Meat characteristics and acceptability of chevon from South African indigenous goats

by

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Abstract

ABSTRACT

Effects of sex, age and pre-slaughter conditioning on the characteristics of South African indigenous goat carcasses (weight, dimensions, and joint and tissue composition) and quality of chevon (pH and temperature profiles, histological, histochemical, metabolic, proteolytic and physical) were determined. Effects of post-mortem ageing and electrical stimulation on the quality of chevon were also investigated. The nutritional quality of chevon in terms of fatty acid and amino acid content was assessed. The acceptability of chevon compared to mutton was tested by a panel of South African consumers.

The goats were large with live weight, carcass weight and carcass dimensions in the range of the large breeds of southern Africa. They had a high lean and low fat content that is typical of most goat breeds. Intact males were suited for high chevon yield because they were heavy, had a high lean and low fat content, and losses during dressing and chilling were reduced by improved nutrition. Goats between two and six teeth yielded heavy carcasses that were comparable to goats in the eight teeth group, and had proportionately more lean. The hind limb appeared to be ideal for high lean and low fat high value cuts but the dorsal trunk was bony and yielded less lean. Pre-slaughter conditioning improved the overall size of the goats and reduced the losses during slaughter and chilling. It also improved the lean/bone and lean and fat/bone indices.

The *M. longissimus thoracis* (LT) had a low glycolytic potential (GP), high initial lactate concentration, low initial pH and high ultimate pH (pHu) values, all of which indicated that peri-mortem handling of goats was a potent stressor. Chevon from carcasses with pHu<5.8 had higher initial GP, glycogen and ATP content. It had longer sarcomeres, low 96-hour shear force values and better colour quality than higher pH meat. Similarly, chevon from the 2-teeth group tended to have lower pHu values than contemporary groups and hence lower 96-hour shear force values and better colour quality. Conversely, mature does tended to have high pHu and hence a high mean 96-hour shear force value and a low mean a* value associated with dark cutting meat. Only up to 20% of the muscle samples had a pHu<5.8. Pre-slaughter conditioning had no effect on GP and pHu but enhanced the rate of pH and temperature decline and resulted in more tender meat with higher a* values.

Generally carcasses with a 3-hour pH (pH_3) of less than 6.1 were heavier, had more carcass fat, maintained a high temperature early post-mortem, had longer sarcomeres, better colour quality and lower 24-hour shear force values than those with a pH_3 of 6.3 or greater. *M. longissimus thoracis* and *M semimembranosus* (SM) samples with pH_3<6.1 constituted less than 22% of the samples.

The LT and SM had different myofibre proportions. Myofibre types were not useful indices of meat quality. The level of immediate post-slaughter calpastatin activity suggests that the proteolytic potential of chevon is not essentially different from that of other meat types.

Ageing and electrical stimulation improved tenderness and colour quality of chevon. Electrical stimulation increased the rate of pH decline to levels outside the risk of cold shortening as well

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as the ageing potential of chevon such that the meat attained tenderness that was within the acceptable limits for four days of ageing.

Chevon had high levels of PUFA, particularly C18:2, which were similar to values reported for ostrich. The high C18:2/C18:3 ratio suggested that the n-6/n-3 fatty acid ratio would be much higher than the recommended ratio of less than four. Most of the fatty acid proportions fell within the ranges that have been reported for chevon and other red meat species. Age and sex of the goats had no significant effect on the fatty acid profile but pre-slaughter conditioning resulted in lower levels of C14:0 and total SFA, and increased levels of C18:1 and hence MUFA. The amino acid proportions suggest that there is no variation in the amino acid profile between *M. longissimus lumborum* muscles from goats of different age or sex classes.

Level of education of the consumers was most important in determining consumer acceptance of the sensory attributes as well as the intended frequency of consumption for chevon and mutton. Population group was a significant factor only when the meats were of more variable acceptability.

Sensory evaluations indicated that chevon and mutton were highly acceptable to the consumers, who were willing to eat any of the meats at least once a week. The study indicated that chevon is acceptable to South African consumers and may be as acceptable as mutton if the meat is from goats of about two years old or younger.

South African indigenous goats may yield high quality chevon, with a low pHu and acceptable colour provided that the meat is from large carcasses (~15kg) with a high fat content (at least 7%) and is not from mature does.

Declaration

I declare that this thesis for the PhD (Animal Science) degree at the University of Pretoria has not been submitted by me for a degree at any other university.

Signed ……..

Langelihle Simela

Summary

Meat characteristics and acceptability of chevon from South African indigenous goats

by

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Experiments were conducted to determine the effects of sex, age and pre-slaughter conditioning on carcass and chevon quality of South African indigenous goats. Effects of post-mortem ageing and electrical stimulation on chevon quality were also investigated. The nutritional quality of chevon in terms of fatty acid and amino acid content was assessed. The acceptability of chevon to South African consumers and in comparison to mutton was tested.

Eight-nine milk- to 8-teeth female and milk- to six-teeth intact male and castrated South African indigenous goats were procured and raised at the experimental farm on a maintenance diet of a pelleted concentrate mix fed at about 3% of total animal weight per pen. Clean water and *Eragrostis curvula* hay were available ad libitum. The goats were slaughtered at a research abattoir after 17 hours in liarage and under conditions similar to those employed in the meat industry in South Africa. All goats were electrically stunned and a subset of four castrates with 4-to-6 permanent incisors and nine 8-teeth does from both the non-conditioned and pre-slaughter conditioned groups were electrically stimulated immediately after exsanguination.

Temperature and pH profiles, sarcomere lengths (SL), myofibrillar fragment lengths (MFL) and myofibre types (MFT) were determined from both the *M. longissimus thoracis et lumborum* (LTL) and the *M. semimembranosus* (SM). Glycolytic potential (GP), ATP and creatine phosphate concentrations, calpastatin activity, fatty acid and amino acid profiles, crude fat and crude protein determinations and sensory analysis were carried out on LTL. Cooking losses, shear force values and colorimetric values of the SM were determined. Separable lean, bone and intermuscular and subcutaneous fat composition of the carcasses were determined from dissections of the right halves.

The goats were large with mean slaughter weights ranging from 27.83±3.81kg to 42.65±3.92kg and cold carcass weights (CCW) ranging from 11.81±2.43 kg to 16.91±2.88kg between the milk-teeth and 8-teeth groups. Chest girth ranged from 71.05±3.44 to 84.09±2.39cm and carcass length from 66.26±3.73 to 74.96±3.22cm between the milk- and 8-teeth groups. Slaughter weight, hot carcass weight (HCW), CCW and carcass dimensions all significantly increased with age of the goats ($P<0.0001$). Intact males and castrates had similar slaughter weight, HCW and CCW that were heavier than those of female goats ($P<0.01$). Intact males had the largest frames

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with mean chest depth and carcass length that were bigger than those of castrates and females (P<0.01). Pre-slaughter conditioning resulted in increased slaughter and carcass weights, carcass dimensions and *M. longissimus thoracis* (LT) area (P<0.05).

Dressing out percentage (DO%) was not affected by sex and age of the goats (P>0.05). Pre-slaughter conditioning resulted in 16% higher DO% and 30% lower chilling losses (P<0.0001). Chilling losses did not vary with the sex of the goats (P>0.05) but were higher for the 2-teeth goats compared to the milk-teeth, 4-to-6 teeth and 8-teeth groups (P<0.05).

Proportionately, carcasses with a higher carcass fat percentage had lower lean percentage. Thus females and castrates had a 6.2% higher carcass fat percentage and 3.2% lower lean percentage than intact males. Similarly, the full-mouthed does had the highest carcass fat percentage of 16.08±8.25 amongst the four age groups and a low lean percentage of 62.13±5.81 (P<0.05). Non-carcass fat content was not affected by sex (P>0.05). There was more of this fat in carcasses of the 8-teeth does than those of younger goats (P<0.001) and in pre-slaughter conditioned than non-conditioned goats (P<0.0001).

Lean/bone and lean and fat/bone indices were not affected by sex and age of the goats (P>0.05). Overall means for the indices were 2.95±0.38 lean/bone and 3.67±0.68 lean-and-fat/bone ratios. Pre-slaughter conditioning resulted in lower percentages of lean and bone (P<0.0001), increased carcass and non-carcass fat content (P<0.0001) and higher lean/bone and lean and fat/bone yield indices (P<0.001).

Amongst the joints of the carcasses, the hind limb had the more ideal composition for high lean and low fat cuts. The dorsal trunk was bony and yielded less lean.

On average the intact males had a significant 2.4% units more weight in the neck and about 1.5% units less weight in the hind limb compared to the females and castrates (P<0.01). Fore limb, dorsal trunk and ventral trunk percentages did not differ significantly amongst the sexes (P>0.05). Overall mean proportions of these joints were 19.08±1.39%, 20.74±1.58% and 18.31± 2.42%, respectively. The proportions of the hind limb and ventral trunk only varied with age. Hind limb percentage was highest in the younger goats and least in the 8-teeth does while ventral trunk proportions were in the reverse order.

Generally the goats had a low initial GP (mean = 101.74±23.21µmol/g), low initial pH (mean = 6.54±0.29), high initial lactate concentration (mean = 30.19±10.57µmol/g) and high pHu (mean = 5.93±0.14), which indicate that they suffered stress during peri-mortem handling. The GP metabolite concentrations, pH and temperature were not affected by the sex of the goats (P>0.05). However mature does had the highest *M. longissimus thoracis* pHu of 6.03±0.19 (P=0.04), the lowest SM a* value of 11.41±3.41 (P=0.002), and hence the lowest chroma value (P=0.003) and tendency to yield tougher chevon (96-hour shear force = 77.39±18.54N). Pre-slaughter conditioning did not improve the response to peri-mortem handling for any of the age and sex groups (P>0.05).

Summary

The average myofibre type ratios (red: intermediate: white) were 26:33:41 in the LTL and 29:37:34 in the SM. Pre-slaughter conditioning resulted in a higher intermediate myofibre percentage (P=0.04) only. Castrated males had a lower proportion of white myofibre than intact males at the 2-teeth stage (P<0.05). Red and intermediate myofibre proportions were not affected by age and sex (P>0.05). Myofibre types were not useful indices of meat quality.

The level of immediate post-slaughter calpastatin activity (mean = 3.18 ± 0.81U/g sample) suggests that the proteolytic potential of chevon is not essentially different from that of other meat types. Calpastatin activity was not affected by the age of the goats (P>0.05) but was significantly higher for pre-slaughter conditioned intact males compares to the non-conditioned ones (P<0.05). Calpastatin activity in the LTL of castrates and females was not affected by pre-slaughter conditioning.

Intact males had a lower 24-hour a*, and hence chroma value than the females and castrates (P<0.05). Pre-slaughter conditioning resulted in lower 96-hour shear force values, more so for castrates than females. Pre-slaughter conditioning reduced the variation of tenderness amongst the different age groups, leading to more uniform and lower 96-hour shear force values. Myofibrillar fragment lengths, cooking losses, L* and b* values of the SM were not affected by sex, age and pre-slaughter conditioning (P>0.05).

The rates of post-mortem glycolysis and carcass chilling and pHu were important determinants of chevon quality. Larger and fatter carcasses were glycolysing fast (pH_3<6.1), maintained high early post-mortem temperature (mean 3-hour LT temperature =16.38±3.48°C) and resulted in significantly better SM colour (24-hour a* = 15.71± 1.99) and longer 24-hour SL (mean = 1.85±0.20µm). The lower values of these traits were associated with muscles with pH_3>6.3. *M. longissimus thoracis* and SM samples with pH_3< 6.1 constituted less than 22% and those with pH_3>6.3 more than 54% of the samples.

On average, carcasses with *M. longissimus thoracis* pHu ≤6.0 had 27.73µmol/g higher GP, 11.5µmol/g more glycogen, 0.52µmol/g more ATP than carcass with a pHu > 6.0 (P<0.05). Carcasses with *M. semimembranosus* pHu<5.8 had the highest a*, b* and chroma (P<0.01) values at both 24- and 96-hours post-mortem. Low pHu chevon also had a mean 96-hour shear force value that was 18N (P=0.005) less than the average 70N of the carcasses with a SM pHu >5.8. Up to 20% of the muscle samples had a pHu<5.8.

