ELECTRICAL STIMULATION IN COLD SHORTENING

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Abstract

*This experiment was designed to show whether delayed high voltage stimulation (ES) is more beneficial than no stimulation (NS) to secure tenderness under circumstances where rigor conditions are dficult to control due to variations in carcass size, fatness and/or chilling capacity. Ten carcasses were split during slaughter the left sides were stimulated at 45 min post-mortem for 45 s, and the right sides were left unstimulated. The carcass sides were then chilled at a medium chilling rate. Sarcomere length measurements confirm that there was neither cold nor heat shortening in the M .longissimus (LD). LD from ES sides aged for 2 days was more tender than non-stimulated LD (NES), although rolonged ageing eroded the advantage of ES to a non-significant advantage after 14 days. Initial tenderness diferences coincided with lower 24 h calpain activity, suggesting an early onset of proteolysis and ageing (tenderisation). In contrast to conventional early ES, delayed ES, appears to be beneficial for the early development of tenderness without too much interference with enzyme. Myofibril fragment length (MFL) was a good indicator of the development of tenderness during prolonged ageing but not for the early post-mortem variation in tenderness. No colour (L *,a *,b *) diferences, occurred due to stimulation treatment, while drip loss was slightly higher at 24 h post-mortem for ES meat.*

Key words: voltage stimulation, carcass size, fatness capacity, chilling capacity

INTRODUCTION

The historical reason for the development of electrical stimulation was the acceleration of post-mortem glycolysis so that when the muscle entered rigor it was prevented from excessive shortening (Swatland,1981). The electrical current causes the muscle to contract, thereby increasing the rate of glycolyses accompanied by a rapid decline in pH. More recent work has focused on other effects of stimulation that contribute to meat quality.

These effects are described as either the physical disruption of the myofibrillar matrix (Ho, Stromer, Rouse & Robson, 1997) or the acceleration of proteolysis (Uytterhaegen, Claeys & Demeyer, 1992). After slaughter,the longissimus has low to intermediate shear force values (probably tender), (Wheeler & Koohmaraie, 1994)

Rigor development induced changes increase its shear force. Maximum toughness is observed between 12 and 24 h post-mortem followed by post-mortem tenderisation caused by enzymatic degradation of myofibrillar, cytoskeletal and associated proteins. Current data indicates that cysteine proteases, particularly calpains (and associated calpastatin), are at least partly responsible for the degradation of these proteins. The variation

in tenderness, due to the development of *rigor* (peak toughness), is related to the conditions (pH and temperature) under which the muscle fibres enter rigor and subsequently, settle into rigor mortis when all supplies of ATP are exhausted (Devine&Hopkins, 2003). Early and recent studies show that minimal shortening occurs at about 12–15 °C resulting in optimum tenderness (Locker&Hagyard, 1963, Tornberg, 1996). Below this temperature, pre-rigor contracture takes place until rigor is completed resulting in higher rigor toughness (Tornberg, 1996). Above 12 –15 ° C the rigor contracture (termed heat shortening when above 15 °C) also has a concurrent reduction in ageing potential leading to less tender meat both at rigor mortis and when fully aged (Devine, Wahlgren&Tornberg, 1999). According to Simmons, Singh, Dobbie and Devine (1996) and Drans Weld, Etherington and Taylor (1992), the higher initial tenderness and lack of ageing potential is, in conjunction with the greater autolysis of calpains at high temperatures, when the pH decreases below 6 –6.2. Under these conditions, calpastatin activity also declines but not at the same rate (Hwang&Thompson,2001). A lower initial tenderness (after 1 day) even occurred when heat shortening was prevented (Devine et al.,1999). For these reasons, the benefit with regard to advanced proteolysis described by Uytterhaegen (1992), appears to apply under rather narrow ranges of pH and temperature decline rates.

