The effect of chilling temperature and carcase mass on meat tenderness

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Introduction

Meat is a very good medium for the growth of bacteria, and as this is detrimental to the keeping quality of meat and to the health of humans, methods were devised to slow down the growth of these bacteria. One of the best known methods today is the chilling of carcases directly after slaughter. In South Africa the chillers used for chilling these carcases operate at a temperature of about 0 °C. Although this temperature seems to have beneficial sanitational influences, the effect of this chilling temperature on certain meat quality characteristics has to be addressed. Various researchers have already indicated that the rapid chilling of carcases immediately after slaughter may have a detrimental toughening effect on the meat as a result of cold shortening (Honikel & Hamm, 1978; Lochner, Kauffman & Marsh, 1980; Honikel & Hamm, 1983).

According to Honikel and Hamm (1978), cold shortening results if a muscle with high energy reserves immediately after slaughter is rapidly chilled to temperatures below 10 °C. They also maintain that this phenomenon usually occurs with smaller carcases. It was therefore decided to determine the effect of carcase size (through carcase mass) and different chilling temperatures on objective meat tenderness.

Materials and Methods

Eighty Afrikaner cross bred steers were used in this experiment. These animals were kept under feedlot conditions at the Animal and Dairy Science Research Institute at Irene, and were fed ad libitum. The animals were slaughtered at the Veterinary Research Institute at Onderstepoort (about 40 km from Irene) to yield 20 carcases in each of four mass categories, namely 111, 152, 203 and 252 kg mass groups, thereby representing the carcase masses of cattle slaughtered in South African abattoirs. One side of each carcase was used. Four carcases of each mass category were chilled after slaughter in comparable chillers at chilling temperatures of 0, 3, 5, 7 and 9 °C respectively for 48 hours. The air speed in all of these chillers was 0,75 m/sec, and the relative humidity, 95 %. Termocouples were inserted 3 cm into the *M. longissimus thoracis* (LT) and *M. semitendinosus* (ST) to determine the temperature of the muscle at 10 hours post mortem as Bendall (1972) advised that for optimal tenderness, muscle temperatures should not fall below 10 °C before 10 hours post mortem. After chilling, the LT and ST were dissected out for shear force determination. In duplicate, 72 hours post mortem, muscle samples of approximately 250 g each were placed in separate plastic bags and cooked in preheated waterbaths for exactly 60 minutes at 60 and 80 °C respectively. After cooking, the samples were allowed to cool to room temperature, after which cores (17,5 mm diameter) were taken from the samples parallel to the fibre direction. The shear force was determined perpendicular to the fibre direction with a Warner-Bratzler shear meter. These shear force values were evaluated against the "highest acceptable value" of 110 N which was indicated by a trained taste panel on work previously done on beef.

Statistical analyses were performed on an IBM personal computer with the NWA STATPAK (1984) programs.

Results and discussion

Muscle temperature 10 hours post mortem

Carcase mass had a highly significant influence (p< 0,01) on the muscle temperature reached 10 hours post mortem (Table 1). The greater the carcase mass, the higher were the muscle temperatures in the LT and ST (Table 2). The average temperature in the LT 10 hours post mortem was less than 10 °C in all the mass groups except in the heaviest group (252 kg) where it was 10,82 °C (Table 2). In the ST, the average temperature in none of the mass groups fell below 10 °C within the first 10 hours post mortem (Table 2).

Table 1 : Results of three-way analyses of variances of the effect of carcase mass and chilling temperature on the temperature 10 hours post mortem (10 hpm) and shear force in the *M. longissimus thoracis* (LT) and *M. semitendinosus* (ST)

Parameter	CV%	F value: Carcase mass (A)	F value: Chilling temperature (B)	(AxB)
Muscle temperature 10 hpm :				
LT	44	** 86,6856	** 124,0030	* 2,2609
ST	22	** 73,9753	** 55,7328	** 4,1110
Shear force :				
60 °C :				
LT	47	2,7273	** 9,1875	0,7510
ST	52	** 15,4541	2,3713	** 2,5848
80 °C :				
LT	18	1,4311	** 14,7284	0,5392
ST	21	** 9,1210	1,0254	0,4945

* = p< 0,05 ** = p< 0,01

Chilling temperature also had a highly significant ($p < 0,01$) effect on the temperature reached 10 hours post mortem (Table 1). As the chilling temperatures increased, the average muscle temperatures in both the LT and ST increased (Table 3). This was also noted by Cliplef and Strain (1976). The effect of carcase mass and chilling temperature on the temperature 10 hours post mortem in the LT is shown in Figure 1.