Ageing the meat for up to 96 hours improved the tenderness of both muscles. This was expressed in decreased MFL and shear force values of the SM. Ageing also improved colour quality such that differences that occurred at 24 hours post-mortem had disappeared by 96 hours post-mortem.

Electrical stimulation (ES) of chevon improved the rate of pH decline to levels outside the risk of cold shortening (mean *M. longissimus thoracis* pH_3 = 6.37±0.25 for NES vs. 5.90±0.14 for ES carcasses). ES had no effect on LTL sarcomere and myofibrillar lengths. In the SM muscle, ES resulted in more tender meat 24 hours post-mortem (mean 24-hour shear force = 77.97±17.26 N for NES vs. 50.39±10.17N for ES carcasses) and a greater rate of tenderisation to 96 hours post-mortem (Mean 96-hour shear force = 74.47±16.96N for NES and 40.86±8.92N for ES carcasses).

Summary

Electrical stimulation resulted in tenderness levels that were within the acceptable limits as defined for lamb and beef. Electrical stimulation also improved the colour of chevon (mean 24-hour a*= 11.86±3.31 for NES vs. 14.56±1.99 for ES), even after ageing for 96 hours mean 96-hour a* = 13.67±2.23 for NES vs. 15.46± 1.38 for ES carcasses). Colour and tenderness were improved despite the high pHu of chevon.

The polyunsaturated fatty acid (PUFA), particularly C:18:2 content of chevon from the South African indigenous goats was high. The overall mean percentages were 18.35±5.74 PUFA and 17.62±5.45 C18:2. Consequently the PUFA/SFA and C18:2/C18:3 ratios were high and typical of grain-fed ruminants. Age and sex of the goats had no significant effect on the fatty acid profile. However, pre-slaughter conditioning resulted in a lower concentration of C14:0 and total saturated fatty acids (SFA), and increased concentration of C18:1, and hence monounsaturated fatty acids (MUFA). Pre-slaughter conditioning did not affect the PUFA content (P>0.05).

There was little variation in amino acid profile with age-class of the goats. Alanine and tyrosine only were significantly affected by the class of the goats (P<0.05). Both amino acids were least concentrated in LL of 2-to-4 teeth females and most concentrated in LL of mature does.

Level of education was the most important consumer characteristic in determining acceptance of the sensory attributes as well as the intended frequency of consumption for the meats. Consumer age and gender were important factors in some cases but population group was a significant factor in the judgement of meats of more variable sensory attributes.

The sensory evaluations indicate that chevon and mutton were highly acceptable (range of mean overall acceptability = 3.79 to 4.27) to consumers, who were willing to eat any of the meats at least once a week. The study indicated that chevon is acceptable to South African consumers and may be as acceptable as mutton if the meat is from goats of about two years old or younger.

It is concluded that South African indigenous goats belong to the large breed of southern Africa. The goats are highly prone to pre-slaughter stress and hence yield high pH meat with a dark colour. However the goats may yield chevon of acceptable quality with pHu of less than 5.8, high a* values and acceptable tenderness provided that the carcasses are large (~15kg HCW), have a relatively high carcass fat content (≥7%) and are not from old does. Chevon has healthful fatty acid and amino acid profiles regardless of age and sex of the goats. The meat is highly acceptable to South African consumers of diverse backgrounds, especially if it is from goats that are one to two years old.

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LIST OF ACRONYMS

ADP	Adenosine diphosphate
AMP	Adenosine monophosphate
ATP	Adenosine triphosphate
BCFA	Branched chain fatty acids
BF	*M. Biceps femoris*
CCW	Cold carcass weight
DFD	Dark, firm and dry
DO%	Dressing out percentage
EFA	Essential fatty acids
ES	Electrical stimulation
G-6-P	Glucose-6-phosphate
GP	Glycolytic potential
HCW	Hot carcass weight
KKCF	Kidney knob and channel fat
LDH	Lactate dehydrogenase
LL	*M. longissimus lumborum*
LT	*M. longissimus thoracis*
LTL	*M. longissimus thoracis et lumborum*
MCP	Multicatalytic protease
ME	Metabolisable energy
MFI	Myofibrillar fragmentation index
MFL	Myofibrillar fragment length
MFT	Myofibre type/typing
MSA	Meat Standards o Australia
MUFA	Monounsaturated fatty acids
pH_0	Initial pH
pH_3	pH at 3 hours post mortem
pH_6	pH at 6 hours post mortem
pH_{24}	pH at 24 hours post mortem (same as pHu)

List of Acronyms

pHu	Ultimate pH = pH_{24}
PUFA	Polyunsaturated fatty acids
SAMIC	South African Meat Industry Co-operation
SDH	Succinate dehydrogenase
SFA	Saturated fatty acids
SL	Sarcomere length
SM	*M. Semimembranosus*
ST	*M. Semitendonosus*
TAG	Triacylglycerides
TCA	Tricarboxylic acid cycle
UFA	Unsaturated fatty acids
WBS	Warner-Bratzler shear force
WHC	Water holding capacity

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CHAPTER 1

1 INTRODUCTION

1.1 PROJECT THEME

Meat quality

1.2 PROJECT TITLE

Meat characteristics and the acceptability of chevon from South African indigenous goats

1.3 AIMS

The aims of this study were to:

- Study carcass characteristic and histological, histochemical, metabolic, proteolytic and physical characteristics of chevon from South African indigenous goats of different ages, sex and nutritional history in order to determine the groups that yield meat of acceptable quality.
- Determine the effects of post-mortem ageing and electrical stimulation on quality characteristic of chevon.
- Determine the nutritive value of chevon in terms of fatty acid and amino acid profiles.
- Investigate consumer acceptance of, preference and consumption intent for chevon and determine the age and /or sex groups that are most acceptable.

The following objectives were investigated, namely whether or not:

1) sex, age and pre-slaughter conditioning have an effect on carcass and chevon quality of South African indigenous goats.
2) length post-mortem ageing and electrical stimulation have an effect on chevon quality.
3) chevon is nutritionally well-balanced for human consumption.
4) chevon from goats of different ages/sex groups is acceptable to South African consumers.

1.4 MOTIVATION

Goats are the second most populous ruminant livestock in developing countries. Over the past two decades, their population in these countries increased by over 50% and chevon production

by 121% to 3.44 million tonnes per annum (Morand-Fehr and Boyazoglu, 1999). Thus, chevon will continue to play a prominent role in the supply of animal protein in developing countries.

In southern Africa, goats constitute an important subsystem of animal agriculture particularly for the region's semi-arid and arid areas (Webb, Mamabolo, Du Preez and Morris, 1999). Generally, uncharacterised, indigenous breeds are kept in flock sizes that vary from as small as one to well over a hundred goats (Sibanda, 1992; Bembridge and Tapson, 1993; Simela, 1993; Simela, Ndebele and Ndlovu, 2000a; Webb et al., 1999; Láforte, 1999; Mahanjana and Cronjé, 2000). In these areas goats are often the only dependable and perennial agricultural output. Panin and Mahabile (1997) and Teufel, Kuettner and Gall (1998) showed that for little investment, goats may be an easy income-generating venture for the smallholder farmers, especially those with limited or no off-farm income.

Productivity indicators such as mortality and utilisation rates (sales and home slaughter) reveal that goat productivity in smallholder farming areas is low. Although 'sales for cash' is always given as the farmers' primary economic reason for keeping goats (Mahanjana and Cronjé, 2000, Simela, Sibanda, Mello and Vaz, 2000b), the proportion of goats that are sold compared to the losses (due to diseases, thefts and predation) is not representative of the importance of goats in income generation (e.g. Figure 1.1). The sales usually constitute less than 20% of all exits from the smallholder flocks while the losses are usually well over 50% of the exits (Figure 1.1; Scoones, 1992; Sibanda, 1992; Simela, 1993; Láforte, 1999). The wastage through deaths and other losses has been reported to amount to 85% of the combined value of the slaughtered and sold animals (Simela et al., 2000b). In Zimbabwe, only 2% of the rural goat flocks ever reach the urban markets (Sibanda, 1992; Simela et al., 2000b).

The findings reported by Simela et al. (2000b) were not unique to Zimbabwe. Similar trends were observed in concurrent studies that were conducted in Zambia (Ahmadu and Lovelace, 2002) and Mozambique (Láforte, 1999), and in earlier studies conducted in Zimbabwe (Scoones, 1992; Sibanda, 1992; Simela, 1993; Pradier, Lecroisey and Gauthier, 1995; Ndlovu and Simela, 1996) and Botswana (Panin and Mahabile, 1997, Seleka, 2001). The poor productivity has been attributed the fact that the rural farmers have limited or no access to formal markets, and hence no incentive to improve their goat husbandry practices (Devendra, 1994; Seleka, 2001).

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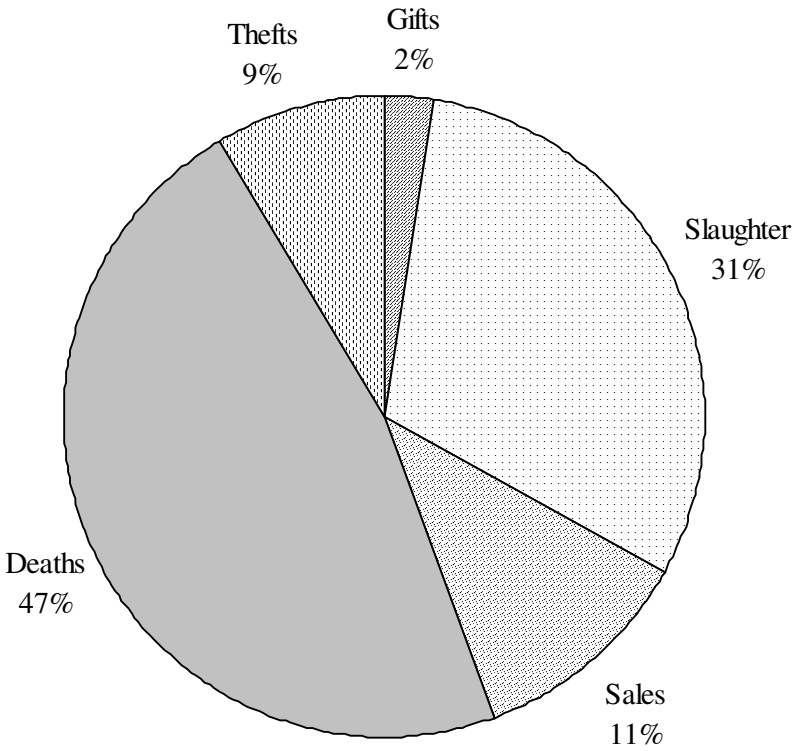

NB The data are of 78 flocks from two villages in Matabeleland South province of Zimbabwe, monitored over one year. The average flock size was 25 and the total exits during the survey were 372 goats.

Figure 1.1 Distribution of goats by manner of exit from smallholder flocks (Simela et al., 2000b)

Urban markets are viewed as potentially lucrative markets for chevon (Pradier et al., 1995; USAID/South Africa and ARC, 1998a and b). The development of the urban chevon markets could therefore be an incentive for improving the performance of smallholder goat enterprises. In view of this, studies of goat production and marketing have been undertaken to identify ways by which goat marketing may possibly be improved in Zimbabwe (Pradier et al., 1995), South Africa (USAID/South Africa, 1998a and b) and a number of southern African countries under the auspices of a European Union funded project (European Union Project TS3*-CT94-0312). The major findings in Zimbabwe were that there is a large, unfulfilled demand for chevon in the urban centres (Simela, 2000). At the same time, retailers were dissatisfied with the quality of the chevon. They contended that the carcasses are too small and of low grade, and that the meat is dark and dries up quickly during storage (Simela, 2000).

