Improving the tenderness of hot boned beef muscles

Restriction methods of rigor mortis contraction can reduce the effects of cold shortening

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Restricting rigor mortis contraction of bovine m. longissimus dorsi (LD) has been studied by three different techniques: i) wrapping with a thin polyethylene film supported with taping, ii) wrapping with a thin polyethylene film alone and iii) packaging with a commercial system (Pi-Vac®) that applies lateral pressure to the muscle. These techniques proved to offer possibilities for chilling hot boned striploins faster without detrimental effects on tenderness. A more attractive shape for whole beef cuts as well as consumer portioned steaks from the restrained muscles was an additional benefit of all muscle restriction methods tested.

The effects of muscle shortening during rigor mortis (rigor) on meat quality has long been recognised (BENDALL, 1951). HERRING et al. (1965) observed that when a muscle was excised and permitted to shorten during the development of rigor mortis, it would not be tender upon processing. Conversely, if another strip of the same excised muscle was restrained to hinder shortening during the development of rigor, it would ultimately become more tender than the unrestrained muscle. A subsequent study on the m. semimembranousus (SM) muscle (HERRING et al., 1967) showed that the tenderness of the contracted muscle did not reach acceptable levels even after 10 days of ageing.

Studies that have been carried out more recently on this subject are OLSSON et al. (1994), KOOHMARAIE et al. (1996) and DEVINE et al. (1999). The latter authors followed the isometric tension and isotonic shortening developed in small strips of LD as the muscle went into rigor at constant temperatures between 15-35 °C. In addition, one of the LD muscle pairs was tightly restrained by wrapping, using a thin polyethylene film, to reduce muscle shortening. The other muscle pair was unrestrained and free to shorten. A minimum isometric tension and muscle shortening occurred at the lowest temperature studied (15 °C). Meat that went into rigor at this temperature also was the most tender. For meat that went into rigor at temperatures higher than 15 °C, wrapping of the muscle significantly improved the tenderness. The wrapped muscles had longer sarcomeres than unwrapped muscles, which indicated that the tenderness effect of wrapping was due to restriction of muscle contraction at the micro level in the muscle. Furthermore, it was observed that at the elevated temperatures the ageing capacity of the meat was also affected negatively in addition to the increased muscle contraction (SIMMONS et al., 1996; DEVINE et al., 1999).

During the last ten years hot boning of beef carcasses has become more desirable for abattoirs in Norway, mostly due to its beneficial effect regarding worker satisfaction, improved efficiency and hygiene, better processing quality and lower plant investment cost (PISULA and TYBURCY, 1996) The market share of hot boned beef has increased steadily, and at present about 20 % of all beef carcasses slaughtered in Norway are boned out before chilling. However, by removing pre rigor muscles from the bones they become more vulnerable to any factor that results in an increased muscle contraction before or during rigor development. Such contraction can arise from either a rigor contracture of muscle fibres entering rigor above the optimum temperatures of 10-18 °C (DEVINE et al., 1999; DEVINE et al., 2002a; DEVINE et al., (2002b) or from a cold contracture occurring below these temperatures. A cold contracture is the worst in effects on tenderness. In practical terms to reduce a contraction a controlled chilling regime needs to be put in place. Thus to obtain the advan-

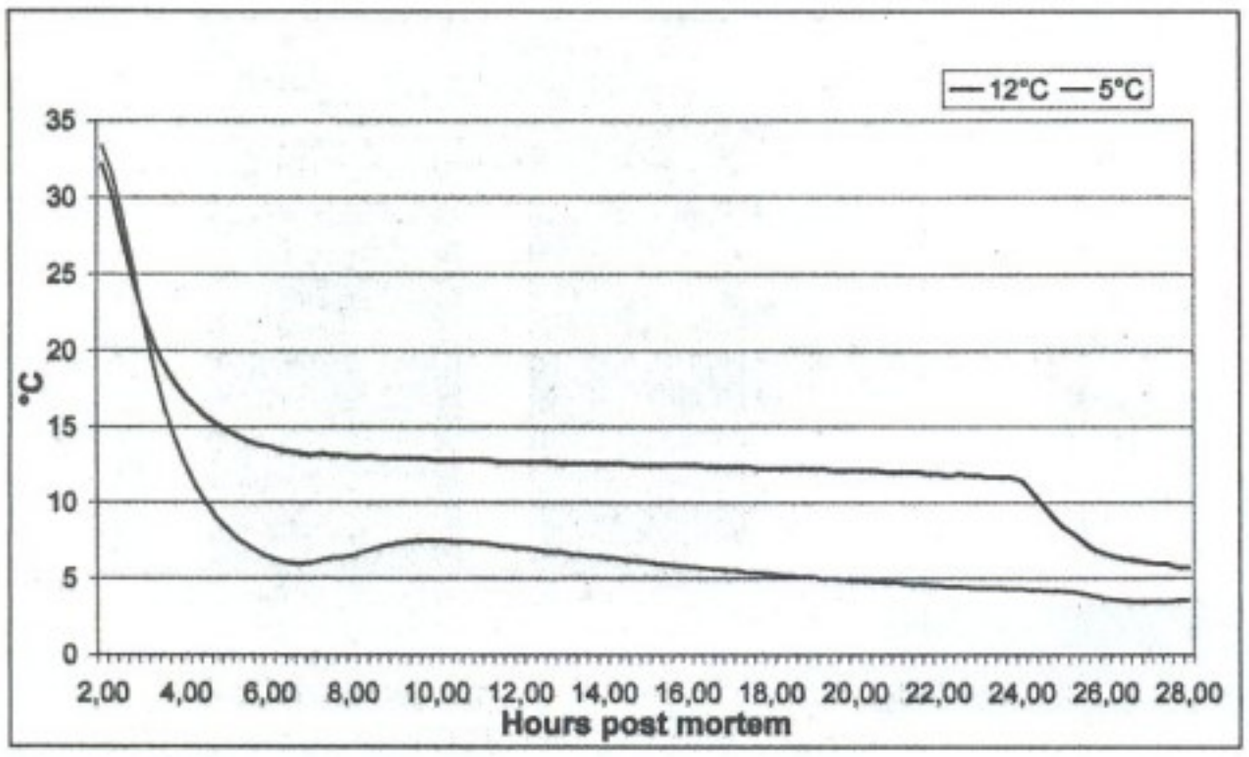

Fig. 1: Chilling rates for m. longissimus dorsi (LD) exposed to fast and slow chilling regimes (centre of loin, Exp. 1).