Table 2 : The influence of carcase mass on the average temperature reached 10 hours post mortem in the *M. longissimus thoracis* and *M. semitendinosus*.

Carcase mass	111 kg	152 kg	203 kg	252 kg
Temperature LT (°C)	$5,95^{a}$	$6,43^{a}$	$8,68^{b}$	$10,82^{c}$
Temperature ST (°C)	$11,58^{a}$	$12,46^{a}$	$14,92^{b}$	$16,26^{c}$

abc Within each row, values with no common superscript differ highly significantly ($p < 0,01$)
The following differed significantly ($p < 0,05$) :
LT : 111 kg and 152 kg
ST : 111 kg and 152 kg

Table 3 : The influence of chilling temperatures on average muscle temperatures in the *M. longissimus thoracis* and *M. semitendinosus*.

Chilling temperature	0 °C	3 °C	5 °C	7 °C	9 °C
Temperature LT (°C)	$4,12^{a}$	$6,28^{b}$	$7,91^{c}$	$9,74^{d}$	$11,88^{e}$
Temperature ST (°C)	$11,33^{a}$	$9,93^{a}$	$13,79^{bc}$	$14,70^{c}$	$16,78^{d}$

abcde Within each row, values with no common superscript differ highly significantly ($p < 0,01$)
The following differed significantly ($p < 0,05$) :
ST : 0 °C and 3 °C; 5 °C and 7 °C

The average temperature in the LT 10 hours post mortem was below 10 °C for all the mass groups when chilled at 0 and 3 °C, at 5 °C for all the mass groups except for the 252 kg group, at 7 °C for the mass groups 111 and 152 kg, but only for the mass group 152 kg at the chilling temperature of 9 °C (Table 4). One would thus expect these muscles to cold shorten and be tough. In the ST, a muscle temperature below 10 °C was only found in the 111 kg mass group at chilling temperatures of 0 and 3 °C (Table 4), and this would indicate that generally no cold shortening would have taken place in the ST. The effect of carcase mass at each chilling temperature is shown in Table 5.

Shear force values

A general decrease in shear force values, thus an increase in tenderness, was found in the LT cooked at 60 and 80 °C, with an increase in chilling temperature, as well as carcase mass (Table 3), which would indicate less cold shortening. From these results it is also important to note that cold shortening is not an "all or none" reaction, but that the toughening effect is very dependent on the rate of chilling. Lochner, Kauffman and Marsh (1980) maintain that the superior tenderness of well finished (fat) beef over poorly finished (lean) beef is due to the different cooling rates. An insulating effect of the outer fat cover might be the reason for this phenomenon. Honikel and Hamm (1983) have already stated that the lower the temperature in the muscle, the more quickly and intensively it contracts, and the higher the level of cold shortening.

Table 4 : The influence of chilling temperature on the average temperature reached 10 hours post mortem, and average shear force values of the different carcase mass categories.