These results explain in part the reasons that researchers and abattoirs have various success rates with electrical stimulation and is the reason that the pH/temperature window was one of the initial specifications for the 'carcass pathways ' grading scheme. This scheme is aimed at minimizing the meat tenderness variation in the carcass in Romania. In smaller abattoirs, which are fairly high in number in North Romania, chilling capacity might not be such that all carcasses enter rigor under the ideal pH/temperature window due to limited infrastructure capabilities. The effect of this on meat tenderness and other quality characteristics is probably further enhanced by a variation in carcass size and often a lack of knowledge on the utilisation of electrical stimulators. The latter relates to timing and the duration of electrical input and also applies to larger highly commercial abattoirs and is probably a result of outdated knowledge.

In this trial, the effect of delayed stimulation of larger carcasses under sub-optimal chilling conditions was compared with no stimulation.

MATERIALS AND METHODS

Animals and treatments

Ten intact bulls were raised under feedlot conditions (11 MJ ME/kg energy and 13.5% crude protein, DM) over 122 days to a final average

weight of 518 kg. At this point, most of the animals had reached the optimum fat cover 2;6 mm fat, but were much heavier than the average carcass on the local market (296 vs.208 kg). Animals were slaughtered at the small private facility under controlled conditions.

After carcass dressing (ca.45 min post-mortem), one side of the carcass was electrically stimulated for a duration of 45 s (400 V peak, 5 ms pulses at 15 pulses/s) and the other was left non-stimulated. Carcasses were chilled directly after dressing at room temperature before loading at 0 –4 °C. As the chilling capacity was limited due to the size of the rooms and the capacity of the system, the initial chilling rate was relatively slow (Table 3). The duration of chilling was 18 h where a deep bone temperature of ca.10 °C was reached.

Post-mortem sampling and storage

The pH and temperature of the M.longissimus (LD) of both sides were measured with a digital handheld meat pH meter between the 11th and 12th rib every hour for 4 h post-mortem, and thereafter at 24 h.

The LD of both sides were sampled. Samples were vacuum packaged and aged at 2 +/- 2 °C for 2 days and 14 days post-mortem. At the specified time, samples were removed for chemical measurements, sarcomere length, myofibrillar length or water holding capacity and colour. Sub-samples were frozen for subsequent shear force and sensory evaluation.

Quantification of calpain, m-calpain and calpastatin activities

Samples removed for enzyme studies (24 h post-mortem) were frozen in liquid nitrogen and preserved at -70 °C. Calpastatin in combination with calpain and m-calpain were extracted from 5 g of the LD frozen samples as described by Dransfield (1996) and separated by means of the two-step gradient ion-exchange chromatography-method according to Geesink and Koohmaraie (1999). Calpain activity in eluates containing both calpain and calpastatin was estimated from calpastatin measurements before and after heating of the eluates. Calpain assays were determined using azo-casein as substrate according to Dransfield (1996). The use of azocasein eliminates the problem of background absorbance of non-specific proteins in the extracts. One unit of calpain activity was defined as an increase in absorbance at 366 nm of 1.0 per hour, at 25 °C. One unit of calpastatin activity is defined as the amount that inhibited one unit of m-calpain activity. Data were expressed as units per gram of muscle.

Sarcomere length and myofbril fragment length (MFL)

The sarcomere lengths were measured using a Video Image Analyser after preparation of a fresh sample (24 h postmortem), according the method of Hegarty (1970), by using distilled water instead of Ringer Locke solution (Dreyer 1979). The myofbril fragment length (MFL) of meat aged for 2 and 14 days postmortem was measured in samples that were homogenised with

a blunt blade. The myofbril fragment lengths were measured by means of a Video Image Analyser. The extraction procedure was conducted as described by the method of Culler, (1978) as modifed by Heinze(1994).

Water-holding capacity and drip loss of fresh meat

The water-holding capacity was determined by calculating the ratio of meat area and liquid area after pressing a 400–600mg fresh meat sample (24 h) on a flter paper (Whatman 4) sandwiched between two Perspex plates, and pressed at a constant pressure for 1min according to the method described by Irie (1996). The areas were measured by means of a Video Image Analyser.