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In South Africa there are no published estimates of the volume of goats entering the various marketing channels but it is supposed that most are marketed through the informal sector while sales through the formal channels (i.e. auctions, speculators, butcheries and abattoirs) are very limited (Coetzee, 1999). Notable is that the number of goats sold through the formal markets has been declining over the years. For example, in 1997, about 0.55% of the goat population was slaughtered in the commercial abattoirs (Coetzee, 1999; Table 1.1). Although 64% of the goat population is found in the rural areas (Table 1.1) a large proportion of the slaughtered stock came from commercial farms.

Table 1.1 Goat populations, proportion in the rural areas and slaughter rate by Provinces in South Africa

Province	Total no. of goats (November 2003)	% in rural areas (1999 estimates)	Slaughter rate (%)† (1999 estimates)
Western Cape	243 387	0	4.02
Northern Cape	494 979	0	0.15
Free State	70 521	13	4.37
Eastern Cape	3 022 155	59	0.64
KwaZulu-Natal	927 578	86	0.10
Mpumalanga	103 423	59	0.25
Limpopo	1 048 771	95	<0.01
Gauteng	8 349	0	0.58
North West	761 673	86	0.04
Total	6 680 836	64	0.55

† Slaughter rate is expressed as a percentage of the total number of goats.

Source: SAMIC website and adaptation from Coetzee (1999)

From informal interviews with the Red Meat Abattoirs Association (RMAA), South African Meat Industry Co-operation (SAMIC) Provincial Heads and abattoirs in the year 2000, indications were that commercial slaughter had decreased significantly, because none of these organisations was aware of any abattoirs that were slaughtering goats. The reasons given for the decline in commercial slaughter were that the supply of goats to the abattoirs was inadequate to justify regular slaughter and the price of commercially produced chevon was too high for the market.

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The market surveys carried out in 1998 (USAID/South Africa and ARC-ANAPI, 1998a and b) indicated that South African urbanites associate chevon with traditional and religious ceremonies rather than with day-to-day consumption (USAID/South Africa and ARC-ANAPI, 1998a, Figure 1.2i), an observation that was also made by Mahanjana and Cronjé (2000). Although the respondents in the USAID and ARC-ANAPI surveys described chevon as smelly, stringy and tough (Figure 1.2ii); a sizeable fraction from different levels of education, economic and ethnic backgrounds expressed willingness to try out chevon once it was drawn to their attention. Only about 2.5% of the respondents actually consumed chevon on a regular basis. However, some 49% of the survey population consumed the meat occasion or used to eat it, had stopped for some reason but were interested in eating again; or had never consumed the meat but were willing to try it (Figure 1.3).

Despite the general lack of familiarity with, and the negative perceptions of chevon, consumers and trained taste panels in sensory studies have found the meat or its products desirable and of satisfactory quality (Breukink and Casey, 1989; Schönfeldt, Naudé, Bok, van Heerden, Smit and Boshoff, 1993a; Schönfeldt, Naudé, Bok, van Heerden, Sowden and Boshoff; 1993b) except when the meat had been from very young animals (Tshabalala, Strydom, Webb and de Kock, 2003). In that case the chevon was very tough, possibly due to cold shortening.

The studies done thus far establish that prior to the development of the chevon industry in South Africa and the southern African region, there is a need to develop a quality evaluation system for chevon that will ensure that meat of acceptable quality is distributed to the consumers. Doing so entails an understanding of the quality of chevon from the indigenous goats slaughtered under commercial conditions. The knowledge may then be used as a basis for the improvement of the meat. All this should be done to ensure that from the onset, consumers are exposed to chevon of acceptable quality and hence no misconceptions are cultivated.

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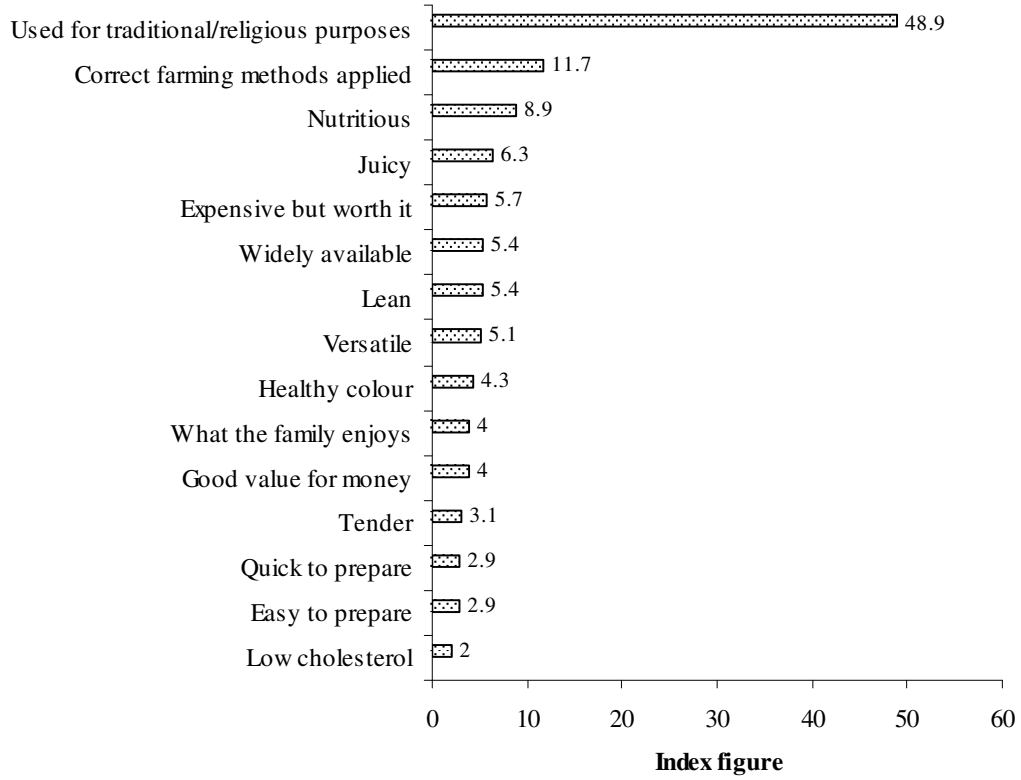

ii)

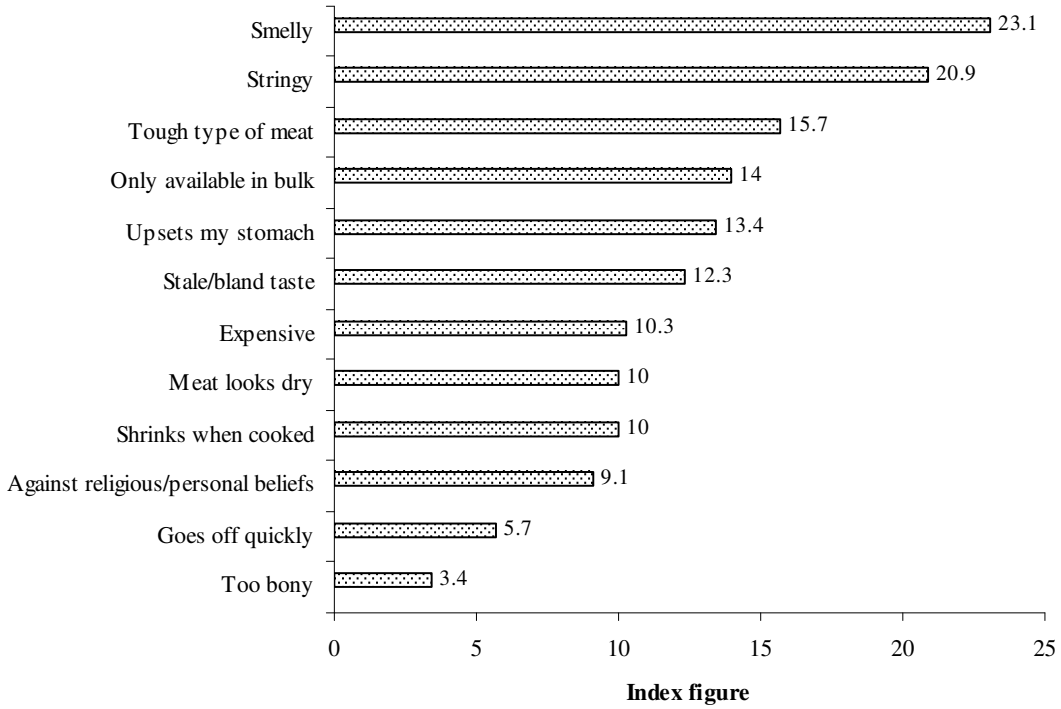

Figure 1.2 i) Positive and ii) negative perceptions of chevon by South African consumers (USAID/South Africa and ARC-ANAPI, 1998a)

CHAPTER 1

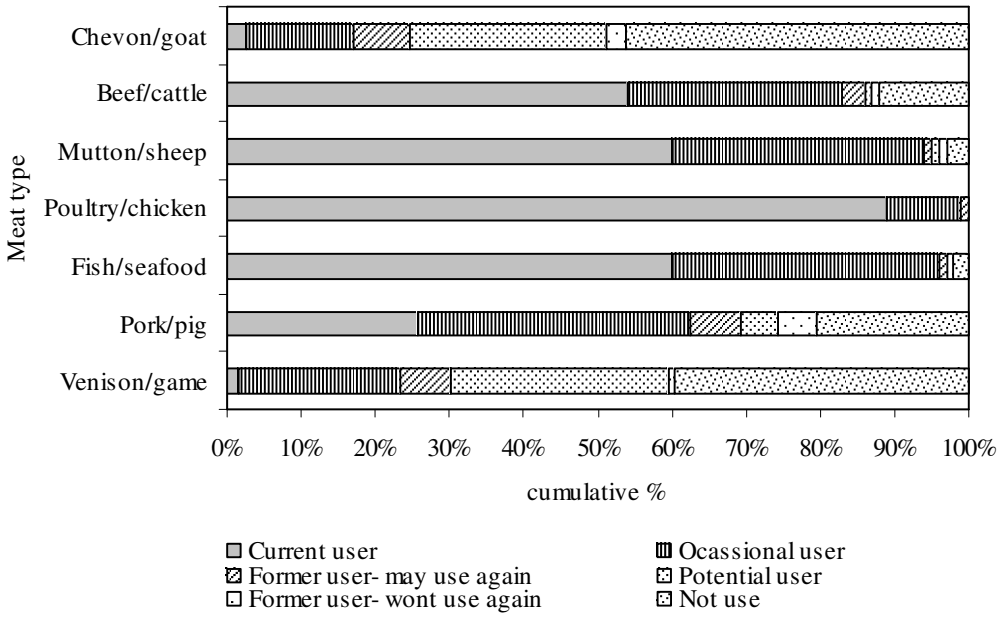

Figure 1.3 South African consumers' behaviour towards various types of meat (USAID/South Africa and ARC-ANAPI, 1998a)

CHAPTER 2

2 LITERATURE REVIEW

2.1 DETERMINATION OF MEAT QUALITY

The properties of meat are determined by several factors spanning from the conception of the animal to the consumption of the meat (Hofmann, 1994). These factors determine the quality of meat as described by indices such as pH, colour, tenderness, flavour, juiciness and nutritive value. In this section, some of the major processes in the evolution of meat quality are reviewed, focusing on how they affect meat quality in general and the quality of chevon specifically.

2.1.1 Myofibre and muscle metabolic types

Muscles are classified into metabolic types on the basis of their predominating myofibre types. There are four myofibre classes which are determined by the metabolic and contractile properties of their constituent myofibres. The three major types are the red (type I or β-red); intermediate (type IIA or α-red) and white (type IIB or α-white) (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971). The fourth class, type IIC exists commonly in neonates and is a transitory link in the formation of types IIA and IIB (Young, 1984; Brandstetter, Picard and Geay, 1998a).

