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The Effects of Spray-chilling on Carcass Mass Loss and Surface Associated Bacteriology

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ABSTRACT

The effect of spray-chilling on carcass mass loss and bacteriology was tested in this trial. The spray-chill treatment consisted of intermittent spraying of carcasses for either 60 or 120 s every 15 min, for 10, 14 or 17 h. The 17 h/120 s spray-chill treatment gave the highest and 10 h/60 s the lowest moisture savings after 18 h of chilling. Due to insufficient drying time between the end of spraying (17 h) and the end of chilling (18 h) the carcass sides of the 17 h/60 s and 120 s treatments appeared pale and wet; this was not the case with the other treatments. Regarding microbial analyses, the results indicated that, except for the 17 h/20 s spray-chill treatment, the mean total and Enterobacteriaceae *counts of the spray-chill treatments were similar to their respective control groups (conventionally chilled). The mean total and* Enterobacteriaceae *counts of the 17 h/20 s spray-chill treatments increased, while those of the controls decreased.*

INTRODUCTION

The South African Hygiene Act (RSA Government Gazette, 1967) lays down the following requirements for the chilling of beef carcasses: in Part XXI under the heading 'Cold Storage Facilities' no post-chilling bone temperature is stipulated; however, a minimum post-mortem chilling time of 16 h, under specified environmental conditions of temperature and air velocity, is as follows: 'while the air temperature should not be in excess of 7°C initially, the air temperature in the terminal stages of chilling shall be maintained between −1 and +2°C, average air velocity over the carcass should be maintained above 0·75 ms^{-1}.'

The average mass loss due to evaporation under these conditions can be up to 2% for 210 kg carcasses with a medium fat cover (Kerens & Visser, 1978). This

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mass loss represents a loss of *R* 23·10 per 210 kg carcass (A-age; no permanent incisors; fatcode 3 at *R* = 5·50 per kg). As the restriction of microbial growth is one of the main reasons for rapid chilling of carcasses, the meat industry has to comply with the prescribed chilling conditions. However, spray-chilling or the application of water to beef carcasses in timed cycles, which was adopted in 1987 by most major slaughter plants in North America, can be used to reduce carcass shrinkage caused by relatively high air speeds in the air chilling plant (Jones & Robertson, 1988). Typical mass losses in beef carcasses over the first 24 h post-slaughter, range from 0·75 to 2·0% in North America and from 1·2 to 1·7% in the UK (Jones & Robertson, 1988).

According to Kerens and Visser (1978) the variations in carcass mass and fat cover have the greatest effect on mass loss, while the effects of air velocity, air temperature and relative humidity are found to be small. The average mass loss is somewhat higher (2%) in South Africa than in North America and the UK, probably due to smaller carcasses (larger surface area per mass) often accompanied by less fat cover. Kerens and Visser (1978) found the variation in carcass moisture loss to vary between 1·3%, for large (390 kg) fat carcasses and 3·2 for small (100 kg) lean carcasses. Therefore, South African abattoirs should benefit from spray-chilling, in terms of savings on carcass mass, which can amount to $2{\cdot}6 \times 10^6$ kg or *R* $11{\cdot}8 \times 10^6$ annually (1% saving on mass loss for a 210 kg carcass at 445 c kg $^{-1}$; RSA: Livestock and Meat Statistics, 1991). It is for this reason that the South African Abattoir Corporation (Abacor) requested the Meat Industry Centre of the Irene Animal Production Institute to investigate spray-chilling on a small scale.

MATERIALS AND METHODS

Procedure

Six different spray-chill schedules were evaluated in this trial. Five carcasses of medium fat cover (10 kg per 210 kg carcass) were used during each spray-chill schedule. One side of each carcass was randomly allocated to a spray-chill treatment and the other side was conventionally-chilled (control). The five carcass sides allocated to each spray-chill treatment were intermittently sprayed for 60 or 120 s four times per hour, for either 10, 14 or 17 h. Chilling commenced (at $t = 0$) as soon as thermocouples, for the monitoring of the different carcass temperatures, were placed in position. The spray volume at the inflow was set at 8 litres min $^{-1}$ (adopted from Jones & Robertson, 1988) and the nozzles, placed halfway between two consecutive sides, delivered 0·67 litres min $^{-1}$. The spraying schedule was controlled by an automatic timer.