Fifty grams of fresh meat (24 h) sliced into cubes of 10x10x20mm were hung on a pin inside a sample bottle (200ml) taking care that the meat did not touch the sides of the bottle. Duplicate samples were stored for 3 days at 4+/-2 °C. The amount of drip measured as the diference between the sample mass before and after was expressed as a percentage of the starting mass.

Meat colour

Meat colour was measured with a Minolta meter (Model CR200, Japan) on fresh samples (24 h post-mortem).

Two freshly cut steaks of 15mm each were allowed to bloom for at least 30 min at chiller temperatures (4+/-2 °C) before recording. Three recordings were performed on each steak. The data was obtained as L* (dark to light); a* (green to red) and b* (blue to yellow) values from which the psychological attribute of saturation (S – measures intensity of the red colour) was calculated MacDougall (1977).

Trained sensory panel evaluation and Warner Bratzler shear force measurements

Frozen samples previously aged for 2 or 14 days were processed into 30mm steaks by means of a band saw before being thawed at 4 °C for 24 h and prepared according to an oven-broiling method using direct radiant heat (AMSA, 1978). The steaks were broiled at 260 °C (pre-set) to 70 °C internal temperature, while drip losses were collected and included in calculations of total cooking loss (drip+evaporation).

A trained sensory panel consisting of ten members evaluated each cooked sample according to tenderness, first bite, amount of residue (connective tissue), initial and sustained juiciness, and aroma and flavour intensity, on a scale of 1–8 (8, extremely tender, no residue, juicy, intensive flavour and aroma; 1, extremely tough, residue abundant, dry or bland). Meat cubes were served warm to panellists, while additional steaks were left at room temperature (18 °C), processed into 12.5mm cores along the fibre and sheared perpendicular to the fibre with a Warner Bratzler shear device

attached to an testing unit. Shear force was measured as the peak force (Newton) average for eight cores per sample.

Statistical analysis

The data of sensory analysis, cooking loss, shear force resistance MFL were subjected to analysis of variance for a split-plot design with the two stimulation treatments as whole plots and the two ageing periods as sub-plots. Means for the interactions between the subplot and whole plot were separated using Fisher's protected t-test least significant diference (LSD) at the 5% level (Snedeco 1980). Sources of variation for the rest of the data collected that were only involved in stimulation efects, were investigated by oneway.

RESULTS

The carcasses in this trial were very large compared to the average carcass weight normally processed in Romania. Combined with the limited chilling capacity of the cold rooms, the carcass and specific muscle chilled relative slowly (Table 3). As the stimulated and nonstimulated sides were in two diferent chiller rooms, not running at exactly the same specifications, the nonstimulated sides chilled slightly faster than the stimulated sides. The pH decline was significantly faster for the stimulated sides for at least the first 4h post-mortem. Due to a slight lag in pH decline between 2 and 3 h postmortem, it can be predicted that pH 6 was reached between 27 and 29°C for the stimulated sides. This point was out of the time range for the non-stimulated sides but the predicted temperature would have been close to 22 °C.

Both electrical stimulation (ES) and ageing significantly improved the tenderness of the LD as measured by means of sensory evaluation (three attributes) and shear force resistance (Table 1). Stimulated meat at 2 days post-mortem was almost 18N (SF) or almost 1 sensory unit ($p<0.05$) more tender than non-stimulated meat. These diVerences were reduced to 8N and 0.4 sensory unit ($p>0.05$) after an additional 12 days of ageing.

Myofibril fragmentation was significantly influenced by both ageing ($P<0.001$) and ES (PD0.048). Prolonged ageing decreased the myofibril fragment length but stimulated carcasses had longer MFL's on average than those non-stimulated. Although the interaction was not significant, Fig. 3 indicates that the diference between stimulated and non-stimulated MFL measurements became evident only with prolonged ageing. Shorter MFL's were found with non-stimulated samples after 14 days than with stimulated samples ($P<0.05$), which coincided with the higher amount of ageing as shown by the diference in SF and sensory tenderness over time.

