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THE EFFECT OF CHILLING TEMPERATURES AND MODE OF SUSPENSION OF BEEF CARCASSES ON SARCOMERE LENGTH AND MEAT TENDERNESS

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OPSOMMING: DIE INVLOED VAN VERKOELINGSTEMPERATUUR EN HANGMETODE VAN BEESKARKASSE OP SARKOMEERLENGTE EN SNYWEERSTAND VAN SPIERE

Jong Afrikaner kruisrasosse wat op *ad lib.* voeding gehou is totdat die gewenste geskatte karkasmassas van 120 en 240 kg bereik was, is in die proef gebruik. Karkasse was in sye geskei – een groep sye het gedien as kontrole (hak-hangmetode) terwyl die eksperimentele sye aan die pelvisbeen gehang is en albei sye is aan een van vyf verkoelingstemperature tussen 0° en 9°C blootgestel. Monsters vir sarkomeertellings en snyweerstand is geneem van die *M. longissimus thoracis* en die *M. semitendinosus.* Sarkomeertellings was gemeet by 1 000 x vergroting en snyweerstand na gaarmaak by temperature van 60° en 80°C. Die 120 kg karkasse het vinniger verkoel en dus het die spiere 'n hoër snyweerstand en korter sarkomere as die van 240 kg karkasse gehad. Die wyse van hang het 'n besliste effek op vleistaaiheid gehad in soverre dat die pelvis-gehangde karkasse se spiere 'n laer snyweerstand en langer sarkomere gehad het, wat beskou kan word as sagter vleis vir die verbruiker. Die pelvis-hangmetode kan vir ten volle geïntegreerde vleisfabrieke aanbeveel word maar nie in die geval waar karkasse vervoer moet word vir verwerking nie. Optimale aanvanklike verkoelingstemperature ten einde sagte vleis te verseker is vir ligte (120 kg) karkasse tussen 7° en 9°C en vir die swaarde (240 kg) karkasse tussen 3° en 7°C.

SUMMARY:

Young Afrikaner crossbred steers were used for the experiment after being fed *ad lib* until a desired estimated carcass mass of 120 and 240 kg was reached. Carcasses were split into sides - one group of sides served as controls (hock hanging method) while the experimental sides were suspended by the pelvic bone and both sides were subjected to one of five chilling temperatures from 0° to 9°C. Samples for sarcomere counts and shear force determinations were taken from the *M. longissimus thoracis* and the *M. semitendinosus.* Sarcomere counts were made at 1 000 x magnification and shear force determined after cooking at temperatures of 60° and 80°C. The muscles from carcasses of 120 kg had a greater chilling rate and as a result had a higher shear force and shorter sarcomeres than the 240 kg carcasses. The mode of suspension had a definite effect on meat tenderness in that the pelvic suspended carcasses had a lower shear force and longer sarcomeres which could be interpreted as more tender meat to the consumer. The pelvic method of suspension can be recommended for fully integrated meat plants but not for plants where carcasses have to be transported for processing. Optimal initial chilling temperatures for light carcasses (120 kg) were between 7° and 9°C and for heavier carcasses (240 kg) between 3° and 7°C.

Meat quality can be influenced by a variety of factors of which the influence of initial chilling temperature on the *pre-rigor* carcass is an important facet. The muscle moving into *rigor mortis* shows a decrease in extensibility and can react to a cold stimulus by shortening. This is reflected in a reduced sarcomere length (Locker, 1959) which in turn causes an increase in fibre diameter. Locker (1959) grouped these sarcomere patterns according to lengths into four types – where type I is relaxed and type IV shows extreme shortening. Through the actin-myosin involvement in sarcomere contraction meat tenderness is adversely affected (Marsh & Leet, 1966).

Locker (1959) stated that on entering *rigor mortis* some muscles such as the *M. psoas major* are in a relaxed condition whereas other muscles like the *M. longissimus dorsi* show a variety of contraction patterns, from totally relaxed to fully contracted over the length of the same muscle. He also established a relationship between these sarcomere and muscle contraction patterns ranging from zero to 80 per cent shortening of the maximum length.

