were between 0.6 and 15.9 generations, with a mean value of 3.8 generations.

For the lamb carcasses, cooling curves for surface temperatures at randomly selected sites were variously smooth or erratic, with some showing temperatures of about 10°C for several hours, and with initial temperature that ranged from 8 to 22°C. All the temperatures at randomly selected sites were <4°C at the times that lamb carcasses were removed from the chiller (Fig. 5). For the pig carcasses, the temperature histories from randomly selected sites typically showed temperature increases of several degrees during the first hour, to temperatures about 10°C, before erratic cooling to minimum temperatures <6°C. The *E. coli* proliferation values calculated from the lamb carcass, randomly-selected, surface-site temperature histories were between 0.0 and 3.5 generations, with a mean value of 1.1 generations (Fig. 6). The *E. coli* proliferation values calculated form the pig carcasses, random-selected, surface-site temperature histories were between 0.0 and 2.8 generations, with a mean value of 0.6 generations. The pseudomonad proliferation values calculated from the lamb carcass temperature histories were between 3.1 and 8.2 generations, with a mean value of 5.4 generations (Fig. 7). The pseudo-

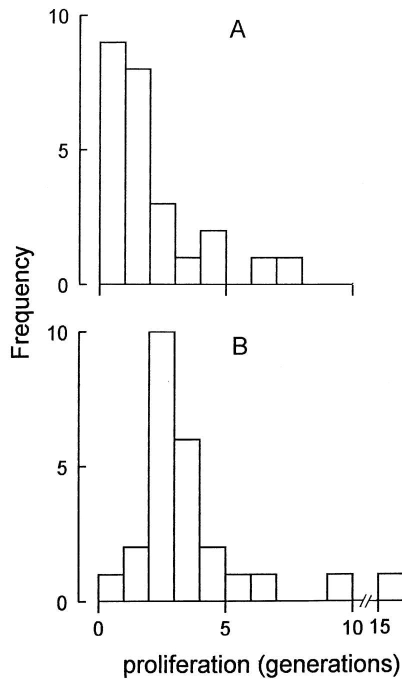

Fig. 4. The frequency distributions of the *Escherichia coli* proliferations calculated from temperature histories from the aitch bone pocket surface site of 25 carcasses passing through the chiller at each of (A) a lamb slaughtering or (B) a pig slaughtering plant.

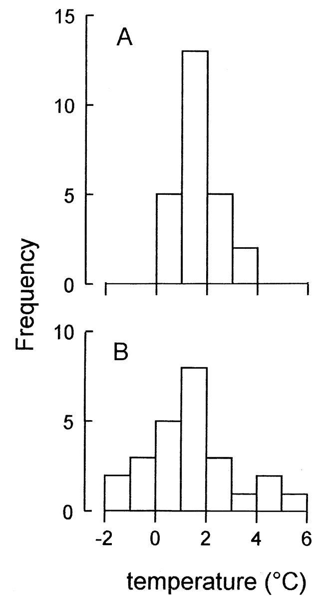

Fig. 5. The frequency distributions of the minimum temperatures attained at randomly selected sites on the surfaces of 25 carcasses on their exit from the chiller at each of (A) a lamb slaughtering or (B) a pig slaughtering plant.

monad proliferation values calculated from the pig carcass temperature histories were between 2.1 and 7.3 generations, with a mean value of 3.9 generations.

At the sheep slaughtering plant, total counts were recovered from all, and coliforms and *E. coli* were recovered from most of the carcasses entering or leaving the cooling process (Table 1). The estimated values for the log mean numbers (log *A*) indicated that the cooling process reduced the log numbers of total counts, coliforms and *E. coli* on carcasses by about 0.5, 1.5 and 2, respectively.

At the pig slaughtering plant, total counts were recovered from all, and coliform and *E. coli* counts were recovered from about half of the carcasses entering or leaving the cooling process (Table 2). The estimated values for the log mean numbers, and the log total numbers of coliforms and *E. coli* recovered indicated that the log numbers of total counts on carcasses increased by about 0.5 during

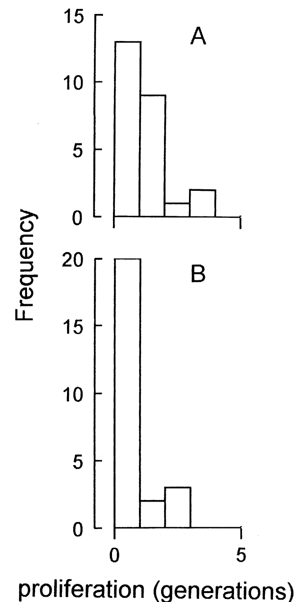

Fig. 6. The frequency distributions of the *Escherichia coli* proliferations calculated from temperature histories from randomly selected surface sites on 25 carcasses passing through the chiller at each of (A) a lamb slaughtering or (B) a pig slaughtering plant.

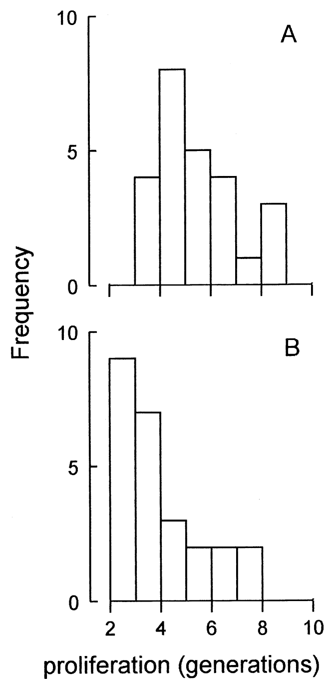

Fig. 7. The frequency distributions of the pseudomonad proliferations calculated from temperature histories from randomly selected surface sites on 25 carcasses passing through the chiller at each of (A) a lamb slaughtering or (B) a pig slaughtering plant.

the cooling process, but that coliform and *E. coli* counts were little affected by the cooling process.