Chillers

Two chillers of identical air temperature (3°C ± 3°C) air velocity (0·75 ms $^{-1}$) and defrost cycle were used, and one of them was fitted with the spray-chilling equipment. After slaughtering, alternative carcass sides were placed randomly (left and right sides) in one of the two chillers. The sides were placed 330 mm apart (suspension hook) with the latero-medial sides facing.

Temperature monitoring

The deep-leg (mid-point of femur) temperature, the muscle temperature of the *M. longissimus thoracis* (depth of 50 mm between 10th and 11th vertebrae) of the spray-chilled and conventionally-chilled sides, and the room temperature were continuously monitored by a Speedomax 2500 Series Multipoint Recorder fitted with type J thermocouples (Babcock International).

Mass loss determination

The masses of all carcass sides (conventional and spray-chilled) were determined before entering the chillers (T_0) and again after chilling for 18 h (T_1). After 18 h chilling the carcass sides were removed from the chillers, kept at 10°C ± 3°C for 6 h and weighed (T_2), simulating the period between weighing and dispatch at a commercial abattoir. The carcass sides were then chilled again for 18 h (T_3) representing conventional-chilling at the wholesaler or retailer (3°C ± 3°C) and then weighed and processed further.

Carcass processing

The wing-rib (between the 11th and 13th vertebrae) and prime-rib (between the 8th and 10th vertebrae) of each side were removed and weighed after the chilling period. Four steaks of equal thickness (25 mm) were cut from the wing-rib and weighed. Two of the steaks were placed singly on styrofoam trays, overwrapped with PVC and displayed in single layers in retail display cabinets (*ca* 0°C) for four days and their mass losses determined. The prime-rib was vacuum packed and aged at 0–7°C for 7 days, weighed, and then treated in the same way as the wing-rib. After the display period, the *M. longissimus thoracis* of the steaks (prime-rib and wing-rib) were removed, weighed, and placed in plastic bags in a water bath at 70°C for 60 min. The mass loss during this period indicated the moisture loss of the meat during the cooking process. The other two steaks were de-boned and a chemical analysis for moisture content was executed on a minced sample of the meat and subcutaneous fat (AOAC, 1985).

Bacteriological analysis

The five beef-carcass sides from each spray-chilled treatment (10 h/60 s, 14 h/60 s, 17 h/60 s, 10 h/120 s, 14 h/120 s and 17 h/120 s) and their respective controls were bacteriologically assessed before (0 h) and after chilling (18 h), using the modified agar sausage technique (Nortjé *et al.*, 1982). The following counts were obtained: total aerobic counts (3 days, 25°C) on Standard 1 nutrient agar (Std 1; Merck) and *Enterobacteriaceae* (2 days, 37°C) on DHL agar (Sakazaki *et al.*, 1960).

Sample areas which were presumed 'clean' or 'contaminated' as a result of the slaughtering process, were selected as follows:

- carcass surface in the region of the anus (contaminated)
- medial side of the hindlimb (clean)
- lateral surface at the 7th and 8th vertebrae (clean)
- carcass surface at the breast area of the 7th and 8th rib (contaminated)
- proximal part of the neck area (contaminated).

Statistical analysis

The carcass data was analysed by analyses of variance to determine which factors, i.e. chilling method (spray-chill vs control) spray-chill period (10 h, 14 h, 17 h) application time 60 s, 120 s), and interaction between factors contributed significantly to differences in moisture loss or bacterial counts. Levels of $P \leq 0{\cdot}05$ were taken to be significant. When an interaction between two or more factors was found significant, a *t*-test was done to determine which level of the factor or interaction was significantly different.

RESULTS

Main effect of chilling method

Means for the effect of chilling method on moisture loss of carcass sides and certain retail and wholesale cuts, as well as moisture content of the soft tissue, are presented in Table 1. Regardless of duration period, spray-chilled carcass sides lost significantly less moisture ($P \leq 0{\cdot}05$) than conventionally-chilled carcasses at any stage (T_1, T_2, T_3) after commencement of initial chilling (T_0).