In 1963, Locker and Hagyard first recognised the effect of cold shortening on the *pre-rigor* muscle. Not all muscles are subject to this phenomenon, notably the "red" muscles of the pig which are affected to a lesser degree (Bendall, 1972). From this stage onward the practical effect of cold shortening on meat quality was more fully appreciated. In the literature reviewed no specific information however, was forthcoming on the

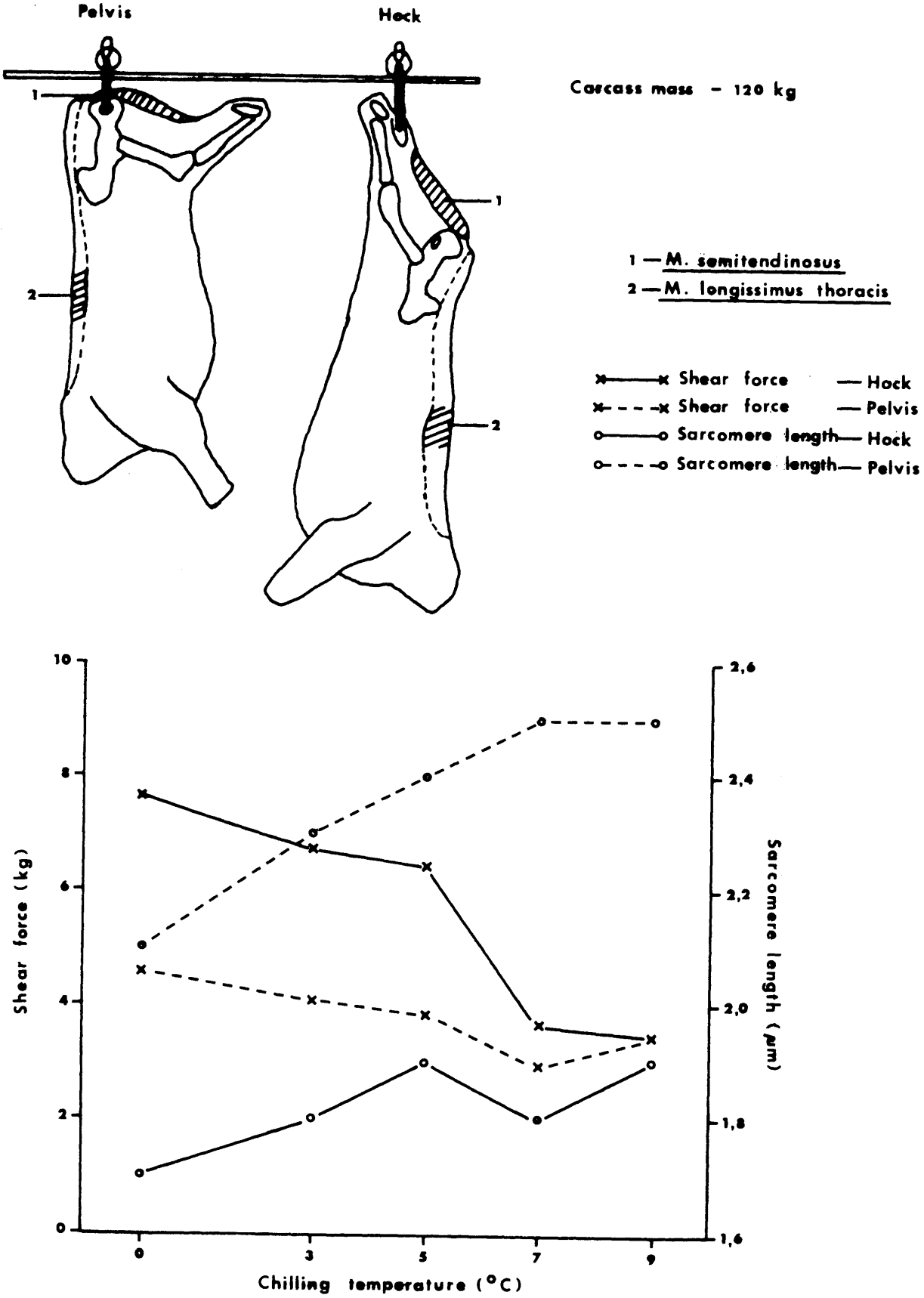

Fig. 1 *The effect of mode of suspension and chilling temperature on shear force and sarcomere length of* M. Longissimus thoracis *(2 days ageing and 60°C cooking temperature).*