4. Discussion

In collecting temperature histories from the pig carcass cooling process, monitoring was not started until after the initial cooling of carcasses by a blast of freezing air, because of practical difficulties with maintaining in place and tracking temperature loggers during the passage of carcasses through the blast cooling tunnel. However, the lack of data for that period would little affect the assessment of the process, as the duration of the blast cooling treatment was maintained at 50±5 min, while a previous study had shown that both *E. coli and* pseudomonad proliferations at the aitch bone pocket site during the treatment would be on average only about 0.5 generations and would in no case exceed 1 generation (Gill and Jones, 1992).

The durations of the temperature histories showed that the pig carcass cooling process was generally better controlled than the lamb carcass cooling process with respect to the times of carcass cooling. However, the deep leg temperature histories indicated that while all lamb carcasses would be below 7°C at the end of the process, some 8% of the pig carcasses would be inadequately cooled. The inadequate cooling of 8% of the pig carcasses was also indicated by aitch bone pocket temperature histories. Thus, the lamb carcass cooling process could be expected to meet a criterion, in the form of a three point attributes acceptance plan, for the estimated proliferations of *E. coli* at the aitch bone pocket site, while the pig carcass cooling process could be expected not to meet such a criterion, because of unacceptable proliferation values estimated for some inadequately cooled carcasses (Gill et al., 1991).

Analysis of the temperature histories from randomly selected sites on carcasses would also indicate an acceptable performance of the sheep carcass cooling process, but would suggest a similar per-

Table 1
Statistics for sets of 25 total aerobic counts (number/cm^2), coliform counts (number/cm^2) and for *Escherichia coli* counts (number/100 cm^2) obtained from randomly selected sites on randomly selected carcasses entering or leaving the chiller at a sheep slaughtering plant

Count	Stage of the process	Statistics				
		$\bar{x}$	s	no	log A	N
Total	Entry	3.02	0.52	0	3.33	[a]4.74
	Exit	2.67	0.41	0	2.86	[a]4.25
Coliforms	Entry	2.48	0.97	1	3.56	[b]4.49
	Exit	1.23	0.80	2	1.97	[b]3.46
E. coli	Entry	2.12	1.12	2	3.57	[b]4.28
	Exit	0.82	0.76	3	1.49	[b]2.86

$\bar{x}$, mean log; s, standard deviation; no, number of samples from which bacteria were not recovered; log A, estimated log of the arithmetic mean; N, log total numbers recovered from [a] 25 cm^2, [b] 2500 cm^2.

Table 2
Statistics for sets of 25 total aerobic counts (number/cm^2), coliform counts (number/cm^2) or *Escherichia coli* counts (number/100 cm^2) obtained from randomly selected sites on 25 randomly selected carcasses entering or leaving a chiller at a pig slaughtering plant

Count	Stage of the process	Statistics				
		$\bar{x}$	s	no	log A	N
Total	Entry	1.06	0.82	0	1.83	[a]3.08
	Exit	2.04	0.68	0	2.57	[a]3.71
Coliform	Entry	0.15	0.77	12	0.83	[b]2.81
	Exit	0.13	0.69	11	0.68	[b]2.57
E. coli	Entry	−0.04	0.59	13	0.35	[b]2.10
	Exit	−0.07	0.65	15	0.42	[b]1.93

$\bar{x}$, mean log; s, standard deviation; no, number of samples from which bacteria were not recovered; log A, estimated log of the arithmetic mean; N, log total numbers recovered from [a] 25 cm^2, [b] 2500 cm^2.

formance of the pig carcass cooling process, with no indication of the inadequate cooling of any pig carcass. Although it is possible that simply by chance no inadequately cooled pig carcass was monitored at a randomly selected site, it seems more likely that the findings reflect the movement of chilled air over the outer surfaces of most carcasses sufficient to preclude the temperature at any of those surfaces rising much above 10°C. The inadequate cooling of the hams of some carcasses would then result from flows of chilled air over the inner surfaces of those hams being prevented, by the inadequate spacing of some carcasses within the chiller.

Certainly, the microbiological data for the pig carcasses are agreeable with the growth of bacteria predicted from the temperature histories of randomly selected sites, as both indicate undetectable growth of *E. coli* during carcass cooling but increases in the log numbers of aerobic counts of no more than one. Such small increases in the total aerobic counts following blast cooling of pig carcasses have been reported by other workers (Greer and Dilts, 1987). In contrast, the decreases in bacterial numbers during the cooling of sheep carcasses could not be predicted from temperature history data, while decreases of coliforms and *E. coli* of the magnitudes observed have previously been reported only for a spray-cooling process (Gill and Bryant, 1997).

Those findings confirm that the microbiological effects of a carcass cooling process should in the first instance be assessed from microbiological data, because factors other than temperature may determine the behavior of the microflora. However, temperature history data would be required to characterize the cooling performance, with the identification of any ineffective cooling. Moreover, appropriate analysis of temperature history data from randomly selected sites on carcasses would apparently allow a realistic assessment of the microbiological effects of those cooling processes, such as that for pig carcasses examined in this study, where temperature alone largely determines the behavior of the microflora.

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