TABLE 1
Means for Moisture Loss (%) of Conventionally and Spray-chilled Carcasses and Certain Retail and Wholesale Cuts

	Conventional chilling	*Spray-chilling*
Carcass†		
T_0–T_1	$1{\cdot}60^a$	$0{\cdot}50^b$
T_0–T_2	$1{\cdot}73^a$	$0{\cdot}72^b$
T_0–T_3	$2{\cdot}09^a$	$1{\cdot}31^b$
Retail and wholesale cuts‡		
PR-vacuum	0·64	0·69
PR-display	2·53	2·59
PR-cooked	34·5	33·9
WR-display	2·06	2·31
WR-cooked	31·2	31·2
Moisture	69·5	69·3

^{a,b} Means with different superscript in the same row differ significantly ($P \leq 0{\cdot}05$)

† T_0–T_1; mass loss (%) after overnight chilling (3°C ± 3°C, 18 h) when conventional or spray-chilling took place.
T_0–T_2; mass loss (%) after 6 h hanging time at despatch (10°C).
T_0–T_3; mass loss (%) after 18 h conventional chilling at wholesaler or retailer (3°C ± 3°C).

‡ PR-vacuum; mass loss (%) of prime-rib vacuum-packaged and aged for 7 days.
PR/WR-display; mass loss (%) of prime- or wing-rib steaks displayed on styrofoam trays in a retail cabinet for 3 days.
PR/WR-cooked; mass loss (%) of *M. longissimus dorsi* of prime- or wing-rib steaks when cooked in plastic bags at 70°C for 60 min.
Moisture; moisture content (%) of soft tissue (muscle and subcutaneous fat) of part of the wing-rib cut.

Contrary to expectation, the saving in moisture loss due to spray-chilling was not reflected in the soft tissue moisture content values. This could possibly be ascribed to the relatively small sample size, obtained from a single specific anatomical location (viz *M. longissimus thoracis*, between 11th and 13th rib) which might not be representative of the moisture content of the whole carcass.

Main effects of spray-chilling duration and application period

Means for the effect of spray-chill duration (10 h, 14 h, 17 h) and application period (60 s, 120 s) on moisture conservation are presented in Table 2. This data are presented as differences in mass loss (percentage units) between conventional and spray-chilled subjects, as these means give a clearer indication of the saving achieved through spray-chilling than do the individual means for mass loss (of sides) between the two treatments. In this respect, intermittent spray-chilling for 10 h conserved significantly ($P \leq 0{\cdot}05$) less moisture than spray-chilling for 14 and 17 h. A spraying period of 120 s every 15 min also saved significantly ($P \leq 0{\cdot}05$) more moisture than the 60 s option. With the exception of the wing-rib

TABLE 2
Means for Differences in Carcass Mass Loss (Percentage Units) between Conventionally and Spray-chilled Carcasses and between their Wholesale and Retail Cuts

		Spray-chill duration			*Application period*	
		10 h	*14 h*	*17 h*	*60 s*	*120 s*
Carcass†						
T_0–T_1 (%)		$0{\cdot}90^a$	$1{\cdot}12^b$	$1{\cdot}28^b$	$0{\cdot}98^a$	$1{\cdot}23^b$
T_0–T_2 (%)		$0{\cdot}79^a$	$1{\cdot}04^b$	$1{\cdot}18^b$	$0{\cdot}89^a$	$1{\cdot}12^b$
T_0–T_3 (%)		$0{\cdot}61^a$	$0{\cdot}86^b$	$0{\cdot}88^b$	$0{\cdot}68^a$	$0{\cdot}89^b$
Retail and wholesale cuts‡						
PR-vacuum	(%)	$-0{\cdot}05^a$	$0{\cdot}14^a$	$0{\cdot}05^a$	$-0{\cdot}05^a$	$0{\cdot}14^a$
PR-display	(%)	$0{\cdot}03^a$	$0{\cdot}00^a$	$0{\cdot}14^a$	$0{\cdot}07^a$	$0{\cdot}05^a$
PR-cooked	(%)	$-0{\cdot}58^a$	$-0{\cdot}73^a$	$-0{\cdot}52^a$	$-0{\cdot}07^a$	$-1{\cdot}15^a$
WR-display	(%)	$0{\cdot}15^a$	$0{\cdot}55^a$	$0{\cdot}06^a$	$0{\cdot}26^a$	$0{\cdot}25^a$
WR-cooked	(%)	$-0{\cdot}75^a$	$1{\cdot}11^b$	$-0{\cdot}37^a$	$0{\cdot}01^a$	$-0{\cdot}01^a$
Moisture	(%)	$-0{\cdot}02^a$	$-0{\cdot}25^a$	$-0{\cdot}31^a$	$-0{\cdot}18^a$	$-0{\cdot}21^a$

^{a,b}Means with different superscripts in the same row and under the same heading differ significantly ($P \leq 0{\cdot}05$)

† T_0–T_1; Period of normal overnight chilling (3°C ± 3°C, 18 h) in which conventional or spray-chilling took place.