effect of various low chilling temperatures on sarcomere length and meat tenderness in different carcass mass groups. However, Bouton, Harris, Shorthouse and Baxter (1973) used two temperatures (0° to 1°C and 15° to 16°C) in their mutton studies and this represented a large gap in degree centigrade. The present study was undertaken to assess whether possible differences in sarcomere length and meat tenderness occur when employing a series of initial chilling temperatures on two carcass mass groups.

Material and Methods

Forty young Afrikaner crossbred steers were used. The animals were kept in feeding lots on *ad lib.* concentrate feeding until they reached the desired mass. Two groups were selected, one to yield carcasses of approximately 120 kg and the other of 240 kg.

The captive bolt was employed for stunning and after bleeding and evisceration all carcasses were split into sides. These sides were kept in two specially designed identical chilling rooms, each of which can accommodate four sides at the same time. Sides were suspended in such a way that a stream of air moved over all the carcasses in a similar manner. The three controllable variables in the cold room were air temperature, velocity and humidity. The latter two parameters were kept constant in both rooms in accordance with trade practices in this country viz. air velocity at 0,75 m per second and relative humidity at 95 per cent. The third parameter was varied between 0°, 3°, 5°, 7° and 9°C. For a specific group of four carcasses at a particular temperature the two sides of a carcass were suspended in different positions – either the conventional hock position or the pelvic position by hanging through the *obturator foramen* (Fig. 1). Sides hanging in a similar manner were grouped together in one room. Both rooms were kept at identical chilling conditions.

The temperature of the *M. longissimus thoracis (M.l.t.)* and the *M. semitendinosus (M. st.)* were continually monitored during the 48-hour chilling period with thermocouples inserted into the muscles to a depth of 3 cm. Following a 48-hour period in the chill room the fat cover of all carcasses was judged according to a four point scale. After quartering between the 10th and 11th ribs the thickness of the subcutaneous fat was measured on the forequarter 2,5 cm lateral to the medial plane of the side. For the 120 and 240 kg carcasses respectively, the mean values for the fat cover were found to be 0,2 and 2,2 and for fat thickness 1,0 and 7,7 mm.

Samples were taken from the light area of the *M. st.* and the *M.l.t.* for sarcomere determinations and tenderness evaluation. According to the method of Hegarty and Naudé (1970), suitably sized samples were taken from the large specimens 48 hours post slaughter, homogenized in distilled water in an Ultra-Turrax blender until the individual fibres were separated with as little damage as possible, and mounted with a small pipette on a glass slide. Under a Zeiss photomicroscope with a reinforced light source and a *camera lucida* attachment giving a 1 000 x magnification on a flat surface, 25 individual fibres were measured for sarcomere length. Over an accurately measured distance of 10 cm the number of sarcomeres per fibre were counted.

To diminish the effect of ageing, muscle samples of approximately 200 g each were taken 48 hours post slaughter and were cooked in plastic bags for one hour without any addition of water. Two water baths were used, regulated at 60° and 80°C. Core samples with a diameter of 19 mm were then taken parallel to the fibre length. A minimum of six determinations on every cooked sample was made on the Warner Bratzler shear meter.