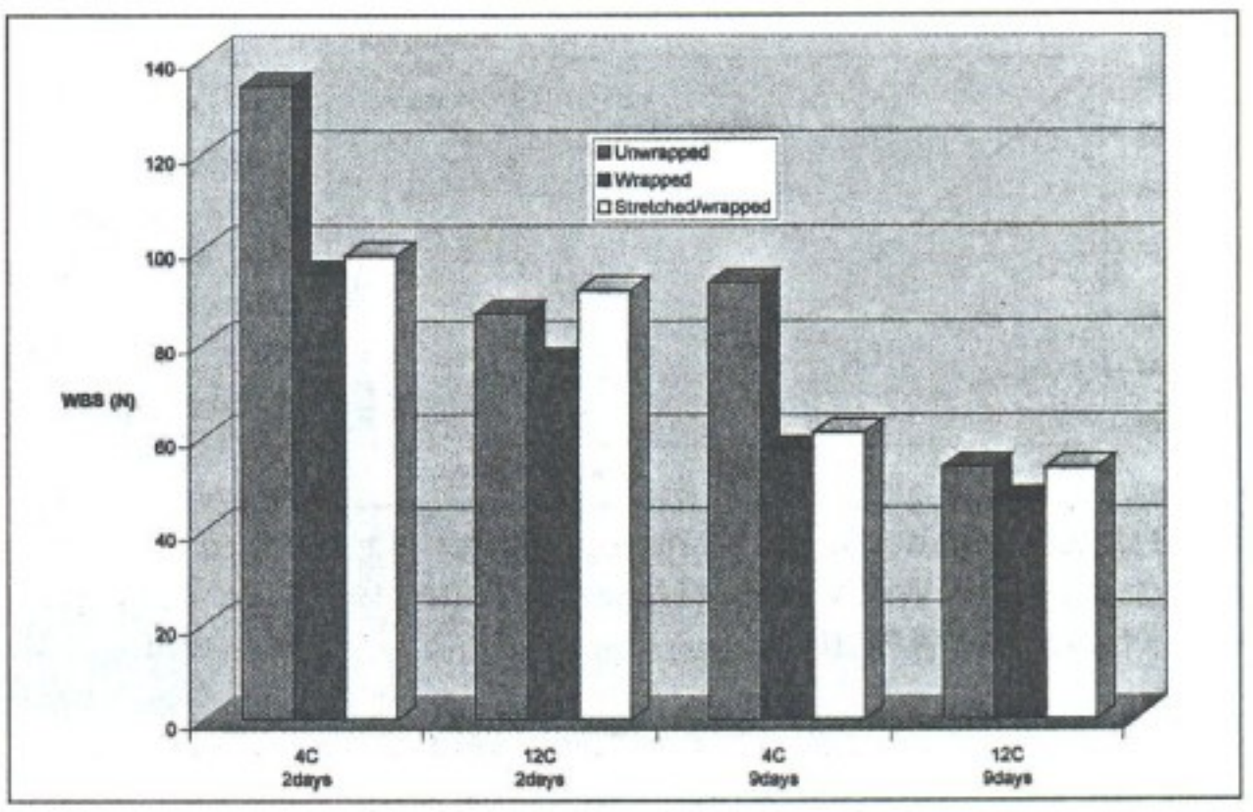

Fig. 2: Effects of wrapping/taping and chilling rate on WBS values of LD muscles after two and nine days of ageing at 4 °C (4C and 12C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 1).

tages of hot boning, there is a need to introduce treatments during processing that can counteract any possible muscle contraction to assure optimum eating quality.

The restraining procedures that have been used in previous studies are rather time consuming and laborious. There is an obvious need for a process that would lend itself to automation. In the present study a novel packaging method, developed by Pi-Vac®, was evaluated together with traditional wrapping techniques using thin polyethylene films and tape.

The Pi-Vac® packaging system operates with plastic film tubes on rolls. The film has a high degree of elasticity that, when stretched, creates forces directed inwards compressing onto the beef cuts. These forces have been proposed to hinder the diametrical muscle expansion, that is caused by the longitudinal contraction developed during rigor (as muscle has a constant volume, restriction expansion also restricts shortening).

Effects of Pi-Vac® packing on meat quality of pork have earlier been reported (STIEBING and KARNITZSCHKY, 1997). Improved colour and overall appearance was reported, as well as a reduced drip loss. The pork was regarded as more tender, but the tenderness improvement was reported to be more definite for beef. However, no details regarding measurement results on tenderness were given.

MEIXNER and KARNITZSCHKY (2001) recently reported the application of Pi-Vac® packaging on hot boned beef. Their statement regarding the Pi-Vac® packaging system and its beneficial effect on hot boned beef are mainly based on preliminary results of the present studies. We now extend and summarise several studies that have been performed on hot boned beef during the last three years in a collaboration between Norway Meat Cooperative and the Norwegian Food Research Institute (MATFORSK). The purpose of these studies has been to optimise the eating quality of hot boned beef as well as to improve the shape and other appearance aspects.

Different muscle restricting techniques have been examined at temperatures that are mostly encountered during commercial chilling of hot boned beef. Three different methods have been studied and compared to traditional vacuum packaging; i) wrapping with polyethylene film supported with taping, ii) wrapping with polyethylene film alone and iii) packing using a novel commercial packaging system (Pi-Vac®). Preliminary reports of parts of the study have been presented earlier (HILDRUM et al., 2000; WAHLGREN et al., 2001).

Tab. 1: Means and standard deviations for important variables in all three experiments. LD and SM are m. longissiums dorsi and m. semimembranousus, respectively. WBS values are given in N/cm².

	Variable	LD mean ± sd	SM mean ± sd
Experiment 1	pH_2	6.54 ± 0.18	6.52 ± 0.23
	pH_7	6.22 ± 0.23	6.08 ± 0.30
	pH_{24}	5.60 ± 0.09	5.60 ± 0.08
	SML (µm)	1.86 ± 0.35	–
	WBS-day 2	95 ± 22	101 ± 22
	WBS-day 9	55 ± 20	78 ± 19
Experiment 2	pH_2	6.53 ± 0.16	–
	pH_{24}	5.71 ± 0.16	–
	SML (µm)	1.71 ± 0.25	–
	WBS-day 2	84 ± 18	–
	WBS-day 8	71 ± 24	–
Experiment 3	pH_{24}	5.60 ± 0.15	–
	SML (µm)	1.78 ± 0.26	–
	WBS-day 2	99 ± 25	–
	WBS-day 9	66 ± 24	–

Materials

Experiment 1: Wrapping in polyethylene film supported with taping

Nine young bulls (15-18 months) of the Norwegian Red breed (NRB) were used. The carcasses (273-377 kg) were slaughtered at a commercial abattoir (Gilde Hed-Opp, Rudshøgda) without electrical stimulation being used. Nine pairs of muscles from the m. longissimus dorsi (LD) and six pairs of muscles from the m. semimembranosus (SM) were excised within two hours of slaughter.

The eighteen LD muscles were allocated to one of three treatments; i) unwrapped LD (control), ii) LD wrapped tightly in a thin polyethylene film and iii) LD wrapped in polyethylene film after a manual stretching to an elongation of approximately 10 %. To further enhance the restraining properties of the polyethylene film, a firm layer of plastic packaging tape was placed over the wrapped LD's. The twelve SM muscles were only subjected to the first two treatments described above. All muscles were cut into two equal parts, across the muscle direction and placed in separate polyethylene bags. The samples were vacuum packed, immersed in water baths and exposed to either a fast chilling regime at 4 °C or to a slow chilling regime at 12 °C. At 24 hours post mortem all samples were transferred to plastic trays and aged at 4 °C for an additional period of one and eight days.