T_0–T_2; T_0–T_1 plus 6 h hanging time at despatch (10°C).

T_0–T_3; T_0–T_2 plus 18 h conventional chilling at wholesaler or retailer (3°C ± 3°C)

‡ PR-vacuum; Mass loss (percentage unit differences) of prime-rib vacuum-packaged and aged for 7 days.

PR/WR-display; Mass loss (percentage unit differences) of prime- or wing-rib steaks displayed on styrofoam trays in a display cabinet for 3 days.

PR/WR-cooked; Mass loss (percentage unit differences) of *M. longissimus dorsi* of prime- or wing-rib steaks when cooked in plastic bags at 70°C for 60 minutes.

Moisture; Moisture content (percentage unit differences) of soft tissue (muscle and subcutaneous fat) of part of the wing-rib cut.

TABLE 3
Mean Carcass Mass Loss (%) for Conventionally and Spray-Chilled Carcass Sides at Various Periods Post-Slaughter

	*Treatment**											
	10 h/60 s		*10 h/120 s*		*14 h/60 s*		*14 h/120 s*		*17 h/60 s*		*17 h/120 s*	
Time	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*
T_0–T_1	$1{\cdot}63^{ef}$	$0{\cdot}88^{d}$	$1{\cdot}73^{f}$	$0{\cdot}66^{cd}$	$1{\cdot}43^{e}$	$0{\cdot}45^{abc}$	$1{\cdot}75^{f}$	$0{\cdot}50^{bc}$	$1{\cdot}47^{e}$	$0{\cdot}27^{ab}$	$1{\cdot}57^{ef}$	$0{\cdot}22^{a}$
T_0–T_2	$1{\cdot}92^{h}$	$1{\cdot}25^{cd}$	$1{\cdot}89^{h}$	$0{\cdot}99^{bc}$	$1{\cdot}63^{gh}$	$0{\cdot}73^{b}$	$1{\cdot}91^{h}$	$0{\cdot}73^{b}$	$1{\cdot}47^{ef}$	$0{\cdot}39^{a}$	$1{\cdot}57^{f}$	$0\,29^{a}$
T_0–T_3	$2{\cdot}07^{cde}$	$1{\cdot}58^{b}$	$2{\cdot}30^{e}$	$1{\cdot}57^{b}$	$1{\cdot}95^{c}$	$1{\cdot}25^{a}$	$2{\cdot}29^{de}$	$1{\cdot}26^{a}$	$1{\cdot}93^{c}$	$1{\cdot}08^{a}$	$2{\cdot}01^{cd}$	$1{\cdot}09^{a}$

^{a,b,c,d,e,f,g,h}Means with different superscripts in the same row differ significantly ($P \leq 0{\cdot}05$).

*All carcass sides (conventional and spray-chilled) were initially chilled for 18 h. Spray-chilled sides were submitted to intermittent spraying (60 or 120 s, four times per hour) for either 10, 14 or 17 h within the 18 h.

C; carcass mass loss (%) of conventionally-chilled carcasses.

S; carcass mass loss (%) of spray-chilled carcasses.

† T_0–T_1; mass loss (%) after overnight chilling (3°C ± 3°C, 18 h) when conventional or spray-chilling took place.

T_0–T_2; mass loss (%) T_0–T_1 plus 6 h hanging time at despatch (10°C).

T_0–T_3; mass loss (%) T_0–T_2 plus 18 h conventional-chilling at wholesaler or retailer (3°C ± 3°C).