Results and Discussions

Mode of suspension

Sarcomere length

Locker (1959) developed the I-IV type division of sarcomeres where the types range from type I (3,7 to 2,4 μm; relaxed) to type IV (1,5 to 0,7 μm; extreme shortening). According to this grouping the sarcomere length of the *M.l.t.* in the hock suspended position (1,9 to 1,7 μm) remains on the verge of the "close to contraction" pattern (Type III; 1,8 to 1,5 μm) for the temperature range from 0° to 9°C (Table 1). Hock suspension compacts the vertebrae of the lumbar and sacral regions at their junction so allowing the muscles to contract (Hostetler, Landmann, Link & Fitshugh, 1970). This was illustrated by the mean sarcomere length of 1,8 μm for hock suspension compared to the relaxed 2,4 μm sarcomere length of the pelvic suspension. The latter constitutes a reversal of the former effect by not permitting the *M.l.t.* to contract to the same degree due to a straightening of the spinal column (Hostetler, *et al.*, 1970). The statistical difference was also highly significant ($P<0,01$, Table 8).

According to Hostetler, Link, Landmann and Fitshugh (1972) the minimum sarcomere length for intact beef muscle in hock suspended carcasses is approximately 2,0 μm. This possibly holds true for carcasses in excess of 200 kg. For carcasses of 120 kg, as in this experiment, sarcomere length showed a mean of 1,8 μm for the *M.l.t.* This could be attributed to the lack of a more complete fat covering, as in heavier carcasses, and the more rapid reaction to the cold stimulus of the lower mass presented to chilling (Parrish, Young, Miner & Andersen, 1973).

Table 1

Sarcomere length (μm) of the M. longissimus thoracis

Carcass mass (kg)	Suspension mode	Chilling Temperature (°C) 0°	3°	5°	7°	9°	Mean (mass) (both modes)	Mean (suspension mode) (both masses)
120	Hock	1,7	1,8	1,9	1,8	1,9	2,1	1,8
	Pelvis	2,1	2,3	2,4	2,5	2,5		–
240	Hock	1,8	1,9	1,8	1,8	1,8	2,4	–
	Pelvis	2,4	2,6	2,5	2,5	2,5		2,4
Mean (temperature)		2,0	2,2	2,2	2,2	2,2		

Table 2

Sarcomere length (μm) of the M. semitendinosus

Carcass mass (kg)	Suspension mode	Chilling Temperature (°C) 0°	3°	5°	7°	9°	Mean (mass) (both modes)	Mean (suspension mode) (both masses)
120	Hock	1,8	2,0	2,0	2,1	2,0	2,2	2,0
	Pelvis	2,1	2,3	2,4	2,5	2,5		–
240	Hock	1,9	1,9	2,0	2,0	2,0	2,3	–
	Pelvis	2,5	2,6	2,7	2,6	2,6		2,5
Mean (temperature)		2,1	2,2	2,3	2,3	2,3		

The *M. st.* did not react to the effects of the mode of suspension to the same degree as the *M.l.t.* but there nonetheless was a highly significant difference ($P<0,01$) in sarcomere length between the two methods (Table 8). These findings agree with those of Joseph and Connolly (1977) which also show the same effect of suspension method on sarcomere length although no definite statistical differences were indicated in their study. Hostetler, Link, Landmann and Fitshugh (1973) noted that the *M. st.* is not a suitable muscle to be used for sarcomere studies as it does not react favourably to methods inducing extension of the fibres. In the present study however, the *M. st.* reacted significantly to the mode of suspension as is recorded above. The mean sarcomere length in pelvic suspended carcasses was 2,5 μm and in hock suspended carcasses 2,0 μm (Table 2).

For all temperatures employed the sarcomere lengths in both muscles were shorter in the hock than in the pelvic suspension, as can be seen in Tables 1 and 2.