Type I myofibres are the smallest in diameter (Rosser, Norris and Nemeth, 1992). They are associated with more blood capillaries, a high lipid, myoglobin, mitochondria and tricarboxylic acid (TCA) cycle enzyme content to suit their high oxidative metabolism (Essén-Gustavsson, Karlström and Lundström, 1992). Strong succinate dehydrogenase (SDH) activity is thus used to identify the myofibres histologically (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971; Swatland, 1981). At the other end, type IIB myofibres are the largest (Rosser et al., 1992). They hold more readily available energy compounds such as creatine phosphate, adenosine triphosphate (ATP) but less glycogen than red muscles (Monin, 1981; Rosser et al., 1992). Histologically they are distinguished by strong ATPase and lactate dehydrogenase (LDH) activity but weak SDH activity (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971; Swatland, 1981). Type IIA myofibres are intermediate in size (Rosser et al., 1992). Their metabolic activity however may either be greater than or intermediate between type I or type IIB depending on the species considered (Ashmore, Tompkins and Doerr, 1972; Monin, 1981).

In line with myofibre classification, muscles are classified into red (type I), intermediate (type IIA) and white (type IIB). Red muscles have a high proportion of type I myofibres. They are

predominantly postural muscles (e.g. *M. trapezius*[*] in the shoulders; *M. semimembranosus* in the hind leg), with high oxidative capacity to meet the requirements for stamina (Totland and Kryvi, 1991; Essén-Gustavsson, 1996). Muscles involved in locomotion (e.g. *M. semitendonosus* in the hind leg) have a higher glycolytic than oxidative capacity for rapid contraction and so are dominated by the type IIB myofibres. Within individual muscles there is a topographical variation in myofibre type. For example, deeper regions of *M. semitendonosus* (ST) tend to be darker and more oxidative than outer ST regions (Dreyer, Naudé, Henning and Rossouw, 1977; Hunt and Hedrick, 1977; Totland, Kryvi and Slinde, 1988). In addition, deep type IIB myofibres are more oxidative and have smaller diameters than the superficial ones (Rosser et al., 1992).

Muscle metabolic type is also influenced by variations between animals, such as species, breed, sex, age, weight, nutrition and exercise (Essén-Gustavsson, 1996). An example of species differences is the classification of some ovine and bovine muscles (Figure 2.1). The remarkable features of this classification are that, firstly, the type IIA ovine muscles are more glycolytic than the type IIB and more oxidative than the type I. In cattle however, type IIA muscles are intermediate between type IIB and type I in glycolytic and oxidative activities. Secondly, the same muscle may classify differently in different species. For instance whereas the *M. semimembranosus* (SM) muscle is type IIA in sheep, in cattle it is type IIB (Monin, 1981).

Sex and age effects on myofibres were illustrated by Spindler, Mathias and Cramer (1980) who reported a twofold increase in the cross-sectional area *of M. biceps femoris* (BF) myofibres in steers and heifers ranging from 28 to 392 days old. As the animals grew the myofibre profile increased in type IIB and decreased in type IIA. Such changes in myofibre size and profile were also observed in later works (e.g. Seideman, Crouse and Cross, 1986; Jurie, Robelin, Picard and Geay, 1995; Brandstetter et al. 1998a). They are a result of the general differentiation pathway of type I → type IIA → type IIB (Ashmore et al., 1972) during early stages of muscle hypertrophy.

[*] The muscle nomenclature system used is that described by Kauffman, Habel, Smulders, Hartman and Bergström (1990).

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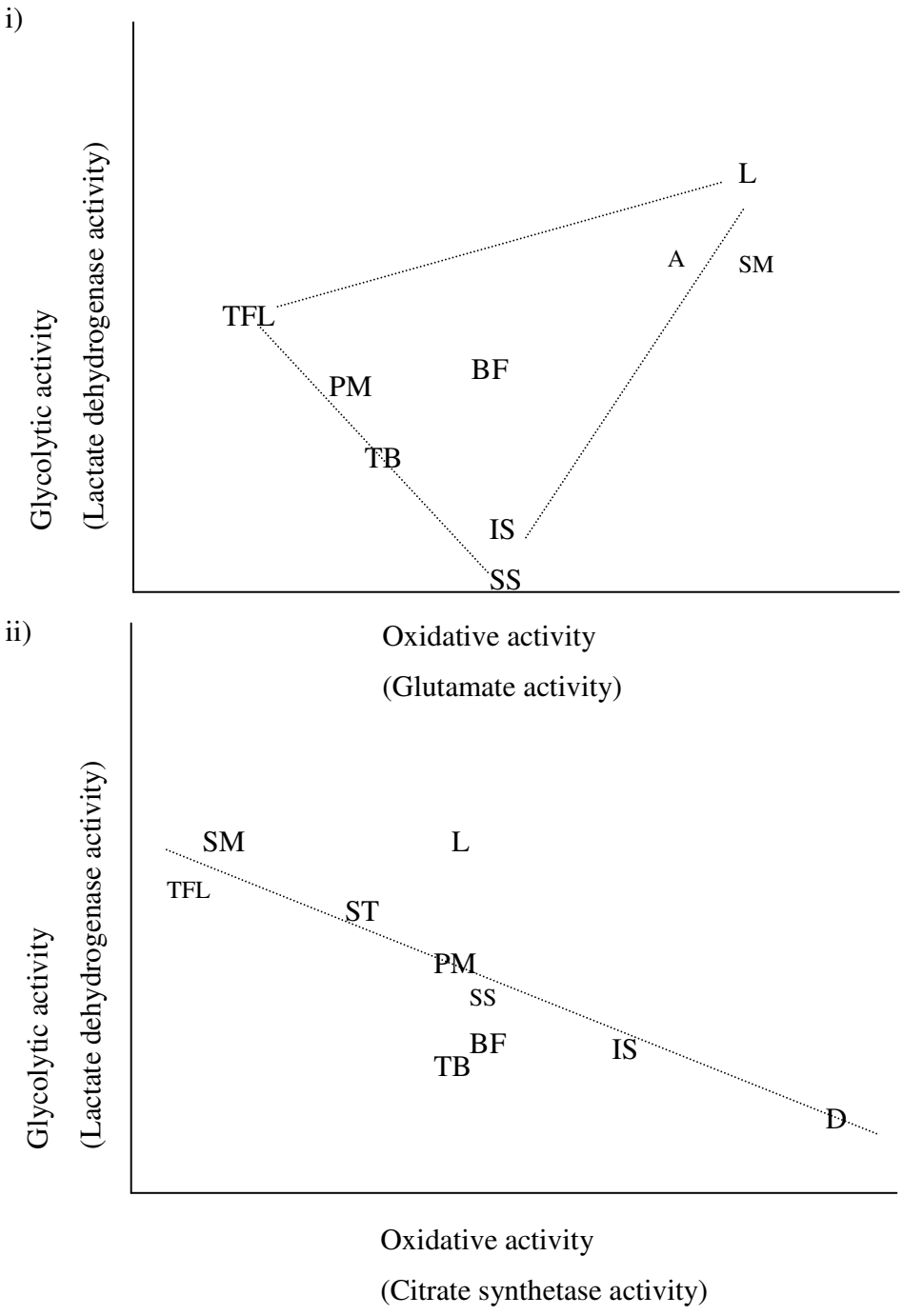

NB

A	*M. Adductor*	L	*M. Longissimus*	SM	*M. Semimembranosus*
BF	M. *Biceps femoris*	PM	*M. Psoas major*	SS	*M. Supraspinatus*
D	*Diaphragm*	TB	*M. Triceps brachii*	ST	*M. Semitendonosus*
IS	*M. Infraspinatus*	TFL	*M. Tensor fasciae latae*		

Figure 2.1 Diagrammatic representation of relative metabolic types of i) ovine and ii) bovine muscles (Adapted from Monin, 1981)

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Amongst the males, castration effects on muscle fibre type composition are manifested post-pubertally. Most reports, such as Dreyer et al. (1977), Young and Bass (1984), Seideman et al. (1986) and Mohan Raj, Moss, McCaughey, McLauchlan and McGaughey and Kennedy (1991) suggest that the proportion of type I myofibres is relatively unaffected by castration while type IIB increase at the expense of type IIA. Brandstetter, Picard and Geay (1998b) however reported pre-pubertal differences between bulls and steers; that bull calves start showing a tendency to a typical myofibre composition from as early as when they are four months old.

Furthermore Brandstetter et al. (1998b) observed that bulls increased in type I and decreased in type IIB myofibres while steers increase in IIB myofibres, but the proportion of IIA myofibres remained unchanged in both sexes. The argument for these changes was that androgens promote an ageing kind of differentiation in myofibres by favouring a shift to type I myofibres (Powers and Florini, 1975). On the other hand, castration delays this re-conversion, and hence the steers had a myofibre type composition that was physiologically less mature than that of bulls of similar age. Despite the differences in the reports on early myofibre type proportions in bulls and steers, most studies agree that androgens promote myofibre hypertrophy, and hence myofibres of steers, particularly types IIA and IIB, tend to be smaller than those of bulls (Dreyer et al., 1977; Young and Bass, 1984; Seideman et al., 1986; Brandstetter et al., 1998b; Dalle Zotte, Verdiglione, Rémignon, Cozzi, Andreoli, Gottardo and Andrighetto, 2000).

In a study involving the three sex classes, Young and Foote (1984) suggested that the proportion of type I myofibres is unaffected by the sex of cattle but the proportion of type IIB myofibres of females lay between that of bulls and steers. Conversely, the proportion of type IIA myofibre is higher in female cattle than in steers (Johnston, Moody, Boling and Bradley, 1981; Young and Foote, 1984).

Energy restriction leads to a reduction in myofibre size with a strong effect on type IIB atrophy (Yambayamba and Price, 1991; Ward and Stickland, 1993). Conversely, increased dietary energy results in a higher proportion of type IIB and less type IIA myofibres, while high protein diets appear to decrease the proportions of both type IIA and IIB myofibres (Johnston, Stewart, Moody, Boling and Kemp, 1975). Sex effects have been observed in myofibre response to nutrition. Brandstetter et al. (1998b) noted that energy restriction and re-alimentation did not

affect the myofibres of steers. Energy restricted bulls however increased oxidative activity but, on re-alimentation, the physiological: chronological myofibre profile was re-established. Yambayamba and Price (1991) observed a similar re-establishment of 'normal' myofibre composition and size on re-alimentation of previously restricted heifers.

Prolonged physical exertion generally causes age related changes on muscle fibre composition. It increases the proportion of oxidative myofibres, oxidative capacity, capillary density of myofibres, myoglobin content and glycogen storage capacity (Aalhus and Price, 1991). Such changes are expected to result in tough meat because red myofibres have less glycogen, are prone to cold shortening and have thicker z-line that are less susceptible to degradation post-mortem (Aalhus, Price, Shand and Hawrysh, 1991). However, Aalhus et al. (1991) reported tender SM from exercised compared to none exercised sheep. This was alluded to the increase in the myofibrillar-to-collagen protein ratio with exercise than to changes in myofibre type composition.

2.1.1.1 Implications of myofibre composition on sampling for meat quality evaluation

Variations in myofibre composition within muscle in addition to the inter-muscle differences suggest that representative sampling procedures should be employed for meat quality evaluations. In the majority of meat science studies, the *M. longissimus thoracis et lumborum* (LTL) is used as the standard muscle for the evaluations. However, in goats this muscle is too small to obtain enough samples for all the standard procedures and hence other muscles such as the SM have also been used along with the LTL muscle (Babiker, El Khidir and Shafie, 1990; Schönfeldt et al., 1993a and b; Swan, Esguerra, and Farouk, 1998). There has been a suggestion that the two muscles are of similar type in cattle and sheep (Pethick, Cummins, Gardner, Jacobs, Knee, McDowell, McIntyre, Tudor, Walker and Warner, 2000) but there is no known classification of these muscles in goats. An understanding of the myofibre profile of the both the LTL and SM of goats would therefore be beneficial in making inferences on quality attributes observed on these muscles.

2.1.2 Conversion of Muscle to Meat

The stoppage of blood circulation at slaughter initiates a complex series of changes in muscular tissue which may be described in two phases. In the first phase, rigor mortis develops during

which muscles become inextensible and attain maximum toughness (Lawrie, 1998; Warriss, 2000). The major events accompanying rigor development are glycolysis and the denaturation of some proteins; of which the proteolytic enzymes are of particular interest. The second phase, known as conditioning, is characterised by a gradual improvement in tenderness during post-mortem storage, which is largely attributed to the activity of the calpains and other proteolytic enzymes (Lawrie, 1998; Warriss, 2000).