Chilling temperature	0 °C	3 °C	5 °C	7 °C	9 °C
Average muscle temperature (°C):					
LT 111 kg	$0,59^{a}$	$4,96^{b}$	$5,76^{b}$	$8,28^{c}$	$10,15^{d}$
152 kg	$3,50^{a}$	$5,06^{b}$	$6,83^{c}$	$7,63^{d}$	$9,14^{e}$
203 kg	$4,89^{a}$	$6,50^{b}$	$8,76^{c}$	$10,03^{c}$	$13,24^{d}$
252 kg	$7,48^{a}$	$8,58^{ab}$	$10,28^{bc}$	$12,78^{cd}$	$14,98^{d}$
ST 111 kg	$7,69^{a}$	$9,93^{b}$	$11,18^{b}$	$13,45^{c}$	$15,65^{d}$
152 kg	$11,81^{ab}$	$11,30^{a}$	$13,29^{bd}$	$12,41^{bd}$	$13,48^{cd}$
203 kg	$12,00^{a}$	$13,28^{a}$	$15,09^{b}$	$16,41^{b}$	$17,84^{c}$
252 kg	$13,80^{a}$	$15,24^{abc}$	$15,60^{bc}$	$16,53^{c}$	$20,14^{d}$
Average shear force (N):					
60 °C:					
LT 111 kg	$165,00^{a}$	$145,46^{ab}$	$139,35^{ab}$	$78,46^{b}$	$74,63^{b}$
152 kg	$148,74^{a}$	$138,47^{a}$	$107,47^{ab}$	$104,23^{ab}$	$61,12^{b}$
203 kg	$149,38^{a}$	$94,38^{ab}$	$82,01^{b}$	$65,63^{b}$	$57,61^{b}$
252 kg	$123,46^{a}$	$102,51^{ab}$	$69,87^{b}$	$81,20^{b}$	$86,99^{b}$
ST 111 kg	$131,04^{a}$	$110,56^{a}$	$114,43^{a}$	$116,25^{a}$	$115,46^{a}$
152 kg	$105,60^{a}$	$136,29^{b}$	$94,23^{a}$	$101,21^{a}$	$95,21^{a}$
203 kg	$93,00^{a}$	$92,14^{a}$	$102,49^{a}$	$94,47^{a}$	$96,09^{a}$
252 kg	$142,59^{a}$	$124,15^{ab}$	$125,94^{ab}$	$107,20^{b}$	$124,07^{ab}$
80 °C:					
LT 111 kg	$344,26^{a}$	$293,61^{ab}$	$242,01^{abc}$	$167,53^{bc}$	$136,46^{c}$
152 kg	$367,73^{a}$	$226,41^{b}$	$182,10^{b}$	$183,50^{b}$	$116,00^{b}$
203 kg	$352,01^{a}$	$163,83^{b}$	$150,73^{b}$	$137,19^{b}$	$111,61^{b}$
252 kg	$286,70^{a}$	$224,21^{ab}$	$210,87^{ab}$	$138,22^{b}$	$148,62^{b}$
ST 111 kg	$186,88^{a}$	$184,60^{a}$	$178,05^{a}$	$172,88^{a}$	$167,04^{a}$
152 kg	$176,38^{a}$	$154,38^{a}$	$161,77^{a}$	$172,83^{a}$	$139,15^{a}$
203 kg	$138,52^{a}$	$120,30^{a}$	$126,01^{a}$	$139,50^{a}$	$126,40^{a}$
252 kg	$182,49^{a}$	$172,24^{a}$	$168,00^{a}$	$143,10^{a}$	$166,87^{a}$

abcde   Within each row, values with no common superscript differ significantly ($p < 0,05$).

The results indicate a linear type of relationship between the muscle temperature 10 hours post mortem and the toughness (shear force value) of the muscle. This relationship between muscle temperature 10 hours post mortem and shear force value was not as clear in the ST. The reason for this might be a result of the muscle temperature generally not being below 10°C 10 hours post mortem, thus no supposed cold shortening resulted (Table 4). With delayed chilling (3,3 and 8,9 °C versus -2,2 °C) of beef carcases, Aberle and Judge (1979) could not, however, find significant differences in shear force values and taste panel tenderness ratings.

When the shear force values were evaluated against the "highest acceptable value" of 110 N, it was found that the different carcase mass groups reached an acceptable value (LT cooked at 60 °C) at different chilling temperatures : both the 203 and 252 kg groups reached this value at chilling temperatures of 3 °C or above, the 152 kg group at a chilling temperature of 5 °C or above, and the 111 kg at a chilling temperature of 7 °C or above (Table 4; Figure 2). The additional toughening effect of cooking meat at a higher temperature (80 °C) could be seen from the results presented (Table 4), as no average shear force value reached an acceptable shear force value of lower than 110 N, although the tendency of a decline in shear force value with increasing chilling temperature and carcase mass was still evident (Table 4). These differences were not as clear-cut in the ST as in the LT, although the same tendencies were observed. In an experiment by Cliplef and Strain (1976), a taste panel gave as reason for preferring steaks from slow-chilled carcases to normally chilled carcases, 76 % of the time, as being improved tenderness. These observations were substantiated by shear force measurements (Cliplef & Strain, 1976). Joseph and Connolly (1977) also found an improvement in tenderness in the *M. longissimus dorsi* with slow-chilling, but not a notable improvement in the ST, which is in accordance with the results obtained in this experiment.

The results clearly indicate that the smaller carcases (possibly having a lower fat cover) chilled quicker than the carcases having a higher mass (possible higher fat coverage). Marsh, Lochner, Takahashi and Kragness (1980-81) have indicated that if lean beef carcases were to be chilled at a rate resembling that of fat carcases for the first 2-3 hours after dressing, the tenderness of the meat from the lean carcases would be significantly improved. The result of this experiment showed a toughening effect on the muscles (especially in the LT), regardless of the carcase mass. A progressive increase in shear force with an increase in chilling temperature (with a lower muscle temperature 10 hours post mortem) was found. Thus, the more rapidly a carcase is chilled, the tougher the muscles would be due to cold shortening. The reason for cold shortening was given by Bendall (1973) as being the lower activity of the calcium pumps at lowered muscle temperatures, thus an increasing Ca^{++} concentration in the sarcoplasm which would activate the contraction of muscles, providing sufficient energy (ATP) is still available.