Experiment 2: Wrapping in polyethylene film alone

Pairs of LD muscles from twelve young bulls of NRB (15-18 months, 256-355 kg) were ex-

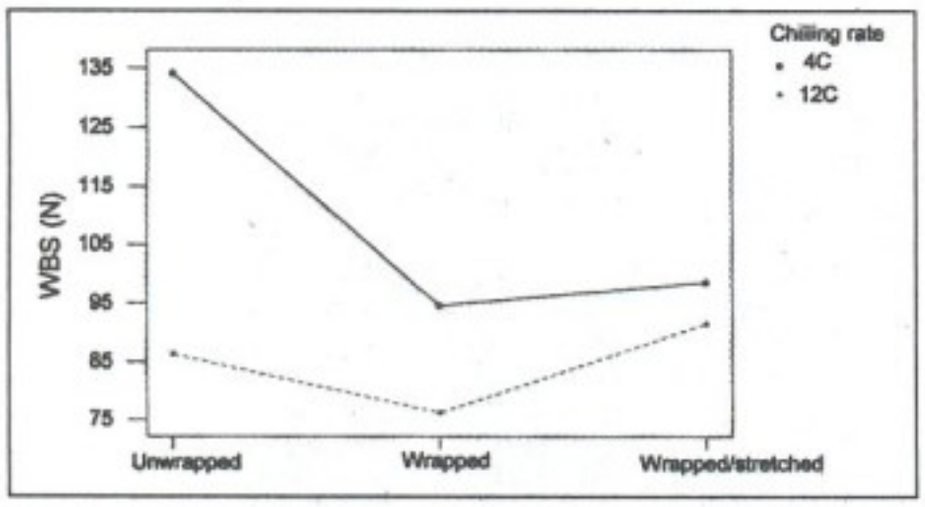

Fig. 3: Interaction between chilling regime and wrapping/taping as for WBS values of LD samples after two days of ageing at 4 °C (Exp. 1).

cised within one hour post mortem. The carcasses were slaughtered at a commercial abattoir (Gilde Hed-Opp, Rudshøgda) without electrical stimulation being used. The silver-skin was left on the muscles. One of the pairs of the muscle was tightly wrapped in polyethylene film (3 layers) to its approximate rest length. The other muscle of the pair was not wrapped and used as control. All muscles were cut into two equal parts across the muscle direction and placed in separate polyethylene bags. The samples were vacuum packed, placed in a single layer in plastic trays and exposed to either a fast chilling regime (air at 4 °C) or to a slow chilling regime (air at 12 °C). At 24 hours post mortem all samples were transferred to 4 °C and aged for a additional period of one and seven days.

Experiment 3: Packaging using Pi-Vac Elasto-Pack®

Pairs of LD muscles from twelve non-electrically stimulated young bulls were slaughtered at a commercial abattoir (Gilde Hed-Opp Otta). The muscles were excised within one hour post mortem. All muscles were divided in two equal parts across the muscle direction and allocated to one of four treatments. Two pieces from one of the muscle pairs were packed in vacuum polyethylene bags. The other two muscle pieces from same carcass were packed in a Pi-Vac Elasto-Pack® (Pi-Vac GmbH Verpackungssysteme, Barleben, Germany). After sealing, the samples were placed in a single layer in plastic trays and exposed to either a fast chilling regime (air at 4 °C) or to a slow chilling regime (air at 14 °C for 8 hours followed by 8 °C for 6 hours and finally 4 °C). The samples were aged at 4 °C until the day of tenderness measurements (two, nine and 26 days post mortem).

The Pi-Vac packaging machine (Pack-Man®) was provided with three chambers of different dimensions. These chambers can alternatively be used for meat cuts of different size. The Pi-Vac Elasto-Pack® film used was a plastic laminate (PE/PVDC/PE) with a thickness of 140µm. The film is delivered as tubing on rolls with eight different widths. The dimensions 135mm and 195mm were used in this experiment.

Inside the chamber a partial vacuum was created on the outside of the tubes of elastic film. This partial vacuum resulted in an expansion of the elastic film until the inside wall of the chamber was reached. This corresponds to an approximate expansion of 80 %. The beef cut is manually inserted into the chamber and the vacuum is released. The film returns to its original dimension and clings firmly to the muscle. Both ends of the final package were sealed in a separate welding operation (MEIXNER and KARNITZSCHKY, 2001).

The experimental design of the three experiments included, chilling regime, packaging method, ageing time, carcass side (right/left) as well as anterior and posterior parts of the muscles.

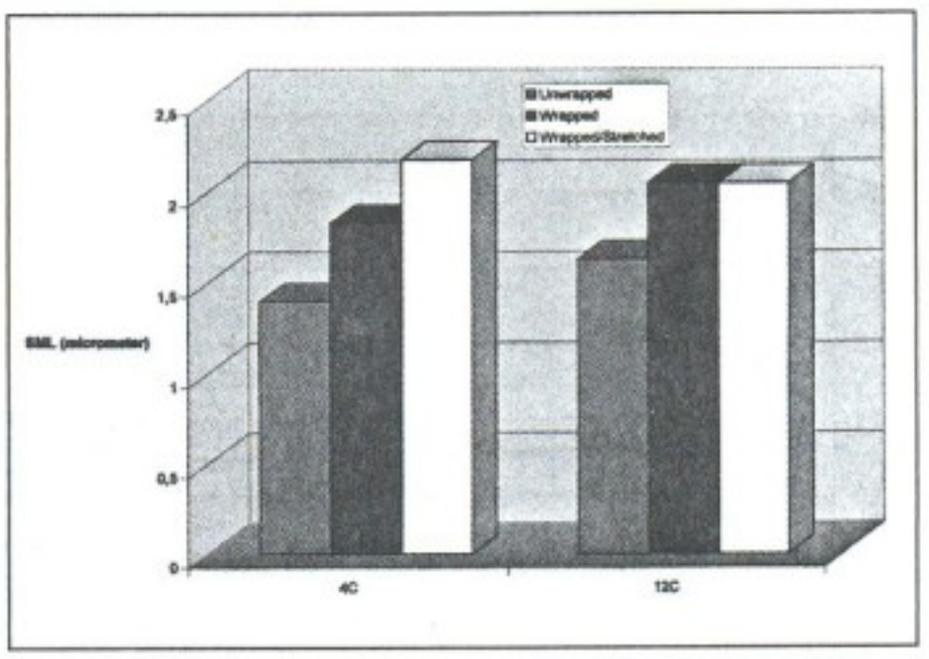

Fig. 4: Effects of wrapping/taping and chilling rate on sarcomere length (SML) of LD muscle samples (Exp. 1).

Methods

After the designated ageing: two days (short ageing) or eight days (Exp. 2) or nine days (Exp. 1 and Exp. 3) post mortem (long ageing), meat slices with a thickness of 3.5 cm from each sample were cut out for Warner Bratzler shear (WBS) force measurements. All slices were vacuum packed in polyethylene bags, heated in a water bath at 70 °C for 50 min and chilled in ice water for 45 min. The samples were then stored at -1.5 °C until the day of WBS analysis (within four days).

At the day of WBS analysis, the samples were conditioned at 20 °C for 20 min, and then slices of 1 cm thickness were cut out along the fibre. The second cut was also performed in the fibre direction to give the final dimension of the samples of 3 cm x 1 cm x 1 cm. Structures of visible fat or sinew were avoided. Mean shear force per sample, sheared across the muscle fibre direction was recorded using a WBS force device (triangular version) in an Instron Materials Testing Machine (Model 4202, Instron Engineering Corporation, High Wycombe, U.K.). An average of the ten replicates per sample was used in the data analysis.

The pH of the muscles at each ageing time was recorded at intervals by direct pH-measurements, using a Knick SE 104 puncture electrode (Knick Elektronische Meßgeräte GmbH & Co, Berlin, Germany). Samples for sarcomere length (SML) measurements were fixed in a borate solution containing 2.5 % glutaraldehyde and homogenised using a Polytron PT3000 homogeniser. The SML were measured with an image analysing program (Image-Pro Plus 4.0, Media Cybernetics, Silverspring, Maryland, USA) from pictures taken with a camera (Hitachi KP-D50 Color Digital, Hitachi Denshi Ltd, Japan) connected to a light microscope (Leica DMLB, Leica Mikroskopie & Systeme GmbH, Wetzar, Germany).

The myofibrillar length (MFL) measurements in Exp. 2 were performed essentially as described by OLSSON and TORNBERG (1992). Approximately 5 g of finely chopped muscle was homogenised in an Omnimixer (11000 rpm) for 60 s with 50 ml isotonic salt solution, centrifuged at 1000 G for 15 min at 2 °C, and the supernatant poured off. The sediment was re-suspended in 25 ml isolation buffer (100 mM KCl, 20 mM K-phosphate, 1 mM EDTA, 1 mM Na-azide, pH 7.0), and diluted 25 times in the same buffer. One drop of the suspension was placed on a microscope slide under a light microscope (x 100).