Non-stimulated sides had slightly shorter sarcomere lengths, measured at 2 days post-mortem, than stimulated sides (PD0.09). The diference was relatively small (ca. 0.07 _m; 3.6%) and actual values varied between a minimumD1.75 and a maximumD1.97 _m.
Colour attributes measured as L*, a* and b* were not significantly afected by ES, while drip loss was significantly greater for stimulated 2 day samples (P<0.05).

Table 1

The efect of electrical stimulation and post-mortem ageing on sensory quality, cooking properties, shear force resistance and myofibril fragment lenght

Nr. crt.		Electrical stimulation				Post mortem ageing				Interaction
	Sensory characteristics (1 – 8)[b]	yes	no	SEM[a]	P value	2 days	14 days	SEM	P-value	P-value
1	Aroma intensity	5,7	5,7	0,0429	0,248	5,5	5,8	0,1245	<0,01	0,803
2	Initial juiciness	5,7	5,8	0,0432	0,281	5,8	5,8	0,0636	0,913	0,331
3	Sustained juiciness	5,7	5,8	0,0343	0,287	5,8	5,8	0,0577	0,856	0,176
4	First bite	5,5	4,9	0,1215	0,009	4,3	6,1	0,1225	<0,001	0,111
5	Owerall tenderness	5,5	4,9	0,1294	0,007	4,3	6,2	0,1166	<0,001	0,009
6	Residual conective tissue	5,7	5,1	0,1045	0,008	4,8	6,4	0,1124	<0,001	0,119
7	Flavour intensity	60	5,7	0,0525	0,155	5,8	6,1	0,0345	<0,001	0,369
8	Cooking loss %	23,1	22,4	0,555	0,392	22,4	23,1	0,313	0,182	0,953
9	Share Force N	41,1	53,8	0,184	<0,001	60,9	34,4	0,196	<0,001	0,075
10	Myofibril fragment lenght	30,6	28,1	0,773	0,048	34,1	24,6	0,696	<0,001	0,291

a Standard error of means

b Score 1, extremely bland for aroma and flavour intensity; extremely tough for first bite and overall tenderness, extremely abundant for residual connective tissue and extremely dry for juiciness. Score 8, extremely intense for aroma and flavour intensity; extremely tender for first bite and overall tenderness, practically devoid of residual connective tissue and extremely juicy for juiciness.

DISCUSSIONS

In this study, delayed stimulation improved the muscle tenderness (both SF and sensory) of early post-mortem meat, which was sustained in actual values (but not signiWcantly) with prolonged ageing up to 14 days (Figs. 1 and 2). This was achieved under conditions where cold shortening was not likely to take place, as rigor had set in at relatively high temperatures even for non-stimulated carcasses (Table 3). Calpastatin and calpain activity was measured only after rigor mortis (24 h) in the present study and not pre-rigor. Therefore, the progress of these systems could not be followed under the diferent rigor conditions, but the post rigor values

could be compared. Higher rigor temperatures (pH 6), due to the accelerated glycolysis by stimulation or by means of other manipulations, are reported to cause earlier activation of calpain and/or calpastatin activity (Rhee & Kim, 2001) and faster degradation of myoWbrillar proteins (titin, nebulin, desmin, troponin-T; Rhee, 2000). This leads to the earlier decrease of enzyme activity (Hwang 2001). In the present trial only calpain was significantly (PD0.028) afected, which also resulted in higher calpastatin-calpain ratios for stimulated sides. Similar results were reported by Hwang (2001b), reported lower 24 h levels of both calpastatin ($p<0.05$) and calpain ($P>0.05$) with high temperature rigor conditions. According to Hwang and Thompson (2001a) and earlier studies by Ducastaing (1985) and Uytterhaegen et al. (1992), therefore, early activation of the calpain system appears to be an important mechanism by which electrical stimulation improves meat tenderness in general or at least early postmortem. Relating specific SF or sensory values to consumer satisfaction is not precise but it gives an indication of threshold values to categorise samples as acceptable or not. Shackelford, Morgan, Cross, and Savell (1991) reported threshold values of 4.6 and 3.9 kg for "retail" and "food service" beef, respectively (samples were prepared according to the same speciWcations as those used in the present study). In practice, the early development of tenderness for ES sides means that 2 day ES samples might not be acceptable to consumers but both 14 day ES and non-stimulated samples would be. However, if 3.9kg is used as the threshold, ES sides could reach that point 5– 7 days earlier than non-stimulated sides.