TABLE 4
Mean Mass Loss (%) of Wholesale and Retail Cuts of Conventionally and Spray-Chilled Carcasses at Various Periods Post-Slaughter

	*Treatment**											
	10 h/60 s		*10 h/120 s*		*14 h/60 s*		*14 h/120 s*		*17 h/60 s*		*17 h/120 s*	
*Cut**	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*	*C*	*S*
PR-vacuum	$0{\cdot}56^{ab}$	$0{\cdot}42^{a}$	$0{\cdot}69^{abc}$	$0{\cdot}74^{abc}$	$0{\cdot}70^{abc}$	$0{\cdot}87^{bc}$	$0{\cdot}56^{ab}$	$0{\cdot}68^{abc}$	$0{\cdot}60^{ab}$	$0{\cdot}44^{a}$	$0{\cdot}72^{abc}$	$0{\cdot}99^{c}$
PR-display	$2{\cdot}26^{a}$	$2{\cdot}20^{a}$	$2{\cdot}69^{ab}$	$2{\cdot}81^{b}$	$2{\cdot}43^{ab}$	$2{\cdot}47^{ab}$	$2{\cdot}54^{ab}$	$2{\cdot}50^{ab}$	$2{\cdot}45^{ab}$	$2{\cdot}68^{ab}$	$2{\cdot}79^{b}$	$2{\cdot}85^{b}$
PR-cooked	$29{\cdot}8^{a}$	$29{\cdot}2^{a}$	$29{\cdot}8^{a}$	$29{\cdot}3^{a}$	$28{\cdot}3^{a}$	$28{\cdot}7^{a}$	$38{\cdot}7^{b}$	$36{\cdot}9^{b}$	$38{\cdot}3^{b}$	$38{\cdot}3^{b}$	$41{\cdot}8^{b}$	$40{\cdot}7^{b}$
WR-display	$1{\cdot}79^{ab}$	$1{\cdot}82^{ab}$	$1{\cdot}82^{ab}$	$2{\cdot}10^{abc}$	$1{\cdot}91^{abc}$	$2{\cdot}50^{abcd}$	$1{\cdot}70^{a}$	$2{\cdot}21^{abcd}$	$2{\cdot}28^{abcd}$	$2{\cdot}44^{bcd}$	$2{\cdot}84^{d}$	$2{\cdot}81^{d}$
WR-cooked	$30{\cdot}7^{bcd}$	$30{\cdot}1^{bc}$	$31{\cdot}9^{defg}$	$31{\cdot}0^{bcd}$	$27{\cdot}7^{a}$	$29{\cdot}4^{ab}$	$32{\cdot}9^{fg}$	$33{\cdot}4^{g}$	$32{\cdot}5^{efg}$	$31{\cdot}5^{cdef}$	$31{\cdot}5^{cdef}$	$31{\cdot}8^{cdefg}$
Moisture	$68{\cdot}2^{ab}$	$68{\cdot}6^{ab}$	$74{\cdot}0^{c}$	$73{\cdot}5^{c}$	$68{\cdot}3^{ab}$	$68{\cdot}3^{ab}$	$65{\cdot}9^{a}$	$65{\cdot}5^{a}$	$69{\cdot}2^{ab}$	$68{\cdot}3^{ab}$	$71{\cdot}2^{bc}$	$71{\cdot}5^{bc}$

^{a,b,c,d,e,f,g}Means with different superscripts in the same row differ significantly ($P \leq 0{\cdot}05$).

* *Cut*:
PR-vacuum; mass loss (%) of prime-rib, vacuum-packaged and aged for 7 days.
PR/WR display; mass loss (%) of prime- or wing-rib steaks, displayed in a retail cabinet for 3 days.
PR/WR-cooked; mass loss (%) of *M. longissimus dorsi* of prime- or wing-rib steaks when cooked in plastic bags at 70°C for 60 min.
Moisture; moisture content (%) of soft tissue (muscle and subcutaneous fat) of part of the wing-rib cut.

† *Treatment*:
All carcass sides (conventional and spray-chilled) were initially chilled for 18 h. Spray-chilled sides were submitted to intermittent spraying (60 or 120 s, four times per hour) for either 10, 14 or 17 h within the 18 h.
C; mass loss (%) for cuts of the conventionally-chilled carcass sides.
S; mass loss (%) for cuts of the spray-chilled carcass sides.

cooking loss, neither the spray-chilling period nor the application period had a significant effect on the difference in moisture loss of vacuum-packaged prime-ribs, rib steaks of the prime, and wingribs or the cooking loss of these steaks. There were no significant interactions between the spray-chill duration and the application period for any parameter. However, the individual means for the different spray-chilling duration × application periods presented in Table 3 also stress the fact that regardless of duration period the spray-chilled carcass sides lost significantly less moisture ($P \leq 0{\cdot}05$) than the conventionally-chilled carcasses.