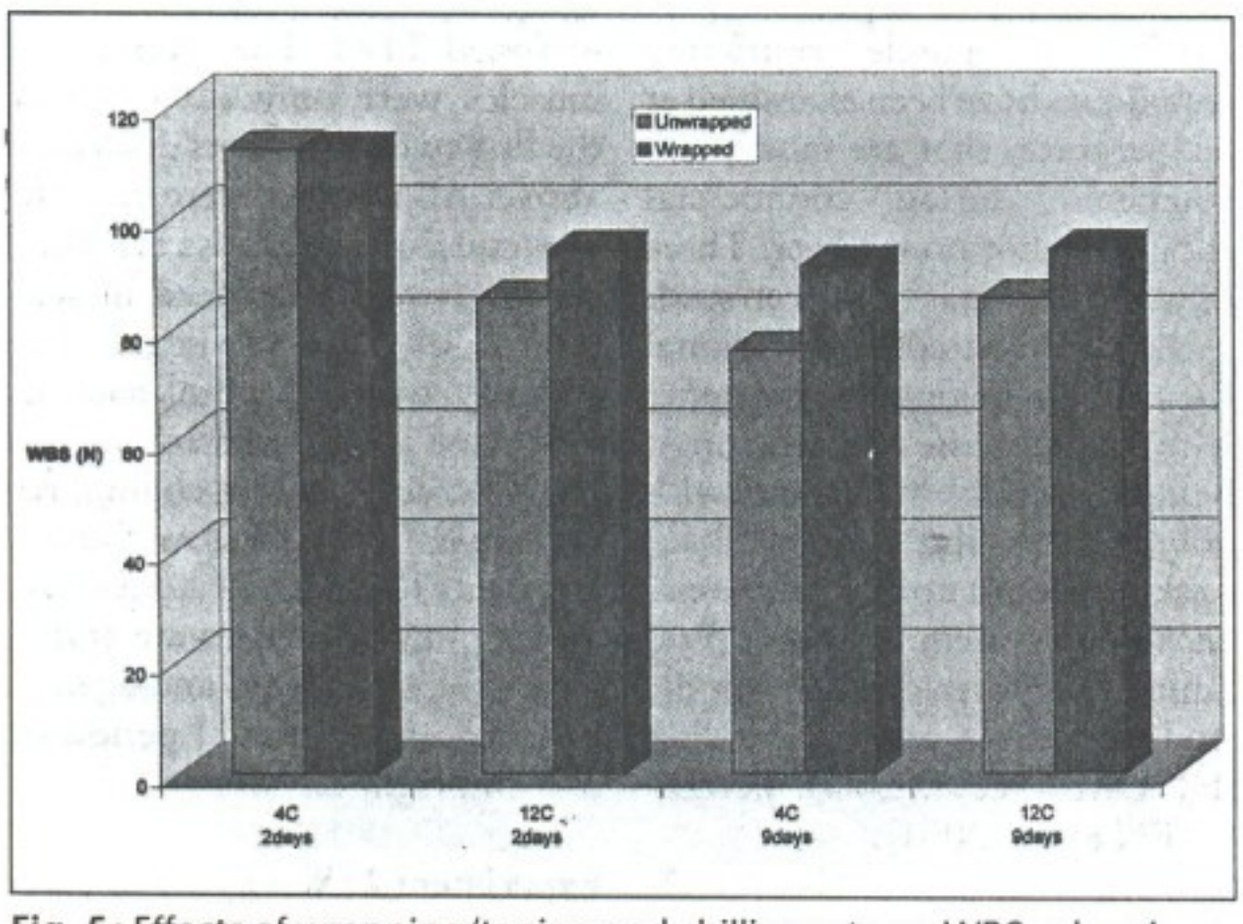

Fig. 5: Effects of wrapping/taping and chilling rate on WBS values in m. semimembranousus (SM) after two and nine days ageing at 4 °C (4C and 12C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 1).

The average MFL was calculated from 150 replicate measurements from each sample.

The statistical analysis was performed in MINITAB, version 13. The analysis of variance (ANOVA) was performed using a general linear model. The model for the crossed design was used according to the formula below.

$$(WBS/SML)_{ijk} = \mu + C_i + W_j + A_k + C_i x W_j + C_i x A_k + W_j x A_k + A_k x W_j x D_i + e_{ijkl}$$

In the model μ is the constant term, C_i = chilling temperature, W_j = wrapping/stretching/packing, A_k = Ageing time and e_{ijk} = residual error. In some cases also a 2-factor model was used. Further details regarding experimental procedures are given by HILDRUM et al. (1999).

Tab. 2: A summary of average WBS (N/cm²) and SML values (μm) with respective standard deviations from all three experiments.

		WBS values				SML values	
		Short ageing		Long ageing			
Treatment	**Exp.**	**Fast chilling**	**Slow chilling**	**Fast chilling**	**Slow chilling**	**Fast chilling**	**Slow chilling**
Shortening not restricted (unwrapped)	1	134 ± 15	86 ± 9	93 ± 24	54 ± 8	1.40 ± 0.22	1.63 ± 0.19
	2	105 ± 14	81 ± 14	98 ± 21	70 ± 23	1.49 ± 0.15	1.78 ± 0.16
	3	128 ± 12	108 ± 17	97 ± 17	66 ± 19	1.52 ± 0.20	1.69 ± 0.08
Shortening restricted (wrapped)	1	95 ± 13	76 ± 14	57 ± 15	46 ± 9	1.83 ± 0.25	2.05 ± 0.33
	2	82 ± 14	70 ± 13	65 ± 13	52 ± 13	1.65 ± 0.25	1.90 ± 0.21
	3	85 ± 17	75 ± 9	54 ± 13	48 ± 11	1.84 ± 0.20	2.05 ± 0.19

Results and discussion

Experiment 1

Mean values and standard deviations for measured variables of the LD and SM muscles are given in Table 1. The pH in the samples at early post-mortem times (from two to seven hours) showed higher variability than after 24 hours. Carcasses to carcass variations and temperature fluctuations at the early stage are probably the main reason for this large variability. The average pH declines in the LD and SM muscles were of similar magnitudes.

The WBS force values showed large variations from carcass to carcass in both LD and SM muscles. However, the average WBS values in LD and SM after two days of ageing were not significantly different ($p>0.05$). The tenderisation rate was higher in the LD than in the SM muscle ($p<0.05$), reflecting a limited tenderisation potential in the latter muscle.