2.1.2.1 Development of rigor mortis

The most immediate change caused by exsanguination is the cessation of oxygen supply to muscles (Lawrie, 1998). Consequently, production of ATP by oxidative respiration is arrested. Anaerobic respiration is stimulated in order to continue to maintain the integrity of cells and the relaxed state of muscles but the amount of ATP produced by this pathway is insufficient to plasticise actin and myosin for long (Tornberg, 1996). Concomitantly, the increasing acidity due to lactic acid production causes denaturation of proteins, including the glycolytic and related enzymes. The regeneration of co-enzymes, such as adenosine diphosphate (ADP) ceases (Greaser, 1986) and all these factors lead to the cessation of glycolysis. The net result is the cessation of the production of ATP and other energy-rich substrates. At extremely low concentrations of ATP (below 5 μmol/g; Warriss, 2000), the myosin filaments of the myofibrils bond with the overlapping actin filaments and the muscle becomes inextensible and rigid; rigor mortis sets in (Goll, Geesink, Taylor and Thompson, 1995).

2.1.2.2 Post-mortem glycolysis

The important aspects of post-mortem glycolysis to meat quality are the rate at which it occurs as well as the extent to which it advances. Intrinsic and extrinsic factors affecting both these processes are listed in Table 2.1.

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Table 2.1 Intrinsic and extrinsic factors affecting the rate and extent of post-mortem glycolysis

Intrinsic factors	Extrinsic factors
Animal species	**Stress**
Genotype	**Pre-slaughter drug administration**
Age	*Environmental temperature*
Temperament	**Post-mortem temperature**
Type of muscle	*Electrical stimulation*
Intramuscular location	*Post-mortem comminution*
Pathology	*Post-mortem salting*
	Post-mortem pressure
	Post-mortem oxygen tension

NB Factors that are in **bold font** affect **both** the rate and extent of glycolysis; in normal font affect the extent only; *italicised* affect the *rate only*

Adapted from Lawrie (1998)

2.1.2.3 Rate of post-mortem glycolysis

Of the extrinsic factors, the effect of temperature on the rate of post-mortem glycolysis is the single most influential factor on meat quality (Pearson and Young, 1989). The glycolytic rate is high at in vivo temperatures and falls as temperature declines to 5ºC (Lawrie, 1998). Within a carcass, various muscles will have different rates of post-mortem glycolysis depending on their myofibre type composition and their location within the carcass. White muscles are better adapted for efficient anaerobic metabolism and so their rate of post-mortem glycolysis can be significantly greater than that of red muscle (Fernandez and Tornberg, 1991; Przybylski, Vernin and Monin, 1994). The differences however may be partly obscured by the influence of the location of the muscle, with the deeper, and hence slow cooling muscles having higher rates than superficial ones.

The general principle in carcass chilling is that the temperature should drop as rapidly as possible to hinder microbial growth (Varnam and Sutherland, 1995). Paradoxically, a fast decline in temperature may result in cold shortening and tough meat. Cold shortening is due to the failure of the sarcoplasmic reticulum and the mitochondria to sequester calcium ions (Ca^{++}) quickly at low temperatures, such as when muscles are cooled to below 10ºC before the onset of rigor

mortis (Cornforth, Pearson and Merkel, 1980; Pearson and Young, 1989). The failure leads to a 30 to 40-fold increase in the concentration of Ca^{++} in the sarcoplasm, which initiates a massive contraction stimulus (Pearson and Young, 1989). If such stimulation occurs while ATP concentration is still high, the resultant contractions deplete ATP; the muscles enter rigor in a contracted state and end up as tough meat (Pearson and Young, 1989).

Cold shortening is common to oxidative rather than glycolytic muscles (Totland et al., 1988; Ceña, Jaime, Beltran and Roncales, 1992). The former have more mitochondria and hence can release more calcium ions, but have a poorly developed sarcoplasmic reticulum and so cannot sequester the Ca^{++} as fast as the white muscles. Cold shortening also occurs more in smaller carcasses, which are poorly insulated and are thus disposed to chilling fast. Consequently, cold shortening is more common in sheep than in cattle (Dikeman, 1996) and may be prevalent in goat carcasses.

Since cold shortening occurs when muscles attain rigor while they still have adequate energy to contract, the recommendation is that the pH of muscles should have dropped to below 6.2 when the temperatures falls to 15ºC and below (Honikel, Roncales and Hamm, 1983; Tornberg, 1996) or below pH 6.0 at 10ºC (Cornforth et al., 1980). To achieve this, a recommended protocol for chilling sheep carcasses is that they be chilled rapidly to 12 - 15ºC, held there for 18 hours and then dropped to below 5ºC (Varnam and Sutherland, 1995). Such a protocol is not acceptable in industry because it disrupts the normal flow through the abattoir and has a high risk of microbial contamination of the carcasses. Another option is to hold the carcasses in such a way that muscles in prime cuts are stretched, and hence are prevented from shortening during chilling at the normal 0ºC to 4ºC. Alternative carcass suspension methods such as tender-stretch and tender-cut have been proposed (Tarrant, 1998; Sørheim, Idland, Halvorsen, Frøystein, Lea and Hikrum, 2000). Above all these methods, electrical stimulation (ES) is widely recommended and employed to avert cold shortening in the meat industry (Savell, Smith, Dutson, Carpenter and Suter, 1977; Geesink, van Laack, Barnier and Smulders, 1994).

Electrical stimulation is the dissipation of ATP and other energy compounds in muscle by passing an electrical current through the muscle to cause intense contractions (Price and Schweigert, 1987). This promotes a rapid fall in pH (Figure 2.2), an earlier onset of rigor mortis

and tenderisation (Dransfield, 1994a). Because the carcass temperature would still be high after stimulation, the sarcoplasmic reticulum can sequester the released Ca^{++} and with the contraction stimulant removed, muscles go into rigor in a relaxed state.

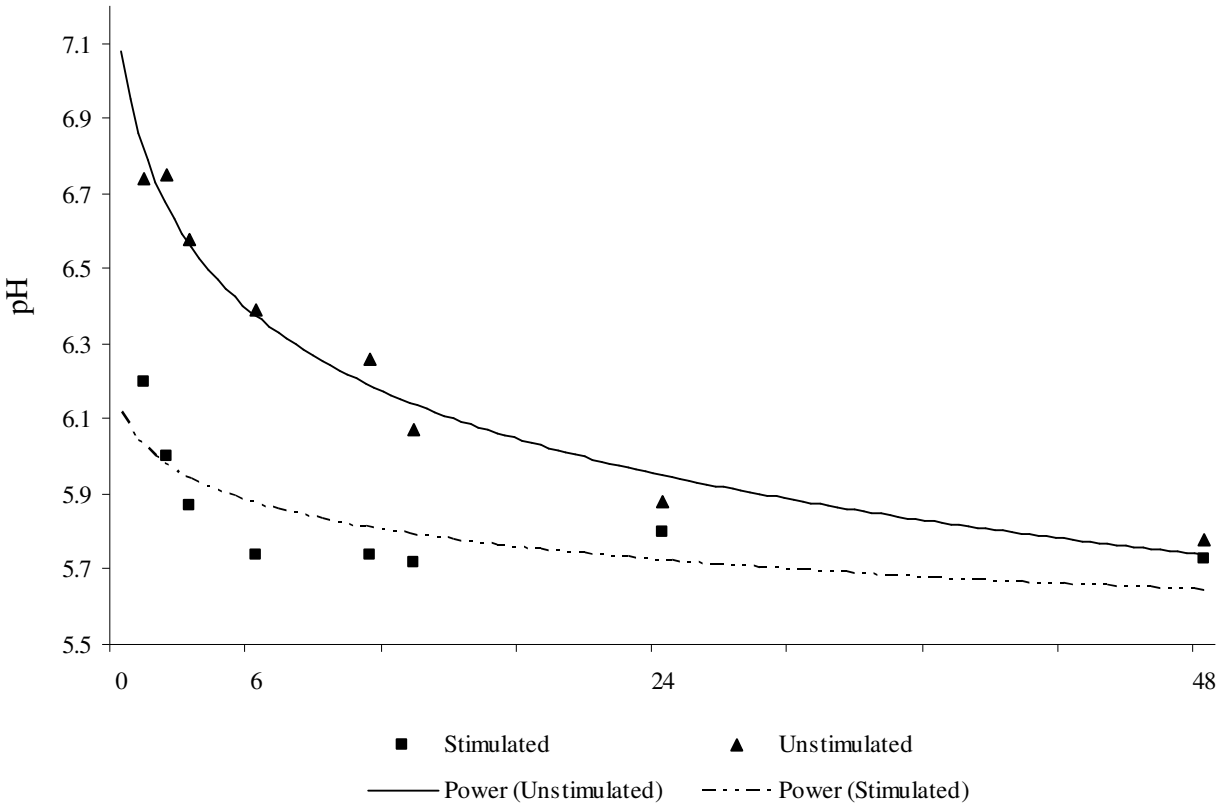

Figure 2.2 Effect of electrical stimulation on the rate of pH decline (Adapted from Geesink, Mareko, Morton and Bickerstaffe, 2001)

2.1.2.4 Extent of post-mortem glycolysis

The extent of post-mortem glycolysis is reflected in the ultimate pH (pHu) attained by muscle. Ultimate pH is dependent on the amount of glycogen available to the muscle at slaughter and is attained when glycolysis ceases but not necessarily when glycogen is depleted (Warriss, Bevis and Elkins, 1989).

The normal glycogen content of skeletal muscle ranges from 30 to 100µmol/g depending on the nutritional status and activity of the animal and muscle type (Bechtel, 1986). Values between 80 and 100µmol/g have been reported for the LTL of well-fed and rested cattle (Warner, Walker,

Eldridge and Barnett, 1998). Glycolysis ceases when the muscle glycogen concentration is about 10µmol/g and lactic acid has increased from about 6-16µmol/g to 80-100µmol/g (Pearson and Young, 1989). The process takes 24 to 48 hours in cattle and some 12 to 24 hours in small ruminants (Dransfield, 1994a). Consequently small ruminant pHu is taken at 24 hours post-slaughter.

The ultimate pH is of particular importance to the chilled meat industry because it directly influences the shelf-life, colour and eating quality of meat (Fernandez and Tornberg, 1991; Przybylski, et al., 1994; Webby, Fisher, Lambert, Daly, Knight and Turner, 2000, Figure 2.3). The desirable range of pHu is 5.5 to 5.8, which is associated with light-coloured, tender meat (Gardner, Kenny, Milton and Pethick, 1999). In the range 5.9 to 6.2, meat is dark, tough, has a high water holding capacity (WHC) and is prone to bacterial spoilage (Warriss, Kestin, Brown and Wilkins, 1984; Warner et al., 1998). Above 6.2, meat has a purplish-black colour, firm texture, dry sticky surface and a reduced shelf-life (van Laack, Smulders and van Lojtestÿn, 1988). Meat with a pHu above 6.0 is associated with the dark cutting condition. The delineation of pH ranges for normal and dark cutting meat varies slightly amongst research groups (Tarrant, 1981), and hence the tendency is that each group defines the ranges they use.

Although pHu is acceptable as an indicator of the extent of glycolysis, there is considerable depletion in skeletal muscle glycogen (about 50% in some cases) before muscle pH shows any change (Warriss, 1990; Sanz, Verde, Sáez and Sañudo, 1996) because the relationship between pHu and pre-slaughter glycogen concentration is not linear (Brown, Bevis and Warriss, 1990, Gardner et al., 1999). Moreover, considerable glycolysis occurs during slaughter. For instance, in Gardner et al. (1999), lactic acid represented 6% and 10% of SM and ST muscle glycogen content of live sheep, respectively. Immediately after slaughter, the lactate concentration had increased to 27% and 43%, respectively. Therefore, for a better comprehension of the glycolytic process in the slaughtered animals, it is advantageous to determine the glycolytic potential (GP) in addition to the pHu values.