Conclusion

Fig. 1 : The influence of carcase mass and chilling temperature on the temperature in the *M. longissimus thoracis* 10 hours post mortem

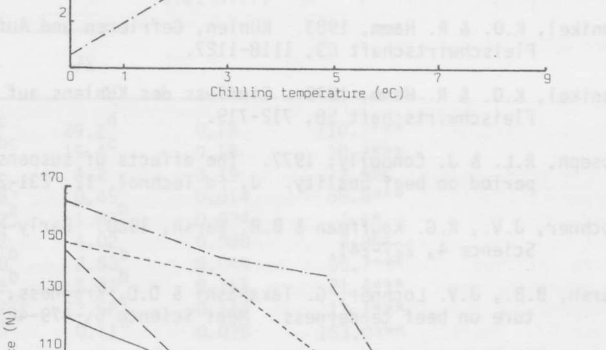
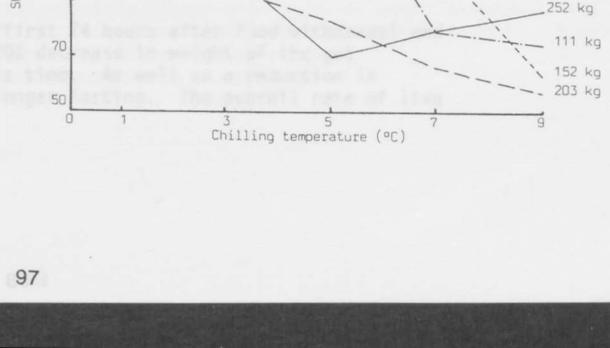


Fig. 2 : The influence of carcase mass and chilling temperature on shear force values in the *M. longissimus thoracis* cooked at 60 °C.



As the meat industry should try to supply the consumer with an optimum product, the meat industry should try to prevent this excessive toughening of the muscles. One way of doing this would be to regulate the chilling rate of carcases in such a way that the internal muscle temperatures do not fall below 10 °C 10 hours post mortem. Alternatively, all carcases that must be rapidly chilled should be electrically stimulated, as this procedure encourages the accelerated depletion of available muscle energy reserves, resulting in rigor mortis setting in before the muscle temperatures drop below 10 °C.

Table 5 : The influence of carcase mass on the muscle temperature reached 10 hours post mortem, and the shear force of the *M. longissimus thoracis* and *M. semitendinosus* at the different chilling conditions (Least Mean Square)

	A1:A2	A1:A3	A1:A4	A2:A3	A2:A4	A3:A4
Chilling Temperature:						
LT 0 °C	**	**	**	-	**	**
3 °C	-	*	**	*	**	**
5 °C	-	*	**	-	**	-
7 °C	-	**	**	**	**	**
9 °C	-	**	**	**	**	*
ST 0 °C	**	**	**	-	-	-
3 °C	-	**	**	*	**	*
5 °C	*	**	**	-	*	-
7 °C	*	**	**	**	**	*
9 °C	**	**	**	**	**	**
Shear force (N):						
60 °C:						
LT 0 °C	-	-	-	-	-	-
3 °C	-	-	-	-	-	-
5 °C	-	-	*	-	-	-
7 °C	-	-	-	-	-	-
9 °C	-	-	-	-	*	**
ST 0 °C	*	**	-	-	**	**
3 °C	*	-	-	**	-	**
5 °C	-	-	-	-	*	-
7 °C	-	-	-	-	-	-
9 °C	**	**	-	-	**	**
80 °C:						
LT 0 °C	-	-	-	-	-	-
3 °C	-	-	-	-	-	-
5 °C	-	-	-	-	-	-
7 °C	-	-	-	-	-	-
9 °C	-	-	-	-	-	-
ST 0 °C	-	-	-	-	-	-
3 °C	-	**	-	-	-	**
5 °C	-	-	-	-	-	-
7 °C	-	-	-	-	-	-
9 °C	-	*	-	-	-	*

* = P<0,05
** = P<0,01
Mass groups: A1 = 111 kg; A2 = 152 kg; A3 = 203 kg; A4 = 252 kg

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