The centre temperature in the muscles exposed to the fast chilling regime had already fallen to below 10 °C after four hours post mortem. This most certainly induced cold shortening in the muscles (Fig. 1). Without electrical stimulation of carcasses the pH-fall in the LD muscle was relatively slow. The slow chilling regime (12 °C) resulted in a faster pH fall of the LD muscles compared to the fast chilling regime although the differences were not significant. As a consequence, these muscles were not exposed to temperatures less than 10 °C before 24 hours post mortem and a minimal muscle shortening was therefore to be expected. There

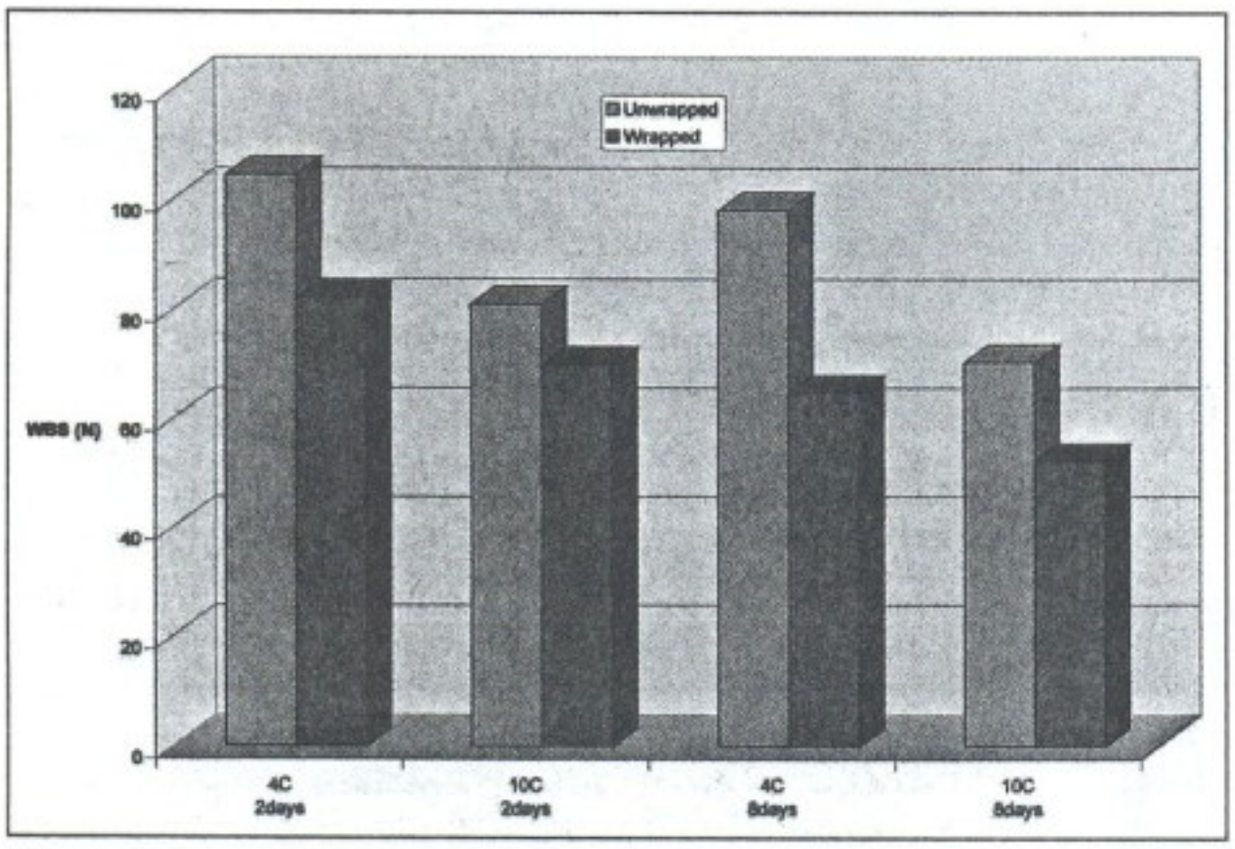

Fig. 6: Effects of chilling regime, wrapping and ageing time on WBS values of LD muscles after two and eight days ageing at 4 °C (4 °C and 10 °C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 2).

was no significant difference in either temperature or pH decline between the wrapped and unwrapped samples.

Wrapping the LD muscle resulted in significantly lower WBS values ($p<0.001$) both after short (two days post mortem) and after long ageing periods (nine days post mortem, Fig. 2). In addition, there was an interaction between chilling rate and wrapping as the advantageous effect of wrapping on WBS was only significant in samples exposed to the fast chilling regime (Fig. 3). Thus no effect was obtained on the LD muscles exposed to the slow chilling regime. This means that wrapping was only effective when muscles are exposed to conditions resulting in increased muscle shortening (either rigor shortening above 10-18 °C or cold shortening less than 10 °C). The chilling regime had also a significant effect on the WBS values ($p<0.001$) of the LD muscles. The effects of slow chilling regime and wrapping of LD were of similar magnitudes (Fig. 2).

There was a slight tendency that wrapping accelerated ageing as shown by reduced WBS values. However, the interaction between wrapping and ageing time was not significant. There was also no significant interaction between chilling rate and ageing time. This means that these treatments were complementary with respect to the WBS values and supports the findings that the effect of wrapping at short ageing times is still maintained after the long ageing time.

Wrapping of LD muscles maintained long SML ($p<0.001$, Fig. 4). This indicated that the effect of wrapping on WBS was mainly due to a restriction of muscle contraction at the micro level in the muscles. There was no significant interaction between wrapping and chilling ($p>0.05$) suggesting that the reduction in SML of unwrapped muscles during rigor was of similar magnitude at both chilling regimes. In other words, wrapping was equally effective in reducing the myofibrillar contraction of the LD muscle at both chilling regimes.

The treatment with manual stretching before wrapping of the LD muscles (iii) did not additionally decrease the WBS values ($p>0.05$, Fig. 2). This confirms the results of HERRING et al. (1967), who found no effect on shear force from stretching of SM muscles up to 48 % beyond the original length. This is in agreement with the results from the SML measurements, which did not show any significant increase upon stretching of the muscle ($p>0.05$). The reason could be that no real stretching occurred, possibly because of mechanical limitations.

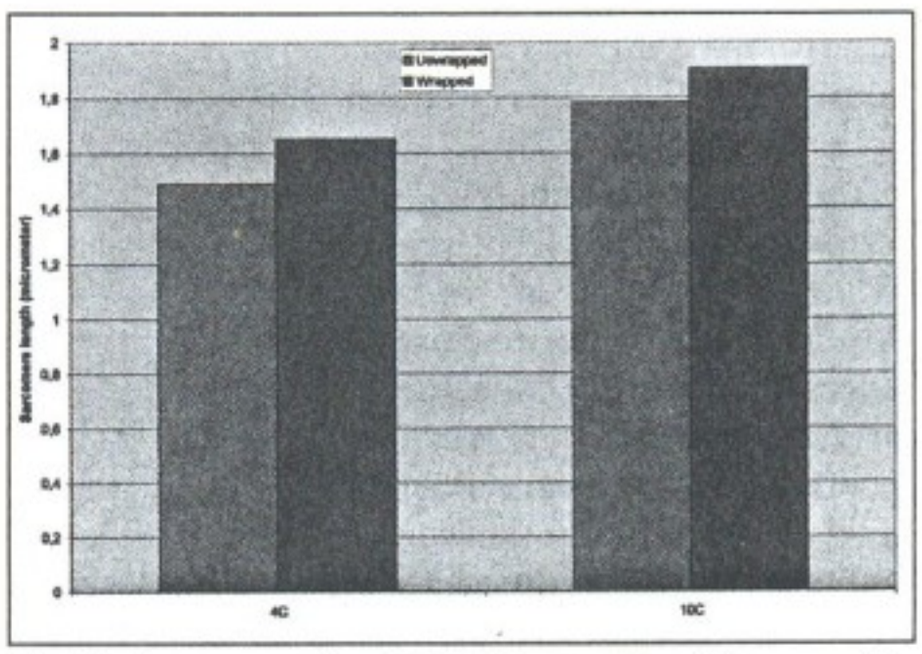

Fig. 7: Sarcomere length in LD samples with regard to chilling rate and wrapping (4C and 10C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 2).