The lower rate of tenderisation (diference between day 2 and 14 SF values) of the stimulated sides corresponds with the lower calpain activity and also the higher calpastatin-calpain ratio (Table 2). This wasconformed by Hwang and Thompson (2001a), while Devine et al. (1999); Devine et al. (2002) and Geesink 2001) reported similar findings with diferent stimulation inputs or high rigor (pH 6) temperature scenarios. While the study of Hwang and Thompson (2001a) and the present study found that stimulated meat still had an advantage (or compared favourably) over non-stimulated meat despite the difrence in ageing rate, Geesink et al. (2001) reported tougher aged meat when high electrical inputs were applied. In addition, Devine et al. (1999, 2002) reported tougher aged meat when rigor temperature was 35 °C compared to 15–18 °C. The conditions of the present trial difred from these scenarios in that rigor temperatures for the two treatments were not that far apart and also lower than the 35 °C extreme reported by two studies of Devine. Furthermore, in the present trial, stimulation was delayed which was apparently advantageous for the earlier onset of ageing (tenderisation) through the processes discussed above. Yet, the detrimental efect of a high rate of glycolysis early post-mortem and very

high rigor temperatures experienced with conventional stimulation was prevented (Hwang & Thompson, 2001a).

Table 2

Twenty-four hour calpain and calpastatin activities, sarcomere length, colour and moisture characteristics for the two stimulation treatments

Nr. crt.		Electrical stimulation			
		yes	no	SEM[a]	P - value
1	Calpastain activity[b]	1,90	2,04	0,127	0,452
2	μ-Calpain activity[b]	1,29	1,76	0,125	0,028
3	m-Calpain activity[b]	0,96	1,01	0,0259	0,199
4	Calpastain/μ-Calpain activity[b]	1,52	1,18	0,075	0,012
5	Calpastain/ m-Calpain activity[b]	2,01	2,05	0,127	0,841
6	L*	41,1	39,9	0,595	0,209
7	A*	15,1	14,5	0,494	0,383
8	B*	7,8	7,1	0,301	0,178
9	Saturation $(a^2+b^2)^{-2}$	16,8	16,0	0,539	0,283
10	Sarcomere lenght, mm	1,92	1,85	0,028	0,090
11	Drip loss, %	2,53	1,88	0,185	0,034
12	WHC	0,38	0,40	0,039	0,223

a Standard error of means; b Units per gram of fresh muscle

Table 3

Muscle pH and temperature for the two stimulation treatments

Nr. crt.		Electrical stimulation			
		yes	no	SEM[a]	P - value
1	Ph (hours postmortem)				
2	1 h (15 min after stimulation)	6,28	6,57	0,0260	<0,001
3	2	6,05	6,29	0,0241	<0,001
4	3	5,98	6,15	0,0310	0,006
5	4	5,96	6,08	0,0228	0,008
6	24	5,88	5,83	0,0361	0,081
7	Muscle tempoerature, °C, (hours postmortem)				
8	1	34,6	34,9	0,1080	0,223
9	2	31,2	33,2	0,0578	0,035
10	3	27,0	28,4	0,372	0,030
11	4	24,1	25,5	0,538	0,108
12	24	7,7	7,2	0,344	0,264