Table 3

Shear force (kg) of M. longissimus thoracis *cooked at 60°C*

Carcass mass (kg)	Suspension mode	Chilling Temperature (°C) 0°	3°	5°	7°	9°	Mean (mass) (both modes)	Mean (suspension mode) (both masses)
120	Hock	7,64	6,74	6,45	3,64	3,46	4,68	4,95
	Pelvis	4,54	4,08	3,85	2,93	3,43		–
240	Hock	5,83	4,74	3,23	3,76	4,03	3,87	–
	Pelvis	3,83	3,93	2,64	3,12	3,60		3,60
Mean (temperature)		5,46	4,87	4,04	3,36	3,63		

Table 4

Shear force (kg) of M. semitendinosus *cooked at 60°C*

Carcass mass (kg)	Suspension mode	Chilling Temperature (°C) 0°	3°	5°	7°	9°	Mean (mass) (both modes)	Mean (suspension mode) (both masses)
120	Hock	6,07	5,12	5,30	5,38	5,35	6,12	5,61
	Pelvis	6,47	5,77	5,31	5,04	5,29		–
240	Hock	6,60	5,75	5,83	4,96	5,74	5,72	–
	Pelvis	6,11	5,86	5,70	4,83	5,77		5,62
Mean (temperature)		6,31	5,63	5,54	5,05	5,54		

Shear force

At both cooking temperatures (60° and 80°C) and at chilling temperatures up to 7°C (Tables 3 and 5) core samples from the *M.l.t.* were more tender from the pelvic suspension than from the hock position in spite of sarcomere length differences at all temperatures. More tender meat can be expected from muscles with longer sarcomeres (Herring, Cassens & Briskey, 1965), but Hostetler, *et al.* (1972), on the other hand, postulated that sarcomere length alone is not a precise index of tenderness variations between animals as numerous other factors must also be considered. These are circumstances, however, when sarcomere length can be primarily related to tenderness such as when a muscle is excised *pre-rigor* (Marsh & Leet, 1966, and Herring, Cassens, Suess, Brumgardt & Briskey, 1967). MacBride and Parrish (1977) felt that there is only a small relationship between sarcomere length and tenderness and that the effect of myofibril fragmentation has a greater influence on the tenderization of aged muscle than does sarcomere length.

Table 5

Shear force (kg) of M. longissimus thoracis *cooked at 80°C*

Carcass mass (kg)	Suspension mode	Chilling Temperature (°C) 0°	3°	5°	7°	9°	Mean (mass) (both modes)	Mean (suspension mode) (both masses)
120	Hock	15,79	13,47	11,10	7,69	6,26	9,35	10,06
	Pelvis	9,80	9,59	7,86	5,33	6,60		–
240	Hock	13,15	10,29	9,68	6,34	6,82	7,71	–
	Pelvis	6,56	6,90	5,60	4,96	6,84		7,00
Mean (temperature)		11,33	10,06	8,56	6,08	6,63		

Table 6

Shear force (kg) of M. semitendinosus *cooked at 80°C*

Carcass mass (kg)	Suspension mode	Chilling Temperature (°C) 0°	3°	5°	7°	9°	Mean (mass) (both modes)	Mean (suspension mode) (both masses)
120	Hock	8,58	8,47	8,17	7,93	7,66	8,03	7,90
	Pelvis	8,88	8,67	7,58	7,17	7,16		–
240	Hock	8,37	7,90	7,71	6,57	7,65	7,46	–
	Pelvis	7,72	7,56	7,36	6,54	7,26		7,59
Mean (temperature)		8,39	8,15	7,71	7,05	7,43		

In this study the effect of ageing was deliberately minimized by using the samples at two days post slaughter.

Whilst the mode of suspension in the case of the *M.st.* had a definite effect on sarcomere length it showed no effect on the shear force (Tables 4 and 6). Table 8 illustrates no statistical significance for the values of this muscle. By comparison Joseph and Connolly (1977) found a slight but significant effect of the mode of suspension on the shear force values.

Temperature

The time taken by carcasses to cool to 19°C at various chilling temperatures are recorded in Table 7. As expected the 240 kg carcasses which also had the greater fat covering had a slower cooling rate than the leaner 120 kg carcasses. The different cooling rates shown between the two muscles are due to their respective anatomic positions.