Wrapping of SM muscles yielded no significant improvement on tenderness, neither after short nor long ageing times (Fig. 5). The reason for this lack of response to wrapping of the SM muscle could be a less regular orientation of myofibrils compared with the LD muscle and the fact that the muscles were already shortened because of the preceding suspension of the carcass by the Achilles tendon before boning out. Other possible explanations could arise from the larger content of connective tissue in the SM muscle. The slow chilling regime yielded significant lower WBS values of the SM muscles after short ageing ($p<0.05$). However, the effect was not present nine days post mortem.

Experiment 2

The average ultimate pH for LD was slightly higher than in experiment 1, while the corresponding SML values were smaller (Table 1). The average tenderisation effect at the end of the ageing period (higher WBS values) seemed to be smaller than for the first experiment, which may be caused by the fact that the time interval here was one day shorter (two to eight days). The variability in all other properties was similar to experiment 1.

While the samples in the first experiment were either wrapped in film or wrapped in film and taped, only wrapping with thin polyethylene film (3 layers) was performed in this experiment. The effects of chilling regime ($p<0.001$), wrapping ($p<0.001$) and ageing ($p<0.01$) on WBS values for the LD were all still highly significant (Fig. 6) and showed that the effects of wrapping and slow chilling were of the same magnitude. This means that a larger effect on tenderness was achieved either by wrapping the LD muscle or by using a slow chilling regime than by increasing the ageing time from two to eight days. In contrast to experiment 1, no significant interaction between chilling regime and wrapping was observed two days post mortem. Wrapping was thus having a significant effect at both chilling regimes ($p<0.05$), but the corresponding interaction was not significant after eight days. Thus even after a long ageing period, the effect of wrapping had a considerable effect and was still evident. When both ageing days were included in the same model, this interaction was barely significant ($p=0.047$). There was a tendency that wrapping increased the rate of tenderisation of loins between two and eight days, although the interaction be-

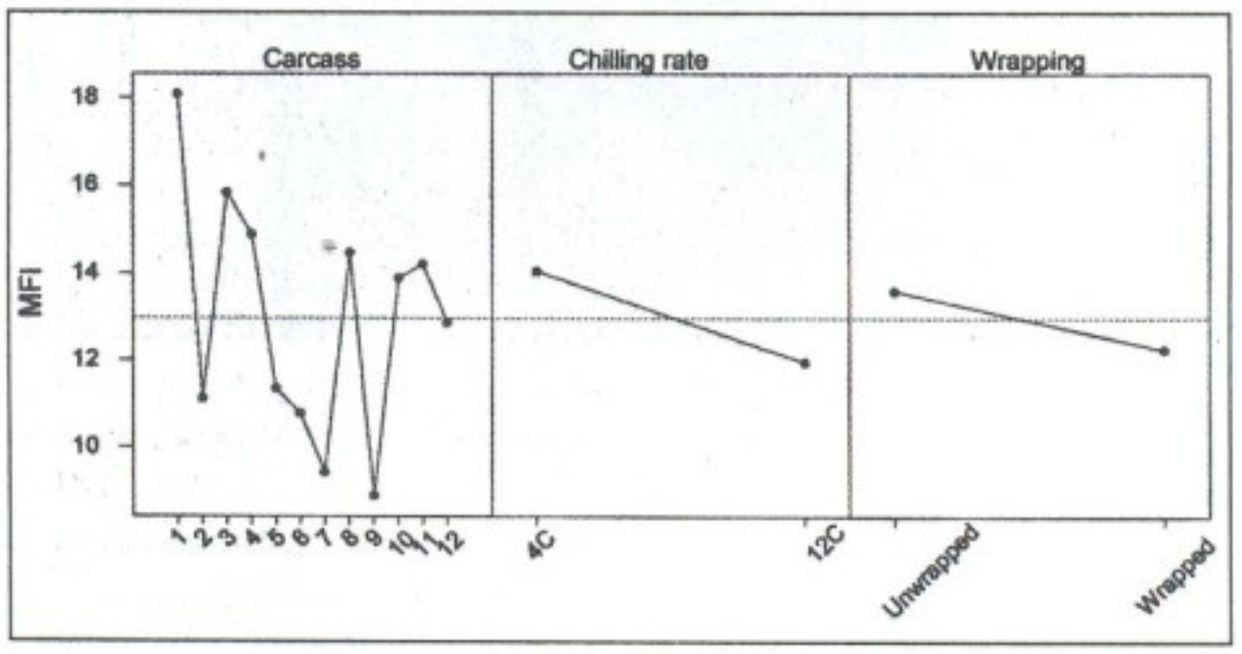

Fig. 8: Effects of chilling rate, wrapping and carcass on myofibrillar length (MFL) in LD (4C and 10C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 2).

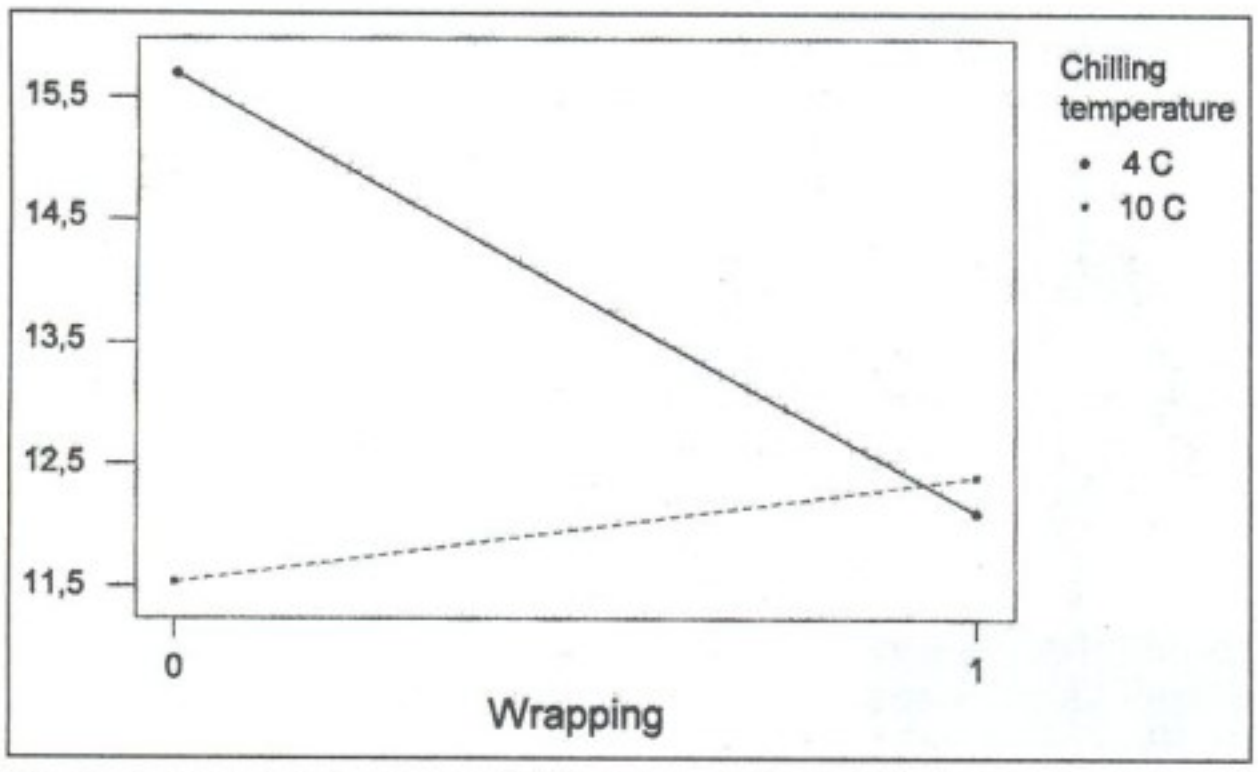

Fig. 9: Interaction between chilling rate and wrapping regarding MFL in LD. The "Mean number" in the figure gives the average length of the myofibrils in micrometers (ordinate). (4C and 10C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 2).