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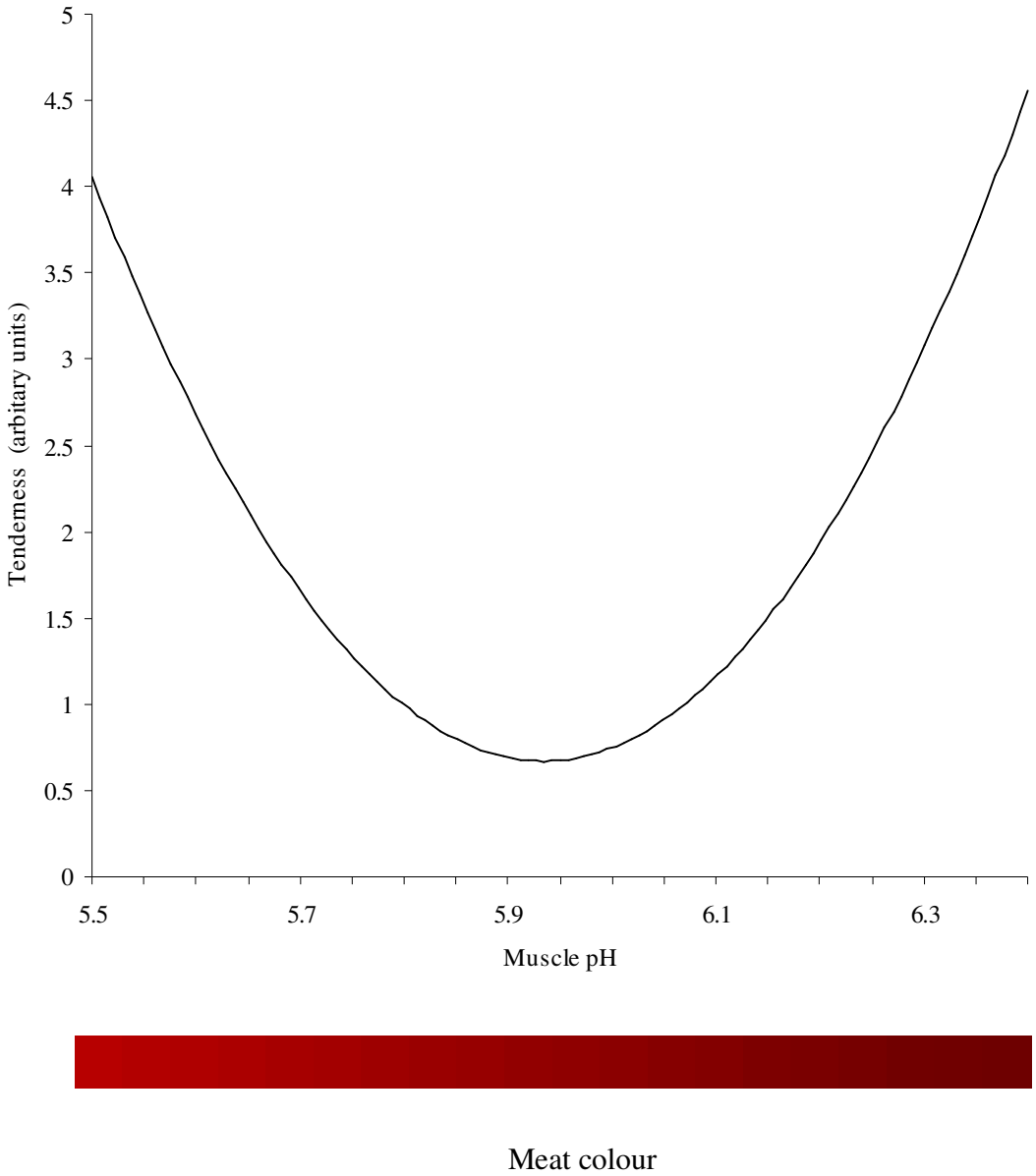

Figure 2.3 Relationship between meat pH, tenderness and colour (Adapted from Wythes and Ramsay, 1979)

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Glycolytic potential is the sum of glycogen and its metabolites and is given by the following equation of Monin and Sellier (1985):

GP = 2([glycogen] + [glucose] + [glucose-6-phospahte]) + [lactate]

It is a measure of the total energy available to the animal pre-slaughter and the energy expenditure during and post-slaughter. It is a more sensitive indicator than pHu of whether carcasses will yield normal or dark cutting meat (Brown et al., 1990; Yambayamba, Aalhus, Price and Jones, 1998; Gardner et al., 1999).

The extent of glycolysis is influenced by the factors listed in Table 2.1 through their effect on the amount of glycogen available to the muscle at slaughter. The extrinsic peri-mortem stressors such as social and physical interactions, emotional excitement and unpropitious hormonal status and nutritional condition (McVeigh and Tarrant, 1982; McVeigh, Tarrant and Harrington, 1982) have a greater impact on pHu than the intrinsic factors. If these factors cause a depletion of glycogen reserves to critical levels, such as less than 65 µmol/g in the LTL of cattle (Shorthose and Wythes, 1988; Varnam and Sutherland, 1995), glycolysis ceases before pHu 5.5, resulting in meat which tends to the dark cutting condition at high pH (Brown et al., 1990). The critical concentration of glycogen has been set at a lower level of 50µmol/g in some instances (Monin, 1981; Purchas and Keohane, 1997).

2.1.2.5 Post-mortem tenderisation

The general consensus in meat science is that proteolysis of structural muscle proteins is the primary cause of post-mortem tenderisation of meat (Goll et al., 1995; Bickerstaffe, 1996; Koohmaraie, 1996). There are however, suggestions that changes in actin-myosin interactions (Goll, Thompson, Taylor and Ouali, 1998), non-enzymatic effect of calcium ions on muscle proteins (Takahashi, 1996) and/or a rise in ionic strength (Ouali, 1990) may be involved.

Three major enzyme systems have been implicated in tenderisation, namely: the calpain system (Koohmaraie, 1992; 1994), the multicatalytic protease (MCP) system (Orlowski, 1990) and the cathepsins (Penny, 1980). Current evidence points to that the calpain system plays the major role in muscle proteolysis (Uytterhaegen, Claeys and Demeyer, 1994; Koohmaraie, 1994; Dransfield,

1994b; Goll, et al., 1998; Sensky, Parr, Bardsley and Buttery, 2001). Koohmaraie (1994) built up a convincing argument to prove that the calpains are the only enzymes that fit the criteria for post-mortem proteolysis in that:

1) It has been established that increasing calcium in muscle results in increased tenderness and calpains are the only enzymes that have an absolute requirement for calcium ions (Koohmaraie, 1990a). Calcium has no effect on MCP (Koohmaraie, 1992) and may inhibit cathepsins (Barrett, 1973);
2) Calpains precisely reproduce post-mortem changes under *in vitro* conditions (Koohmaraie, 1994);
3) Calpains and MCP are localised in the cytosol, a requirement for post-mortem tenderisation enzymes (Koohmaraie, 1992) whereas cathepsins are in lysosomes that seem never to breakdown during post-mortem (Lacourt , Obled, Deval, Ouali and Valin, 1986 as cited by Koohmaraie, 1994).

2.1.2.5.1 The calpains

The calpains are responsible for the tenderisation that occurs up to 96 hours post-mortem (Dransfield, 1993). Their mode of action is thought to be through the degradation of costameric glycoproteins whose role is to maintain the structure of the sarcomeres and the filamentous structures linking adjacent myofibrils (Koohmaraie, 1994; Taylor, Geesink, Thompson, Koohmaraie and Goll, 1995; Goll et al., 1995). Degradation by the calpains significantly excludes the major myofibrillar proteins, actin and myosin, and the major Z-disk protein, α-actinin, all of which remain intact during normal tenderisation (Koohmaraie, 1994; Taylor et al., 1995). It thus appears that the role of calpains is to degrade the structural components of myofibres leaving substrates for possible degradation by other enzyme systems such as MCP (Koohmaraie, 1996) and cathepsins (O'Halloran, Troy, Buckley and Reville, 1997a). Calpains have thus been aptly labelled the rate-limiting step in the tenderisation process.

The calpain system consists of several ubiquitous and tissue specific enzymes but μ-, m- and p94 calpain are the three that are presently implicated in post-mortem tenderisation (Goll et al., 1998). Experimental evidence so far points to μ-calpain as the primary enzyme of post-mortem proteolysis. The enzyme is thought to be the first to be activated post-mortem as the pH declines to 6.02 and below, and intracellular calcium concentration rises from 0.1– 0.2 μM to over

100μM (Vidalenc, Cottin, Merdaci and Ducastaing, 1983; Jeacocke, 1993, Dransfield, 1993). Under normal muscle post-mortem conditions (pHu 5.5. to 5.8 and 5ºC) the enzyme retains 20 to 38% of at-death activity by 24 hours post-mortem (Koohmaraie, Schollmeyer and Dutson, 1986; Boehm, Kendall, Thompson and Goll, 1998, Figure 2.4). Such levels of activity are said to be sufficient to produce changes in myofibrils that are associated with stored meat (Koohmaraie et al., 1986).

The mechanisms of μ-calpain activities have not been fully elucidated. What is understood to date is that under conditions similar to post-mortem storage, the enzyme is active even under high concentration of its inhibitor, calpastatin, and this is evident from progressive autolysis and degradation of the inhibitor (Doumit and Koohmaraie, 1999) and degradation of myofibrillar proteins (Geesink and Koohmaraie, 1999a). Autolysed μ-calpain is however unstable under post-mortem conditions (Geesink and Koohmaraie, 2000) and hence the enzyme gradually loses its activity, especially under high temperatures, at which autolytic activity is greater than proteolytic activity. Consequently several studies have shown that muscles that go into rigor at temperatures above 25ºC yield tough meat (Marsh et al., 1987; Devine et al., 1996; Devine et al., 2002) owing to the reduction in calpain activity and hence ageing potential (Geesink, Bekhit and Bickerstaffe, 2000). μ-Calpain is thought to be responsible for the 50% tenderisation of muscles that occurs within the first 24 hours (Dransfield, 1994b).

m-Calpain is activated at calcium concentrations of 300 to 800 μM at pH 5.7 (Dransfield, 1993). There are doubts that such calcium levels are ever attained in normal physiological conditions. There are however suggestions that an adequate calcium concentration for m-calpain activation may be attained when the sarcoplasmic reticulum pump stops working and costameres are degraded, causing leakages in the sarcolemma, and hence an influx of Ca^{++} into the sarcoplasm (Boehm, et al., 1998). Post-mortem m-calpain concentration is high throughout (Figure 2.4) and there is yet no explanation for the lack of autolysis that is expected of active calpains (Boehm et al., 1998).