Table 7

Time lapse (h) post mortem *to reach 10°C*

Carcass mass (kg)	Muscle	Chilling temperature (°C) 0°	3°	5°	7°	9°
120	M. st.	9,60	10,25	12,00	15,18	21,72
	M.l.t.	5,23	5,63	6,00	7,83	10,38
240	M. st.	13,49	16,31	19,25	22,75	43,00
	M.l.t.	8,34	9,04	11,13	14,35	19,63

Sarcomere lengths

The values obtained for sarcomere lengths of the *M.l.t.* as well as the *M. st.* at 0°C were different from readings at 3°, 5°, 7° and 9°C. Therefore, at 0°C sarcomere lengths are shorter than at the other upward ranging temperatures (Tables 1 and 2). No actual differences in sarcomere lengths were noted from 3° to 9°C (Table 7).

Chilling rate had a serious effect on meat texture when applied too rapidly in the *pre-rigor* condition before muscle pH has dropped below 6,2 (Bendall, 1972). According to Locker and Hagyard (1963) maximum muscle contraction of 48 per cent occurs at 0°C and between 14° to 19°C there is a very small reaction (<10 per cent). Interpretation of sarcomere length/temperature relationship would be less complicated if sarcomere length, within limits, responded in an orderly manner to temperature increases or decreases, but this would be biologically improbable. In this study it was found that sarcomere length was at its shortest at 0°C but between the range of 3° to 9°C no statistically significant differences in sarcomere length could be established (Table 8).

Hostetler *et al.* (1970) stated that it is the quantity of actomyosin formed and not so much sarcomere length that will have an influence on tenderness In 1972 Hostetler *et al.* also established that sarcomere length contributes only 12 per cent to the variation in tenderness between muscles. This can explain the reason why sarcomeres appear to be in the relaxed state while the shear force values indicate a reasonable degree of toughness.

Shear force

In Tables 3 to 6 the mean shear force values for the *M.l.t.* and *M. st.* are given for cooking temperatures of 60° and 80°C. The effect of 0°C chilling temperature on the *M.l.t.* differed highly significantly ($P<0,01$) from the effect at 5°, 7° and 9°C (Table 8). As the sarcomere lengths were also shorter at this temperature and as sarcomere length is purported to be linked to tenderness (Herring, *et al.*, 1965, and Hostetler, *et al.*, 1972) a higher shear force can be expected at 0°C, as indeed was the case. The shear force value of the *M.l.t.* at 3°C also differed from that at 7°C and 9°C (Table 8) even though no statistically significant differences in sarcomere lengths at these temperatures were found.

In the *M. st.* the same pattern occurred in the sense that the shear force value at 0°C differed from those at 3°, 5°, 7° and 9°C. According to Hostetler *et al.* (1973) the *M. st.* is preferred for studies on sarcomere lengths and tenderness on account of its optimal orientation of fibres but they found this muscle not very sensitive to experimental treatments. The findings of the present study are therefore in agreement with those of the latter authors. The even morphology could have its advantage in the lower variability within the muscle and this is illustrated by the lower coefficients of variation in the *M. st.* (5 to 15 per cent) as compared to those of the *M.l.t.* (8 to 35 per cent).

Findings in this experiment were that while the *M.l.t.* reacted very differently to the two cooking temperatures (60° and 80°C) by almost doubling its toughness from one temperature to the other (Tables 3 and 5), the *M. st.* did not react to nearly the same extent. While the *M. st.* tended to have a higher shear resistance than the *M.l.t.* at 60°C it was on par or slightly lower at 80°C cooking temperature (Tables 4 and 6). Differences in connective tissue content and composition were most probably the contributing factors to this discrepancy in shear force values between the two muscles at different cooking temperatures. According to the results of Boccard, Naudé, Cronjé, Smit, Venter & Rossouw (1978), the collagen content of the *M. st.* in young bulls and steers was 88 per cent higher than that found in the *M.l.t.*

Mass

Sarcomere lengths

Mass did not affect sarcomere length in the case of the *M.l.t.* (Table 8). The *M. st.*, however, showed an interaction between mass x suspension and while mass had no effect on sarcomere length in the vertical suspended carcass, the sarcomere values were greater in the 240 kg carcasses than in the 120 kg carcasses in the case of pelvic suspension. Table 8 shows a highly significant interaction of mass x suspension in sarcomere length for the *M. st.* which is most probably due to the reduced effect of chilling on the 240 kg carcasses with the totally relaxed sarcomere pattern (2,5 μm).