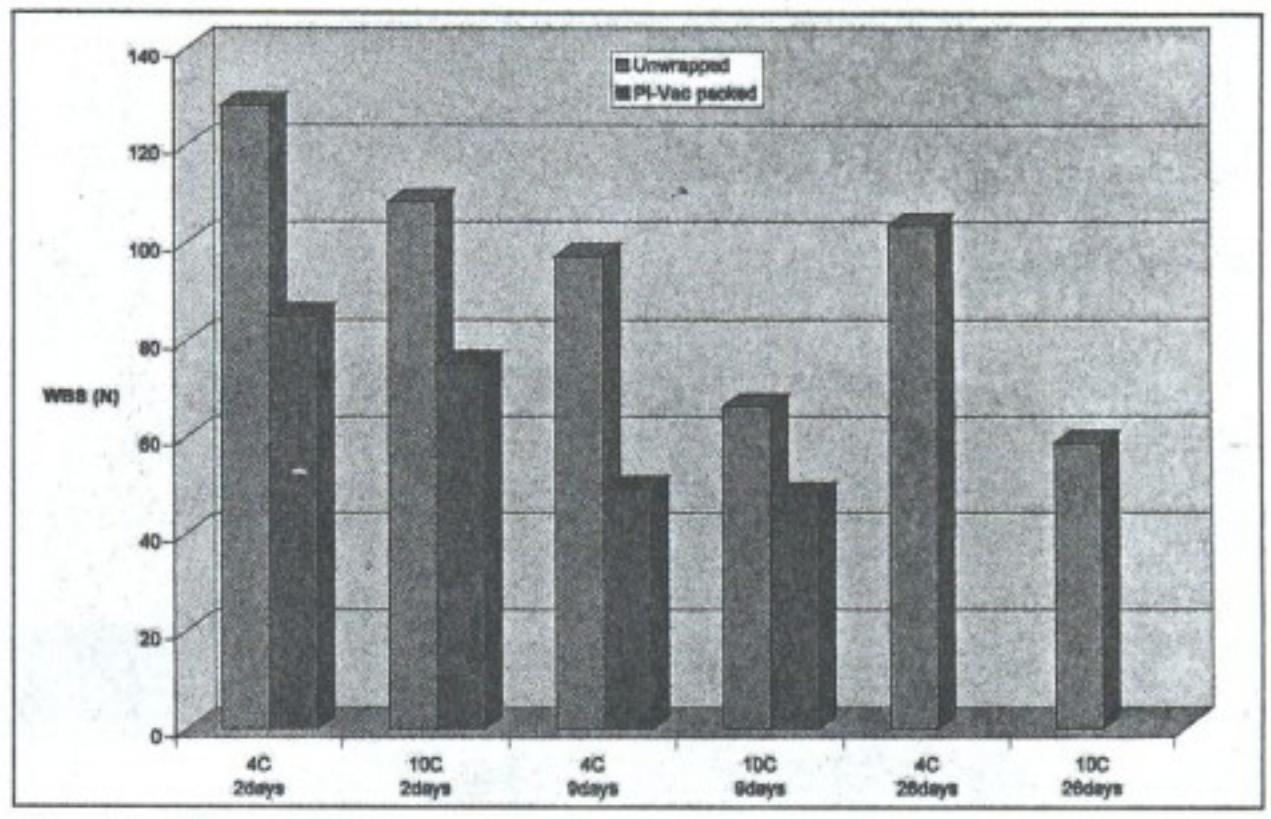

Fig. 10: Effects of Pi-Vac packing or vacuum packing (unwrapped) and chilling rate on WBS values of LD muscles after two, nine and twenty six days of ageing at 4 °C (4C and 10C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 3).

tween wrapping and ageing time was not significant.

The SML measurements also showed significant effects with regard to chilling rate ($p<0.001$) and wrapping ($p<0.05$, Fig. 7) confirming the earlier observation that wrapping and slow chilling reduces the myofibrillar contraction during rigor.

A highly significant difference in MFL was found between the individual carcasses ($p<0.01$, Fig. 8). The figure shows that the average effects of chilling regime and wrapping on MFL were modest in comparison to the variation in MFL between the carcasses. Neither chilling regime nor wrapping showed significant effects on mean MFL, although chilling rate was close to a significance level of 0.05 ($p=0.087$). However, a significant interaction ($p<0.05$) between chilling rate and wrapping was found (Fig. 9). While wrapping resulted in no significant effect on MFL when slow chilling regimes were used, the effect of wrapping at fast chilling regimes was significant ($p=0.025$). Figure 9 shows that wrapping had the same lowering effect on MFL at the fast chilling regime as slow chilling regime had on LD muscles free to shorten. This shows that both wrapping and slow chilling exerted their effects through the same mechanism of promoting fragmentation of myofibrils during ageing of the loins.

Experiment 3

All the three variables of packaging method, chilling regime and ageing time were shown to have significant effects on the tenderness of the LD muscle (Fig. 10). The largest impact on the WBS values were from samples subjected to the Pi-Vac® packaging method and long ageing times (including the longer ageing time of unwrapped samples after 26 days). This is evident from the large improvement in tenderness two days post mortem of Pi-Vac® packed beef as compared to vacuum-packed beef exposed to the same fast chilling regimes. The effect of ageing time was demonstrated by the large decrease in WBS shear force between two and nine days post mortem suggesting that both packaging method and rigor temperature had additive effects on the resultant tenderness of hot boned LD muscles. A consistent observation was that ageing up to 26 days for vacuum packed LD muscles, exposed to the fast chilling regime, only had a minor improvement on the ultimate tenderness. This observation confirms that muscles that are severely cold shortened have a limited tenderisation.

The packaging method had also significant effect on SML at both chilling rates (Fig. 11). This indicates that the Pi-Vac® packaging system also has the ability to reduce the muscle contraction that occurs during rigor development and in fact the packaging method had a larger impact on SML than when using the slow chilling regime. The overall results in this experiment imply that the Pi-Vac® packaging method improved the tenderness of hot boned strip loins more than the controlled chilling regime. The industrial benefits of Pi-Vac® packaging method are that a faster chilling regime can be used with a higher through-puts, better hygiene with a presumably lower total drip losses.

It was observed that the Pi-Vac® packaging system resulted in a rounded and attractive shape for the hot boned LD muscles. This is not always the case when using traditional vacuum packing systems on hot boned beef such as for hot boned strip loins placed in boxes or plastic trays in conventional processing, when they usually lose their natural shape due to the pressure from the surrounding beef cuts. The round shape was maintained even after the film had been removed and the LD cut into consumer portioned steaks (Fig. 12-13).