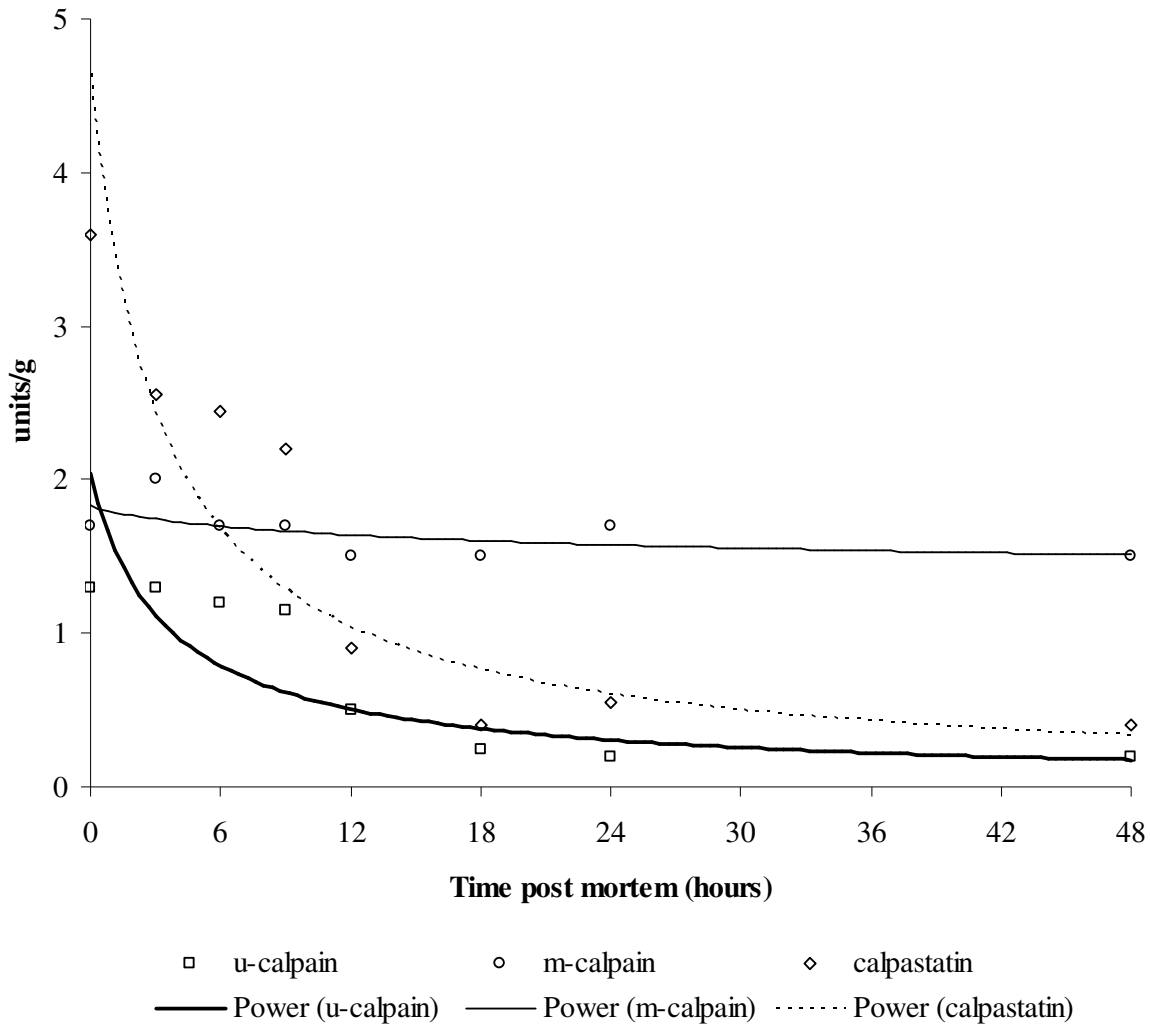

Figure 2.4 Post mortem changes in u-calpain, m-calpain and calpastatin in the *longissimus* muscle of lamb (adapted from Bickerstaffe, 1996)

m-Calpain is said to be responsible for tenderisation that occurs beyond 24 hours post-mortem (Dransfield, 1994b) but other workers doubt its contribution because its concentration remains largely unchanged during post-mortem ageing (Vidalenc et al., 1983; Ducastaing, Valin, Schollmeyer and Cross, 1985; Geesink and Koohmaraie, 1999b) and because of its high calcium requirements (Goll et al., 1995).

Calpain p94 was discovered more recently by Sorimachi, Ishiura and Suzuki (1989). It has been observed to bind to titin at the N_2-line, a site at which proteolysis in the early post-mortem period

has been linked to tenderisation. (Geesink et al., 2000). There is evidence that this enzyme could be one of the major proteases of post-mortem tenderisation (Ilian, Morton, Kent, le Couteur, Hickford, Cowley and Bickerstaffe, 2001). Its role is however not yet fully understood, mainly because it is not easily extractable from muscles and it undergoes rapid autolysis at physiological levels of calcium ions (Geesink et al., 2000).

2.1.2.5.2 Calpastatin

Calpastatin in the allosteric inhibitor of the calpains. The *in vivo* activity of this enzyme is high at high pH, such as soon after death (Figure 2.4) but its levels drop as the pH declines, mainly as a result of degradation by the calpains (Dransfield, 1993). As the pH falls from 6.5 to 5.7, the enzyme is inactivated but μ-calpain activity increases from 15% to 97% of at-death activity (Dransfield, 1993), and hence the extent of tenderisation increases. Meanwhile, calpastatin activity drops to some 20% to 70% of at-death activity by 24hours post-mortem (Dransfield, 1993; Figure 2.4).

2.1.2.5.3 Factors influencing concentration of calpains

Concentration of μ- and m-calpain are less variable but the inhibitor varies significantly with species (Ouali and Talmant, 1990; Koohmaraie, Whipple, Kretchmar, Crouse and Mersmann, 1991a), genotype (Shackelford, Koohmaraie, Miller, Crouse and Reagan, 1991), β-adrenergic agonist administration (Koohmaraie, Shackelford, Muggli-Cockett and Stone, 1991b), sex (Morgan, Wheeler, Koohmaraie, Savell and Crouse, 1993a), myofibre types (Ouali and Talmant, 1990) and stress (Sensky, Parr, Bardsley and Buttery, 1996; Parr, Sensky, Arnold, Bardsley and Buttery, 2000). In all these instances animals that yielded tougher meat had elevated levels of calpastatin and little or no differences in the μ- and m-calpain levels. Therefore, since calpastatin levels vary more widely in response to different treatments than the calpain levels do, it ay be concluded that muscle calpastatin and not muscle calpain activity is related to the degree of post-mortem tenderisation (Ouali and Talmant, 1990; Koohmaraie, Killefer, Bishop, Shackelford, Wheeler, and Arbona, 1995a; Goll et al., 1998; Sensky et al.; 2001).

CHAPTER 2

2.2 MEAT QUALITY FACTORS

Meat quality is objectively defined as the sum of all quality factors of meat (Hofmann, 1994). The quality factors may be presented in groups that are closely related and determine a defined component of meat quality (Table 2.2).

Table 2.2 The major components and factors of meat quality

Component	Meat quality factors
Yield and gross composition	Ratio of fat to lean
	Muscle size and shape
Appearance and technical characteristics	Colour and water holding capacity of lean
	Fat texture and colour
	Marbling (intramuscular fat)
	Chemical composition of lean
Palatability	Texture and tenderness
	Juiciness
	Flavour
	Aroma
Wholesomeness	Nutritional quality
	Chemical safety
	Microbial safety
	Acceptable animal husbandry

Adapted from Hofmann (1994)

The quality factors related to visual appeal (colour, water holding capacity and fatness) and palatability (tenderness, juiciness, flavour and aroma) are regarded as the key factors that determine consumers' initial and continued interest in the meat (Chambers IV and Bowers, 1993; Issanchou, 1996). These factors may be evaluated directly or indirectly by various physical, biochemical, histological and sensory analyses.

CHAPTER 2

2.2.1 Meat Colour

Colour is one of the most important factors in consumers' selection and decision to purchase meat and meat products (Hedrick, Aberle, Forrest, Judge and Merkel, 1994). It is considered to be the single most influential criterion in this process (Kropf, 1980). For that reason an assessment of colour is included in some carcass classification systems (e.g. USDA, 1994 as cited by Page, Wulf and Schwotzer, 2001).

The characteristic colour of meat is a function of its pigment content and light scattering properties (MacDougall, 1982, Ledward, 1992). Myoglobin is the basic pigment in fresh meat and its content varies with production factors such as species, animal age, sex, feeding system, exercise, type of muscle and muscular activity (Ledward, 1992; Varnam and Sutherland, 1995). Myoglobin's physio-chemical state; i.e. purple reduced myoglobin, red oxymyoglobin and brown metmyoglobin, determines the colour of fresh meat (Varnam and Sutherland, 1995; Lawrie, 1998). Formation of the desirable oxymyoglobin is enhanced by conditions that increase oxygen solubility, such as low temperature, low pH, high oxygen tension, and low enzyme activity (MacDougall, 1982, Ledward, 1992).

Meat pH has a great effect on colour development (Abril, Campo, Önenç, Sañudo, Albertí and Negueruela, 2001; Figure 2.3) through its effect on the physical state of muscle proteins. At high pHu (>6.0), myofibres hold a lot of water which swells them up (Offer and Trinick, 1983). At such high myofibrillar volume, incident light is able to penetrate considerable depth and be absorbed by myoglobin before it is scattered (MacDougall, 1982). The meat appears translucent and dark. Furthermore, enzymes that use up oxygen are more active resulting in less oxygenation of the surface myoglobin and a dark colour (Price and Schweigert, 1987; Ledward, 1992). At normal pHu (~5.5), the myofibres hold less water, and oxygen utilising enzymes are less active. The meat appears brighter and glossier (Ledward, 1992). At the other extreme, low pH meat is pale (MacDougall, 1982; Ledward, 1992). This is due to that reduced myofibrillar volume (Offer and Trinick, 1983) as well as that denatured myosin and sarcoplasmic proteins increase the refractive properties of the meat (MacDougall, 1982; Offer and Trinick, 1983). Consequently more incident light is scattered at shallow depths of penetration and relatively little is absorbed by myoglobin.

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Besides its strong relationship with pH (Orcutt, Dutson, Cornforth and Smith, 1984; Purchas, 1990; Watanabe, Daly, and Devine, 1996), meat colour is also highly correlated with water holding capacity, evidently because the changes in myofibrillar lattice with pH also affect the ability of the muscle to retain water. Meat colour is reported to be related to tenderness (e.g. Purchas, 1990; Jeremiah, Tong and Gibson, 1991; Watanabe et al., 1996; Wulf, O'Connor, Tatum and Smith, 1997) and carcass fatness (e.g. Tatum, Smith and Carpenter, 1982; Page et al., 2001).

Meat colour is objectively defined often in terms of the Hunter colorimetric co-ordinates, L*, a* and b* (Warriss, 2000). L* is the lightness component, indicating the black-whiteness of the meat. Its values range from 0 (all light absorbed) to 100 (all light reflected); a* spans from -60 (green) to +60 (red) and b* spans from -60 (blue) to +60 (yellow) (Young, Priolo, Simmons and West, 1999). Other parameters may be calculated from these basic three, such as hue angle [$\tan^{-1}$ (b*/a*)], which describes the fundamental colour of a substance; and chroma [$\sqrt{}$ ($a^{*2}+b^{*2}$)], which describes the vividness of the colour. Hunter a* and chroma have been observed to be strongly related to visual colour scores (Eargerman, Clydesdale and Francis, 1978).

2.2.1.1 The colour of chevon

Some L*, a* and b* values that have been reported for SM and *M. longissimus* of goats are shown in Table 2.3. Babiker and Bello (1986) compared the effects of different post-mortem rates of chilling and found that although exposing carcasses to high ambient temperatures post-mortem resulted in lower L* and b* values, the differences were not perceived by consumers. In another case, a taste panel did not perceive colour differences between meat from Sudanese desert lambs and kids, even though the chevon had lower L* and b* and higher a* values (Babiker, et al., 1990). The differences in the meat colour in these studies may have been in a range that was too narrow to be detected by consumers.

Dhanda Taylor, Murray and McCosker (1999) reported chevon became darker with increase in age. On the other hand Nuñez Gonzalez, Owen, and Arias Cereceres (1983) did not observe differences in the colour of chevon from goats ranging from 8kg to 24kg.