Shear force

The effect of longer sarcomere length can be related to the shear force values. The readings of the *M.l.t.* showed a 4 : 5 kg ratio in favour of the 240 kg carcasses at a cooking temperature of 60°C while at 80°C cooking temperature, the ratio was 8 : 9 kg also in favour of the 240 kg carcasses (Tables 3 and 5). Cooking temperature had a very pronounced influence in the case of the *M.l.t.* where it doubled in shear force resistance from 4 to 8 kg. With the *M. st.* the difference was not as marked as it differed at a ratio of 6 : 8 between 60° and 80°C. (Tables 4 and 6.) There was no statistically significant effect of mass for *M. st.* values. Giles (1969) studied the effect of two cooking temperatures (60° and 70°C) on four beef muscles and could not detect any significant effects of the treatment on the ultra-structure of the fibres. He found, however, that with heating to 70°C the myofibrils were disrupted to a greater extent than at 60°C and that the sarcomeres showed a very noticeable shortening at 70°C. Contraction of the sarcomeres with heat treatment could well influence the shear force resistance of a particular muscle.

Conclusions

Observations in this experiment showed that carcasses with a low mass, due to its greater chilling rate, have higher shear force and shorter sarcomere length values of their muscles than carcasses with a larger mass.

As initial chilling temperature was increased from 0° to 9°C so the shear force decreased for both the *M. longissimum thoracis* and the *M. semitendinosus* while no significant changes in sarcomere length were noted between chilling temperatures of 3°C and 9°C. The sensitivity of sarcomere length to lower initial chilling temperatures seemed to be less than that reflected in muscle toughening.

Method of suspension has a pronounced effect on meat toughness in that the muscles from pelvic suspended carcasses have a lower resistance to shearing and have longer sarcomeres. The favourable effect of pelvic suspension on shear force values and sarcomere length, as factors affecting tenderness, can be given consideration in integrated meat processing plants where all the stages

Table 8

Analyses of variance of sarcomere length (μm) and shear force (kg) values of two beef muscles

Muscle	Parameter	C.V. %	F-Values							L.S.D. (Temperature –°C)									
			A (mass)	B (temperature)	C (suspension)	A x B	A x C	B x C	A x B x C	0:3	0:5	0:7	0:9	3:5	3:7	3:9	5:7	5:9	7:9
M. longissimus thoracis	Sarcomere length	8,48	1,51	3,39 *	226,69 **	1,35	1,58	0,53	0,31	*	**	**	**						
	Shear force (60°C)	32,62	6,78 *	6,14 **	18,47 **	2,35	2,26	1,65	0,59		**	**	**		**	*			
	Shear force (80°C)	35,02	5,99 *	8,86 **	20,88 **	0,92	0,00	2,58	0,06		*	**	**		*	**	*		
M. semitendinosus	Sarcomere length	5,52	15,71 **	7,59 **	328,62 **	3,26 *	22,09 **	0,18	0,47	**	**	**	**						
	Shear force (60°C)	15,13	1,22	4,50 **	0,00	0,60	0,44	0,29	0,29	*	*	**	*						
	Shear force (80°C)	15,92	4,17 *	3,03 *	1,27	0,47	0,02	0,08	0,30			**	*		*				

* $P < 0,05$
** $P < 0,01$

from slaughtering to final processing is carried out under the same roof. The superior quality of the final product will merit this change-over. Due to the unusual shape of the *post rigor* carcass following this method of suspension it would not be practical to use these carcasses in non-intergrated plants should transport be involved.

It can be concluded that chilling temperatures from 0° to 5°C can have a marked shortening and toughening effect on muscles of the lighter carcasses and that temperatures between 7° and 9°C will be more effective in avoiding this problem. The heavier carcasses, through the advantage of mass and fat covering, can be chilled at temperatures from 3° to 7°C without any serious detrimental effect on tenderness.

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