It must be emphasized that although the relative moisture loss between T_1 and T_3 (i.e. period after spray-chilling) was greater for the spray-chilled sides, their total mass loss (T_0 to T_3) was nevertheless significantly ($P \leq 0{\cdot}05$) less than that of the conventionally chilled sides. Spray-chilling had no significant effect on either the moisture loss of the prime-rib which was vacuum-packaged and aged for 7 days, and prime-rib and wing-rib steaks displayed for 3 days in a display cabinet, or on cooking losses of these steaks. Once again the individual means for spray-chilling duration × application period supported these findings (Table 4).

Chilling rate

With the exception of the LT of 10 h/60 s treatment, there were no differences in chilling rates, as reflected by the *M. longissimus thoracis* and the deep-leg temperatures. The *M. longissimus thoracis* of the spray-chilled sides of the 10 h/60 s treatment tended to chill faster than those of the conventionally-chilled sides. Jones and Robertson (1988) reported that the temperatures of both the *M. longissimus thoracis* and the *M. semitendinosus* of spray-chilled carcasses were significantly ($P < 0{\cdot}05$) lower than those of conventionally-chilled carcasses following 8 or 24 h of chilling. The duration of spray-chilling was 8 h. One could therefore expect that the chilling rate during spray-chilling will be higher than that during conventional chilling due to extended heat transfer through prolonged evaporation of the added water. This being the case, it must be kept in mind that the two chiller rooms were not loaded to full capacity and could, therefore, handle the heat load very easily. In conventional abattoirs with large chillers loaded to capacity, spray-chilling may improve the chilling rate through evaporation, which is a more effective way of dispensing heat energy than is the circulation of chilled air.

Bacteriological analysis

According to Nortjé *et al.* (1982) the excision technique gives the most reliable count when monitoring beef carcasses, although the agar sausage technique is specifically used under commercial conditions. Therefore microbial counts recorded with the modified agar sausage technique were transformed to be comparable to an excision count using the following equation (Nortjé *et al.*, 1982:

$$\log(\text{excision count}) = (\log \text{modified agar sausage count} - 0{\cdot}8374)/0.5758$$

Total counts

According to statistical analyses of the total counts of the spray-chilled and conventionally-chilled carcass sides, the counts recorded were significantly influ-

enced (P = 0·0233) by the application period (the main factor) the spray-chill duration × application period (P = 0·0308) as well as the application period × chilling time (0 and 18 h; P = 0·0050) interaction. The chilling treatment (spray-chilled vs conventionally-chilled) did not influence the different total counts significantly (P = 0·4535). The latter ranged between 0·67 and 4·27 log cm $^{-2}$ for all the carcass sides following 18 h chilling (Table 5). Except for the 10 h/120 s control, 10 h/120 s spray-chilled and 17 h/120 s spray-chilled treatments, the 0 h total count recorded for all the other treatments decreased after 18 h chilling. According to the application period × chilling time interaction (P = 0·0005) the mean total counts recorded for the 60 s applications before chilling (0 h, log 2·8 cm $^{-2}$) decreased (log 1·6 cm $^{-2}$) after 18 h chilling, while the counts for the 120 s applications (log 2·3 cm $^{-2}$) increased (log 3·4 cm $^{-2}$) after 18 h chilling.

Enterobacteriaceae counts

According to Table 5 the *Enterobacteriaceae* counts were significantly influenced by the application period (P = 0·0001) and the chilling time (P = 0·0001) main effects. The spray-chill duration × application period P = 0·0001) and applica-

TABLE 5
Microbiological Counts Obtained from Spray-Chilled and Control Beef Carcass Sides before (0 h) and after (18 h) Chilling