Conclusions

The results from all three experiments are summarised in Table 2. It can be seen that the relative relationship between the experiments regarding WBS and SML values was maintained with no significant differences being obtained. This shows a high reproducibility between the experiments as for the effects from both chilling rate and from the muscle restriction techniques. If the chill-

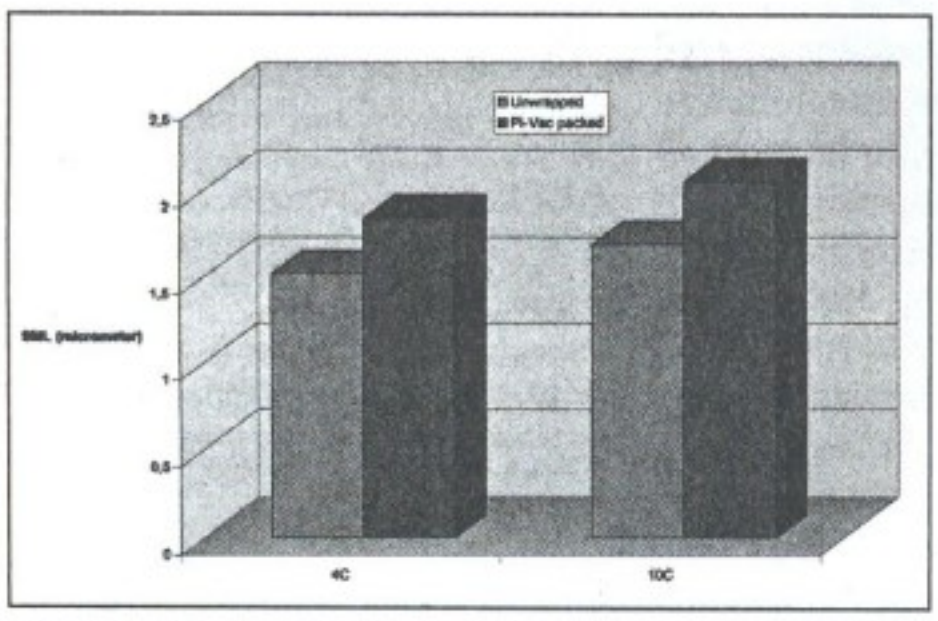

Fig. 11: Effects of Pi-Vac packing or vacuum packing (unwrapped) and chilling rate on SML values of LD muscles after two, nine and twenty six days of ageing at 4 C (4 °C and 10 °C in abscissa refer the fast and slow chilling regimes used during the first 24 hours) (Exp. 3).

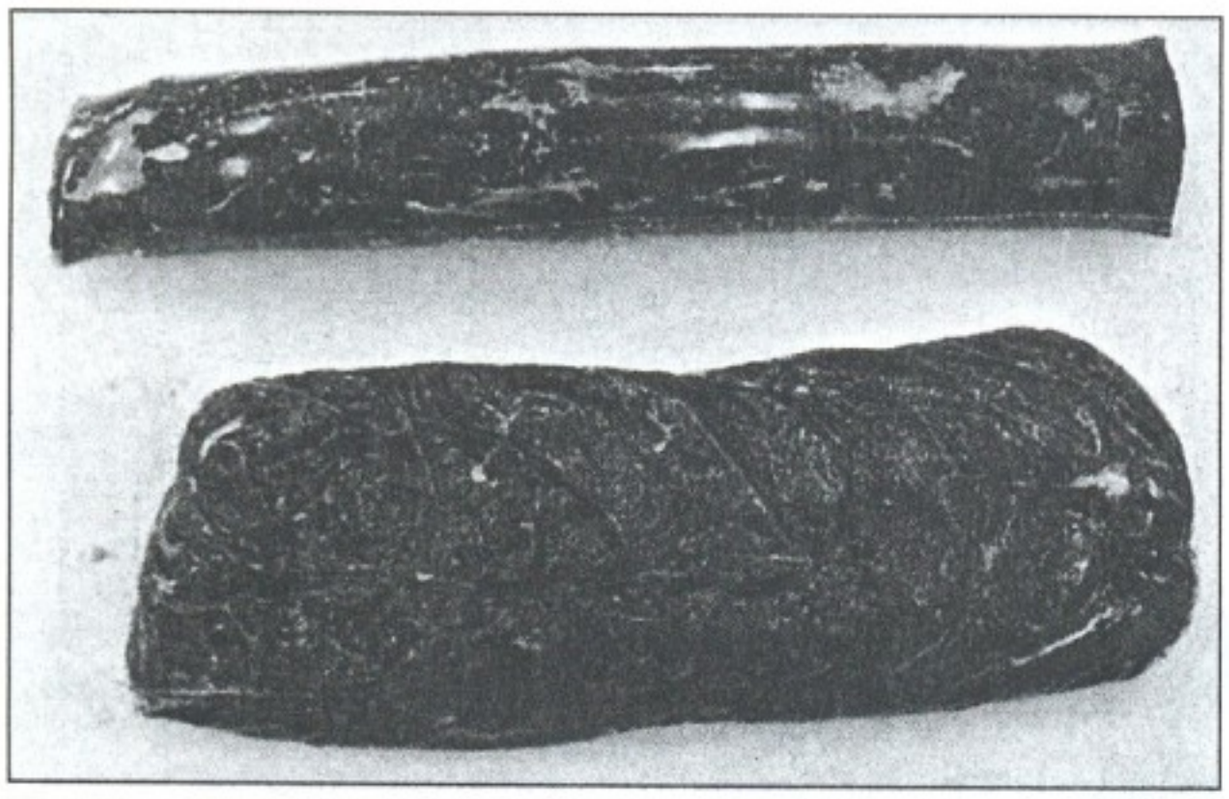

Fig. 12: Whole hot boned muscles after nine days of ageing that have been Pi-Vac packed (upper muscle) or vacuum packed (unwrapped; lower muscle) (Exp. 3).

ing was too rapid (unwrapped samples), hot boned beef cuts will become tough and ageing times up to four weeks had only a minor effect on reducing this toughness. Both slow chilling regimes and muscle restriction methods were able to prevent hot boned muscles from extensive shortening and will therefore have a beneficial effect on the tenderness. Thus meat will become tender at an earlier stage post mortem and the level of tenderness can be assured. The results also showed that when an effective method for restricting muscle shortening was used, hot boned beef cuts can be exposed to a faster chilling regime without detrimental effects on tenderness.

Both wrapping using a thin polyethylene film and the use of the Pi-Vac® packaging system fulfil the requirements of a good practical restriction method. The wrapping technique is a simpler system, but also more laborious and time consuming, as the beef cuts after being wrapped must be placed in traditional vacuum bags adding extra production costs for the industry. The Pi-Vac Elasto Pack® film has both the muscle restriction properties due to its orientated elasticity and the same physical and microbiological protective barrier characteristics as traditional vacuum bags. All muscle restriction techniques resulted in round and attractive shapes of the hot boned muscles and also yielded attractive shapes of the muscles when the meat was cut into consumer portioned steaks.

Fig. 13: Sliced hot boned muscles after nine days of ageing that have been Pi-Vac packed (Exp. 3).

Summary

Wrapping hot boned muscles tightly with polyethylene film and additional support with plastic tape reduced Warner Bratzler shear (WBS) force significantly both two and nine days post mortem. Wrapping alone with a polyethylene film produced the same result. The effect of wrapping on WBS force values was of the same magnitude as increasing the chilling temperature of non-wrapped LD muscles from 4 °C to 10-12 °C. Wrapping of LD also resulted in significantly longer sarcomere length (SML) of the rapidly chilled muscles. No significant effect of wrapping on WBS force was observed by wrapping m. semimembranosus (SM) muscles. Neither chilling rate nor wrapping showed overall significant effects on myofibrillar length (MFL). However, a significant interaction between chilling rate and wrapping with regard to MFL was observed. While wrapping resulted in no effect on MFL on LD muscles exposed to slow chilling regimes, a significant effect was found when fast chilling regimes were used. This indicates that both wrapping and slow chilling equally promoted fragmentation of myofibrils during ageing. Also the third muscle restraining method using a commercial packaging system, based on an elastic laminate film (Pi-Vac Elasto-Pack®), reduced muscle fibre contraction during rigor development. A reduction in muscle shortening and significant improved tenderness were observed from increased SML values and from reduced WBS force values. There was a high reproducibility in results between all three experiments and all three muscle restriction techniques were found to be efficient tools for reducing the undesirable effects of cold shortening as a consequence of fast chilling of hot boned LD.

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