a Standard error of means

In addition, Hwang et al. (2003) also believe that the optimum pH-temperature combination for rigor development difers between in vitro (Devine et al., 2002, 1999) and in situ conditions such as the present trial and those of Hwang and Thompson (2001a, 2001b) due to a gradient in temperature experienced under in vitro conditions. In the present study, the

diference in pH decline was not as high as could be expected from stimulated and non-stimulated sides. For instance, in the study of Hwang and Thompson (2001a) pH 6 was reached at 35.3 and 20.7 °C for stimulated and non-stimulated sides, respectively, compared to 28 and 22 °C for the present trial. In addition, the final pH values for both treatments were almost 0.4 units lower than in the present study. Even the slower chilling rate due to the size of the carcasses and the chilling capacity did not result in very high rigor temperatures. Under conditions where animals are not stressed, these values might have been diVerent, although there is a strong suggestion that the delayed stimulation reduces the risk of unfavourable rigor conditions. Both the studies of Hwang and Thompson (2001a, 2001b) suggest that optimum in situ rigor temperatures may be closer to 28 °C that Hwang and Thompson (2001b) regarded as the rigor temperature for most tender meat after 14 days. The present study adhered to these conditions, yet the non-stimulated sides caught up with the stimulated sides during prolonged ageing so that the Wnal tenderness was similar for both treatments. It has to be considered that the chilling conditions and even the manipulation of glycolysis in the present trial was not as variable due to the reasons discussed above (slow chilling regime only, slightly stressed animals, delayed stimulation).

The studies by Devine (Devine et al., 2002), Hwang and Thompson (2001a, 2001b) and Geesink et al. (2001) emphasise the eVect of high (or low) rigor temperatures on sarcomere shortening. Devine et al. (1999) and Geesink et al. (2001) related both the shortening and decreased ageing to lower tenderness under high rigor conditions. In addition, Hwang and Thompson (2001a) reported that shorter sarcomeres due to stimulation (directly post-mortem) and the subsequent high rigor temperature coincided with tougher meat although the actual sarcomere lengths were in the normal range (1.75 _m). However, Devine et al. (2002) found that a reduced rate and extent of tenderisation were the main reasons for lower tenderness and not shorter sarcomeres (heat contracted) as a consequence of high rigor temperature.

Diferences in rigor temperature between treatments in the present trial was lower compared to the study of Hwang and Thompson (2001a) and the rigor temperature lower for the stimulated sides (28 °C). The average sarcomere length was also within the normal range (Koohmaraie, 1996) and even slightly longer (PD0.09) for the stimulated sides compared to the nonstimulated sides (Table 2). Therefore, in the present study, sarcomere length did not play a role in tenderness diferences. Shorter MFLs are normally associated with a higher degree of proteolysis and supposedly a larger degree of ageing (tenderisation). Both shorter MFLs at 14 days post-mortem and the higher rate of ageing of the non-stimulated samples

coincided with higher-calpain activity and/or lower calpastatin/calpain ratios as presented in Table 2. In contrast, the lack of significant variation between the treatments at 2 days post-mortem, did not explain the advantage in tenderness of stimulated sides, which was expected to originate from the early onset of proteolysis and tenderisation. While Devine et al. (1999) agreed that MFL indicates the degree of proteolysis, they found a similar lack of correspondence between MFL and tenderness diVerences under diVerent rigor and conditions of muscle contracture as in the present trial. On the other hand Wahlgren, Olssen, and Tornberg (1997) found good relationships between MFL and shear force (rD0.68) but not sensory tenderness (rD0.45), for meat from diVerent pH–time courses during rigor. King et al. (2004) found no eVect of low or high voltage stimulation on MFL during prolonged ageing although stimulated meat was more tender at 1 and 3 days post-mortem.

In most cases, it is dificult to distinguish between the efect of physical disruption and the efect on the calpain system related to improved tenderness (Hwang & Thompson, 2001b; Simmons et al., 1996). It is argued that the detrimental efects on the calpain system could erode the benefit gained from physical disruption in extreme conditions. In the present trial, these two eVects could also not be distinguished but, with the limited information, the not too extreme rigor conditions appeared to have favoured tenderness to a great extent.