Chilling method	*Spray period*	*Before after chilling*	*Total count (log cm $^{-2}$)*	*Standard error*	Enterobacteriaceae *(log cm $^{-2}$)*	*Standard error*
Spray-chilled	10 h/60 s	0 h	2·83	0·54	0.00	0·00
control		18 h	0·69	0·33	0·00	0·00
		0 h	1·60	0·54	0·00	0·00
		18 h	1·17	0·51	0·00	0·00
Spray-chilled	14 h/60 s	0 h	3·42	0·74	0·28	0.28
control		18 h	2·71	0·63	0·93	0·38
		0 h	3·18	0·61	0·67	0·38
		18 h	2·44	0·62	0·91	0·37
Spray-chilled	17 h/60 s	0 h	1·91	0·67	0·00	0·00
control		18 h	0·67	0·37	0·24	0·24
		0 h	3·51	0·92	0·00	0·00
		18 h	2·89	0·73	1·21	0·67
Spray-chilled	10 h/120 s	0 h	3·05	0·75	1·05	0·50
control		18 h	3·86	0·80	3·46	0·82
		0 h	1.89	0.67	1.10	0.62
		18 h	3.72	0.88	2.74	0.85
Spray-chilled	14 h/120 s	0 h	2·30	0·58	0·00	0·00
control		18 h	2·48	0·71	1·51	0·64
		0 h	2·74	0·71	0·00	0·00
		18 h	3·28	0·84	1·69	0·73
Spray-chilled	17 h/120 s	0 h	1·34	0·54	0·33	0·33
control		18 h	4·27	0·67	1·90	0·54
		0 h	3·06	0·90	1·21	0·67
		18 h	2·61	0·58	0·82	0·39

tion period × chilling time interactions also significantly influenced the *Enterobacteriaceae* counts recorded. As noted for the total counts, the *Enterobacteriaceae* counts did not react significantly differently regarding the various chilling methods. Only the *Enterobacteriaceae* count of the 17 h/120 s control samples decreased after 18 h storage (1·21–0·82 log cm^{-2}), while the count recorded for all the other samples increased or remained stable (Table 5). The *Enterobacteriaceae* count was acceptable for all treatments (range log 0·00–1·90 cm^{-2}) except for both the 10 h/120 s conventionally-chilled (log 2·74 cm^{-2}) and spray-chilled (log 3·46 cm^{-2}) treatments. *Enterobacteriaceae* counts of the 120 s application period increased from log 0·6 to log 2·0 cm^{-2} after 18 h chilling, while the counts of the 60 s application period also increased (log 0·1 to log 0·5 cm^{-2}) after chilling, but to a lesser extent. The application period × chilling time interaction (P = 0·0064) also indicate these described differences.

DISCUSSION

The average mass saving achieved by spray-chilling carcass sides in the present trial was 1·10% (T_0–T_1). This figure is very similar to the 1·14% saving reported by Allen *et al.*, (1987). A higher average figure of 1·43% was recorded by Jones and Robertson (1988) with spray-chilling over a shorter period of time (8 h vs 10 h minimum) and with heavier carcasses than in the present trial (317 kg vs 200 kg).

The mass saving achieved in all cases was significant, irrespective of the spraying schedule used. In addition, none of the conserved moisture was lost during normal vacuum-packaging, retail display of steaks, or cooking of retail cuts. Jones and Robertson (1988) reported similar findings for vacuum-packaged and aged cuts. Allen *et al.* (1987) on the other hand, reported a significantly ($P < 0·05$) higher drip loss for topside cuts of spray-chilled carcasses that were vacuum-packed and aged for 15 days, than for similar cuts of conventionally-chilled sides (1·98% vs 1·72%). Both Allen *et al.* (1987) and Jones and Robertson (1988) agree that retail cuts displayed for 4 or 5 days under simulated retail conditions tended to have similar losses independent of treatment. Steaks cut from the *M. longissimus thoracis* and *M. semimembranosus*, and wrapped with PVC film lost between 6·3 and 7·6% moisture over 5 days at 3°C. Rib steaks lost 1·12%, which is in agreement with losses recorded for prime-rib and wing-rib steaks in this trial (2·56 and 2·15%, respectively).

The different spray-chilling schedules resulted in varying moisture conservation levels, differences in some cases being significant. The 10 h/60 s resulted in the lowest mass saving at all stages T_1, T_2 and T_3). The difference between this treatment and the 10 h/120 s and 14 h 60 s sub-trials was, however, not significant. The 17 h/120 s treatment gave the highest saving at T_1 and T_2, although these savings did not differ significantly from those of the 17 h/60 s and 14 h/120 s treatments. Although not significantly more important than the 17 h/60 s and 17 h/120 s treatments, the 14 h/120 s treatment gave the highest saving at T_3.

The most important stages for an abattoir are T_1 and T_2, because any losses are incurred while the carcasses are still at the abattoir.