The denaturing conditions usually arise when the pH decline is very rapid, as in the PSE condition in pork but can also occur when normal rates of pH decline combine with very slow chilling (Babiker & Lawrie, 1983; OVer & Knight, 1988). Electrical stimulation, by accelerating pH decline, contributes to reduced water binding capacity in beef, though the magnitude of the efect depends on the chilling rate (Babiker & Lawrie, 1983; den Eikelenboom, Smulders, & Ruderus, 1985; Martin, Murray, Jeremiah, & Dutson, 1983). Time of stimulation post slaughter post-mortem was also reported to have an efct on drip loss in pork muscle (Taylor & Martoccia, 1995). The conditions in the present trial were not as severe as conditions where a high level of denaturation is expected to occur (pH 6 at 35 °C; Scopes, 1964) and, although the diference in drip loss was significant (PD0.034), it was relatively small (0.65 of a percent; Table 2). The water holding capacity was not afected (Table 2) and neither was cooking loss or sensory appraisal of juiciness (Table 1) as was found by Unruh, Kastner, Kropf, Dikeman, and Hunt (1986) with electrical stimulation and slow chilling. Devine et al. (2002) also reported diferences in cooking loss for conditions of rigor temperature (35 °C) compared to low rigor temperature (15 °C).

Electrical stimulation afects meat colour in beef, although, as with water holding capacity, the extent of the changes depend on the chilling rate and the muscle type. In general, electrical stimulation (associated with high rigor temperatures) produces a paler colour (generally a higher L* value because of increased protein denaturation and myofibrillar lattice shrinkage (Offer & Trinick, 1983; Swatland, 1993). Furthermore, the higher L* value following electrical stimulation could be due to a greater amount of light being reflected from the muscle as a result of a looser structure occurring, also allowing deeper oxygen penetration (Unruh et al., 1986). In the present study, the L* values for stimulated meat were only one unit higher than for non-stimulated meat (PD0.209). As with drip loss, slightly higher than normal final pH values as well as the absence of more extreme rigor temperatures were the reasons for this contradiction. Stimulation had no efect on redness (a*) and yellowness (b*), while King et al. (2004) found higher b* values for stimulated muscles and Eikelenboom et al. (1985) and Sleper, Hunt, Kropf, Kastner, and Dikeman (1983) found that electrically stimulated beef at 24 h was typically more red, an eVec attributed to damage to enzyme systems responsible for oxygen consumption, reduced oxygen consumption rate and, hence, higher concentrations of oxymyoglobin in the surface meat layer (Ledward, 1992).

CONCLUSIONS

In general, electrical stimulation is desirable as the meat is tender at an earlier stage and the me tenderness situation for non-stimulated meat is only reached with prolonged ageing. While cold shortening was not an issue in the present study, it may occur in some other situations where here is a large range of carcass sizes in the same chiller. Under these conditions, delayed stimulation can prevent extreme rigor temperature conditions, while ensuring that cold shortening with smaller, leaner carcasses is prevented. Thus, electrical stimulation often provides a commercial advantage with reduced ageing times and a greater guarantee of quality with variable carcasses.

On the other hand, with proper inventory control and prolonged ageing at appropriate temperatures, carcasses need not be stimulated. Under the latter conditions, less denaturation of muscle protein could also lead to lower drip loss although this advantage may or may not be lost with prolonged ageing depending on the duration of ageing and the re-uptake of water.

The trial has shown that MFL does not distinguish between early post-mortem diVerences in tenderness but is a good indicator of prolonged ageing. Similarly, calpain activity (reduction) at 24 h gave a good indication of early post-mortem development of tenderness.

REFERENCES

1. AMSA, 1978, Guidelines for cooking and sensory evaluation of meat. American Meat Science Association, National Livestock and Meat Board, Chicago.
2. Devine, C. E., Wahlgren, N. M., & Tornberg, E., 1999, EVect of rigor temperature on muscle shortening and tenderisation of restrained and unrestrained beef M. longissimus thoracicus et lumborum. Meat Science.
3. P.E. Strydom et al. / Meat Science 70 (2005) 733–742 741 DransWeld, E., 1994, Modelling post-mortem tenderisation-V: inactivation of calpains. Meat Science.
4. DransWeld, E., Etherington, D. J., & Taylor, M. A. J., 1992, Modelling post-mortem tenderisation-II: enzyme changes during storage of electrically stimulated and non-stimulated beef. Meat Science.
5. .Dreyer, J. H., Van Rensburg, A. J. J., Naudé, R. T., Gouws, P. J., & Stiemie, S., 1979, The eVect of chilling temperatures and mode of suspension of beef carcasses on sarcomere length and meat tenderness. South African Journal of Animal Science.
6. Ducastaing, A., Valin, C., Schollmeyer, J., & Cross, R., 1985, EVects of electrical stimulation on postmortem changes in the activities of two Ca dependent neutral proteinases and their inhibitor in beef muscle. Meat Science.
7. Eikelenboom, G., Smulders, F. J. M., & Ruderus, H., 1985, The efect of high and low voltage electrical stimulation on beef quality. Meat Science.
8. Geesink, G. H., & Koohmaraie, M., 1999, Efect of calpastatin on degradation of myofibrillar proteins by calpain under postmortem conditions. Journal of Animal Science.
9. Heinze, P. H., & Bruggemann, D., 1994, Ageing of beef: inXuence of two ageing methods on sensory properties and myofibrillar proteins. Sciences Des Aliments.
10. .Hegarty, P. V. J., & Naudé, R. T., 1970, The accuracy of measurement of individual skeletal muscle fibres separated by a rapid technique. Laboratory Practice.
11. .Hwang, I. H., & Thompson, J. M., 2001a, The efect of time and type of electrical stimulation on the calpain system and meat tenderness in beef longissimus dorsi muscle. Meat Science.
12. .Hwang, I. H., & Thompson, J. M., 2001b, The interaction between pH and temperature decline early postmortem on the calpain system and objective tenderness in electrically stimulated beef longissimus dorsi muscle. Meat Science.
13. Irie, M., Izumo, A., & Mohri, S., 1996, Rapid method for determining water-holding capacity in meat using video image analysis and simple formulae. Meat Science.
14. .King, D. A., Voges, K. L., Hale, D. S., Waldron, D. F., Taylor, C. A., & Savell, J. W., 2004, High voltage electrical stimulation enhances muscle tenderness, increases aging response, and improves muscle color from cabrito carcasses. Meat Science.
15. .Ledward, D. A., 1992, Colour of raw and cooked meat. In D. E. Johnson, M. K. Knight, & D. A. Ledward (Eds.), The chemistry of muscle-based foods. The Royal Society of Chemistry.
16. Locker, R. H., & Hagyard, C. J., 1963, A cold shortening efect in beef muscles. Journal of the Science of Food and Agriculture, 14, 787–793.
17. Martin, A. H., Murray, A. C., Jeremiah, L. E., & Dutson, P. J., 1983, Electrical stimulation and carcass aging efects on beef carcasses in relation to postmortem glycolytic rates. Journal of Animal Science.

18. Offer, G., 1991, Modelling of the formation of pale, soft and exudative meat: efects of chilling regime and rate and extent of glycolysis. Meat Science.
19. P.E. Strydom, L. Frylinck, M.F. Smith, Should electrical stimulation be applied when cold shorteningis not a risk? Meat Science.
20. Rees, M. P., Trout, G. R., & Warner, R. D., 2003, The influence of the rate of pH decline on the rate of ageing for pork. interaction with method of suspension. Meat Science.
21. Snedecor, G. W., & Cochran, W. G., 1980, In Statistical methods Iowa State University Press.