The 17 h/120 s treatment may therefore appear to be the obvious spraying schedule to use. However, in considering other factors besides moisture preservation (such as running costs and carcass appearance) the 14 h/120 s treatment proves to be a better option, based on the following information:

1. The 14 h/120 s option used 192 litres less water than did the 17 h/120 s option (in the present trial) using only five carcass sides. In a commercial abattoir the savings will obviously be far greater.
2. The 14 h/120 s option did not differ significantly from the 17 h/120 s option at any stage (T_1 to T_3) of chilling.
3. Due to insufficient drying time between the end of spraying (17 h) and the end of chilling (18 h) the carcasses appeared pale and wet; characteristic of 'wet carcass syndrome'. This was observed to a far lesser extent with the 14 h/120 s treatment by T_1, and by T_2 the carcasses could not be distinguished from conventionally-chilled carcasses. In a commercial abattoir where carcasses are handled intensively after chilling, excessive moisture on carcasses may have a negative effect on the microbiological status of these carcasses.

Bacteriological analysis

The results clearly indicate that except for the 17 h/120 s spray-chilled treatment, the mean total and *Enterobacteriaceae* counts of all the other spray-chilled treatments reacted similarly to their respective control groups. Regarding the 17 h/120 s treatment, the mean total and *Enterobacteriaceae* counts of the spray-chilled beef carcass sides increased, while the counts recorded for the control samples decreased. In contrast to the decreasing tendency of the total counts, the *Enterobacteriaceae* count seemed to increase during chilling, the increase being more than 2 log units (log 1·05–3·46 cm^{-2}) in the 10 h/120 s spray-chill treatment.

This is explained by the fact that although the initial microbial contamination of meat contains both mesophilic and cold-tolerant bacteria, only the latter groups will compete favourably at chill temperatures (Gill & Newton, 1987).

The only spray-chill treatment which had a significant influence on the mean total and *Enterobacteriaceae* counts of the beef carcass sides was that of 17 h/120 s. All other treatments did not seem to influence the beef carcass sides adversely. Hamby (1987) found that the aerobic plate count of sides sprayed intermittently with water did not differ ($P > 0{\cdot}05$) from that of conventionally-chilled sides. Furthermore, the 60 s spray-chill applications resulted in significantly lower total and *Enterobacteriaceae* counts after 18 h chilling than did the 120 s applications. Although it seems that the spray-chilling treatments resulted in very similar final microbiological counts, it is imperative to note that if proper hygiene management is not present, either during slaughtering or further processing of the beef carcass, the microbial quality of the moist beef carcass will definitely be adversely influenced. The bacterial analysis indicates the following:

1. The 17 h/120 s spray-chill treatment is microbiologically more risky.
2. Although all the final (18 h) total counts were acceptable, total counts on the 10, 14 or 17 h/120 s applications tended to increase compared to those of the 60 s applications following 18 h of chilling.
3. Regarding microbiological quality, either 10, 14 or 17 h spray-chilling for 60 s is acceptable, the choice depending on the respective moisture conservation.
4. Effective hygiene control during and after slaughter, processing and distribution is imperative.

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REFERENCES

Allen, D. M., Hunt, M. C., Luchiari Filho, A., Danler, R. J. & Goll, S. J. (1987). *J. Anim. Sci.*, **64**, 165.

Association of Official Agricultural Chemists. (1985). Official methods of analysis, 14th edn, Washington (AOAC).

Gill, C. O. & Newton, K. G. (1978). *Meat Sci.*, **2**, 207.

Hamby, P. L., Savell, J. W., Acuff, G. R., Vanderzant, C. & Cross, H. R. (1987). *Meat Sci.*, **21**, 1.

Jones, S. D. M. & Robertson, W. M. (1988). *Meat Sci.*, **24**, 177.

Kerens, G. & Visser, C. J. (1978). CSIR report. ME 1597.

Nortjé, G. L., Swanepoel, E., Naudé, R. T., Holzapfel, W. H. & Steyn, P. L. (1982). *J. Food Prot.*, **45**, 1016.

Republic of South Africa Government Gazette (1967). Act No. 87. **52**, No. 2540.

RSA: Livestock and Meat Statistics (1991). Printed and published by the Meat Board, May 1991.

Sakazaki, R., Nanoika, S., Osada, A. & Yamada, C. A. (1960). *Japanese J. Ex. Med.* **30**, 13.