Table 2.3 Hunter colorimetric co-ordinates of goat *M. semimembranosus*[1] and *M. longissimus thoracis*[2]

Goat	Weight	L*	a*	b*	Source
Male Sudanese desert[1]	28-30 kg	31.97 32.43 33.98	16.47 16.40 17.48	8.65 8.77 9.60	Babiker and Bello (1986)
Sudanese desert[1]	35kg	34.80	13.10	8.65	Babiker et al. (1990)
Boer x Angora[2]	32.4kg	37.7	12.0	3.0	Dhanda et al. (1999)
Boer x Saanen[2]	36.2kg	37.7	14.8	2.1	
Feral[2]	30.6kg	37.1	14.4	2.0	
Saanen x Angora[2]	34.1kg	37.0	14.0	2.5	
Saanen x Feral[2]	36.0kg	34.6	12.7	1.7	
Boer crosses[2]	Capretto	42	13	3	Husain, Murray and Taylor (2000)
Spanish does[1]	-	42.5	17.8	8.9	Kannan, Kouakou and Gelaye (2001)

2.2.2 Water in Meat

Fresh meat contains about 75% water at slaughter (Offer and Trinick, 1983). Some of this water is lost post-slaughter in one of three ways. First are evaporative losses, which occur during carcass chilling and from the surface of cuts on display. Chilling losses are about 3% in normally processed beef carcasses but may be reduced by rapid chilling (Offer, Restall and Trinick, 1984). The latter is however not practised because it may lead to cold shortening, which could mean a greater loss in meat quality. Second is drip loss, which occurs from cut surfaces of meat. High drip loss is undesirable because it detracts from the appeal of the meat, and valuable proteins and flavour compound are lost in the exudate (Varnam and Sutherland, 1995; Lawrie, 1998). Drip loss is normally in the order of 3% in beef but may be exacerbated by very low pHu and by freezing and thawing to as much as 15% (Offer, et al., 1984). Chilling and drip losses not only affect the appeal of the meat but reduce its weight, and hence economic value. Finally, during cooking, even greater losses that may be as high as 40% occur (Offer et al., 1984). High cooking

losses not only reduce the size of the meat portion but also result in reduced succulence and tenderness and loss of flavour.

The ability of meat to retain its natural water content is termed water holding capacity (WHC, Hamm, 1986). Most of the water is held in the interfilament spaces within the myofilament lattice. The amount held depends on the volume of the interfilament spaces (Offer and Trinick, 1983) which in turn is determined by pH, sarcomere length, ionic strength, osmotic pressure and whether the muscle is in pre- or post-rigor (Offer and Trinick, 1983).

Water holding capacity is high at high muscle pH and in fact water is not readily lost from meat that is cut soon after slaughter (Offer and Trinick, 1983). This is because at high pH, the net negative charge of myofilaments results in strong repulsive electrostatic forces between the filaments, which push the filaments apart, swells the up the lattice and hence increases the space where the water is lodged. As the pH declines, the negative charge and hence the repulsive force of the filaments is gradually lost to a point when the filaments have no net charge, at the iso-electric point of actin and myosin (about pH 5.0, Hamm, 1986). The myofilaments relax, thus shrink the interfilament space and in so doing expel the water. The expelled water accumulates in the space between the muscle fibres and the endomysium and is driven to the cut surfaces by the pressure of the endomysium (Offer et al., 1984). Water holding capacity of meat is at it's lowest at pH 5.0 and any alteration of pH in the range 5.0 to 6.5 has a great influence on WHC (Hamm, 1986).

Cooking losses occur through a similar mechanism to drip loss. The denaturation of the myosin at 40 to 53ºC (Bendall and Restalll, 1983) causes a transversal shrinkage in the myofibres and a slow loss of water from the myofibres. At 60ºC, the collagen of the basement membrane shrinks, resulting in rapid fluid loss from the myofibres (Bendall and Restall, 1983). Above 64ºC collagen of the perimysium and endomysium network shrinks (Sims and Bailey, 1981; Bendall and Restall, 1983; Bailey, 1984) and thus exerts more pressure on the aqueous solution leading to a rapid loss of volume of the cooked meat.

The WHC of meat is closely correlated to meat colour in that both factors are largely determined by the effect of pH on the myofilament lattice structure (Offer and Knight, 1988). Water holding

capacity also increases with increase in intramuscular fat content, probably because the fat loosens up the myofibre microstructure and allows more water to be entrained (Lawrie, 1998). It is for this reason that good quality meat loses less water during cooking (Lawrie, 1998) besides the fact that it has less water and more fat.

In addition to its effect on the aesthetic appeal of the meat, WHC affects the technological value the meat; how well it can be processed into other products. An example is that although it is aesthetically unappealing, dark cutting meat is perfectly acceptable for a number of manufacturing purposes because of its high WHC (Hofmann, 1994).

Water holding capacity of fresh meat is best determined by gravity and suction methods that do not destroy the tissue or denature the proteins (Hofmann, 1994, Honikel, 1998). Cooking loss is recommended for heated meat (Hofmann, 1994).

2.2.2.1 Water losses in chevon

Evaporative losses during chilling are probably the first water losses to have an impact on the appeal of chevon because the carcasses are relatively lean and have a high surface area to volume ratio. The losses tend to be higher for smaller than the larger carcasses. This was shown in a study conducted in Zimbabwe in which chilling losses from goats that were less than 35kg were about 3% while the losses from heavier goats were only 2.3% (Simela, Gumede, Ndlovu and Sibanda, 2000c).

While water remaining in the cooked product is the major contributor to the sensation of juiciness (Forrest, Aberle, Hedrick, Judge and Merkel, 1975), chevon cooking losses are often close to or over 35% (Babiker and Bello, 1986; Babiker et al., 1990; Swan et al., 1998; Dhanda et al., 1999). Cooking losses of the meat are possibly exacerbated by its limited fat content (Lawrie, 1998). It is partly because of these high losses that chevon has been perceived to be less juicy than lamb or mutton (Pike, Smith and Carpenter, 1973a, Schönfeldt et al., 1993b; Tshabalala et al., 2003) and beef (Pike et al., 1973a).

CHAPTER 2

2.2.3 Fat in Meat

Fats are present in meat as structural components of muscle membranes and as storage droplets between muscle fibres. The latter constitute what is perceived as marbling (Varnam and Sutherland, 1995). Marbling affects consumers' visual appreciation and their perception of the eating quality of the meat, and hence their decision of whether or not to buy the meat (Issanchou, 1996; Brewer, Zhu, and McKeith, 2001). Increased marbling is associated with good eating quality (Dolezal, Smith, Savell and Carpenter, 1982; Fernandez, Monin, Talmant and Mourot, 1999). Dolezal et al. (1982) demonstrated this phenomenon in that juiciness, tenderness and flavour desirability increased with increase in beef marbling score. In a similar line of research, Fernandez et al. (1999) reported an increase in ratings for pork flavour, tenderness and juiciness with increase in intramuscular fat content.

Even though it may be associated with good eating quality, excessive marbling is unacceptable to consumers. This was aptly illustrated in the work of Brewer et al. (2001) in which consumers expressed a higher degree of purchase intent for leaner than for highly marbled pork chops but found the latter more juicy, tender and flavourful than the lean ones in a 'blind' sensory test.

The extent of marbling and the colour of fat in red meat modify consumers' perception of the meat colour. Consumers appreciate white fat but yellow fat, such as that of beef from dairy cows or grass fed animals, may be less appealing (Varnam and Sutherland, 1995). Fat stained by blood from drip also reduces the visual appeal of meat.

Fats are implicated in the oxidative stability of meat and hence its shelf life (Gray, Gomaa and Buckley, 1996; Morrissey, Sheehy, Galvin, Kerry and Buckley, 1998; Enser, 2001). The oxidative stability of meat is dependent on the balance between oxidative substrates (e.g. the polyunsaturated fatty acids of the phospholipids); pro-oxidants (e.g. haeme proteins such as myoglobin, haemoglobin and cytochromes) and anti-oxidants (e.g. vitamin E,) (Morrisey et al., 1998). Once the balance is upset, oxidative deterioration occurs and results in adverse changes in colour, flavour, texture, nutritive value and possibly the production of toxic compounds (Kanner, 1994; Gray et al., 1996).

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The interest in fat in relation to consumer health lies in its content of essential fatty acids (EFAs), polyunsaturated/saturated fatty acids ratio, n-3/n-6 ratio and conjugated linoleic acid (CLA) and cholesterol. The basic EFAs are linoleic (18:2n-6) and linolenic (18:3n-3) acids. These fatty acids cannot be synthesised in human tissues but are required for the synthesis of prostaglandins, prostacyclins and thromboxenes. An intake of 1–2% of total calories as EFA is recommended (Mead, Alfin-Slater, Howton and Popják, 1986).

Linoleic acid is one of the most abundant PUFA, particularly in animals raised on grain based diets (Wood and Enser, 1997, Fisher, Enser, Richardson, Wood, Nute, Kurt, Sinclair and Wilkinson, 2000). In recent years there has been increased interest in its geometric isomer, CLA, which occurs naturally in meat particularly that of ruminants off grass diets (Shantha, Moody and Tabeidi, 1997; Enser, 2000). Conjugated linoleic acid is associated with several health enhancing properties such as anti-carcinogenesis, anti-artherogenesis, anti-diabetes, immuno-modulation and shifting the partitioning of energy towards protein instead of fat deposition (Cannella and Giusti, 2000; Stanley and Hunter, 2001).

Linoleic acid and other polyunsaturated fatty acids (PUFA) of the n-6 series have a desirable hypocholesterolaemic effect of reducing low-density lipoprotein (LDL)-cholesterol (Wiseman, 1997). N-3 PUFA (particularly eicosapentanoic acid and docosahexanoic acid) are similarly desirable because of their antithrombogenic effect and their association with low mortality from cardiovascular diseases (Wiseman, 1997). On the other hand saturated fatty acids, especially lauric (12:0) and myristic (14:0) acids increase total blood LDL- and high density lipoprotein (HDL)-cholesterol as well as the LDL:HDL ratio (Khosla and Hayes, 1994). These conditions are conducive to cardiovascular diseases. Some researchers also implicate palmitic acid (16:0) but Khosla and Hayes (1994) and Ng (1994) suggested that 16:0 only enhances hypercholesterolaemia in persons who already have high concentration of cholesterol. MUFA and stearic acid (18:0) are considered neutral in this effect (Voet and Voet, 1990). For these reasons, dieticians recommend fats that are high in PUFA, low in SFA and cholesterol.

The recommendations by the British Department of Health are that the energy supply by fats in a diet should not exceed 35% (Wood and Enser, 1997) while the USDA recommends less than 30% (Lichtenstein, Kennedy, Barrier, Danford, Ernst, Grundy, Leveille, van Horn, Williams and

Booth, 1998). Both Departments recommend that energy from SFA should be limited to less than 10% of the dietary total energy. The PUFA/SFA ratio should be between 0.4 and 1.0 (Enser, 2000). This ratio is easily attainable with non-ruminant meats such as pork, chicken and fish but ruminant meat normally has a ratio of 0.1 or less (Marmer, Maxwell and Williams, 1984; Enser, Hallett, Hewitt, Fursey, Wood and Harrington, 1998).

The fat content of meat is assessed in several ways. In industry, the traditional online methods are the visual scoring of carcass subcutaneous fat cover or measuring fat depth at specified points on the carcass, usually along the LT (Fisher and De Boer, 1994). In the laboratory, intermuscular and subcutaneous fat are traditional determined by dissections of a side or three rib sample (Miller, Cross, Bakers, Byers and Recio, 1988; Fisher and De Boer, 1994). Intramuscular fat is determined by extraction with an organic solvent such as light petroleum (Boccard et al., 1981). In addition to these methods that are several methods that have been developed for live animal and carcass evaluations, particularly for use in the industry. These include techniques such as ultrasound imaging, optical lean/fat probes, x-ray computerised tomography and magnetic resonance imaging (Cross and Belk, 1994; Monin, 1998). The detailed composition of fats, such as fatty acid and cholesterol content, is determined by chromatographic analysis (Maxwell and Marmer, 1983).

2.2.3.1 Fat in chevon

Development of fat in goats occurs very late and only reaches appreciable levels when the animals are near or at their mature body weight (Owen, Norman, Philbrooks and Jones, 1978.; Owen, Arias Cereceres, Garcia Macias and Nuñez Gonzalez, 1983). The fat content is highly variable and is influenced by such factors as age, sex, body weight and growth rate (Owen et al., 1978, Kirton, 1988). Most of the fat is deposited in the visceral rather than carcass depots and hence goat carcasses are lean (Devendra and Owen, 1983; Kirton, 1988). Typically goat carcasses have about 60% dissectible lean and 5% to 14% dissectible fat (Devendra and Owen, 1983; Norman, 1991). Their subcutaneous fat cover is negligible (Pike, Smith, Carpenter and Shelton, 1973b; Dhanda et al., 1999; Simela, Ndlovu and Sibanda, 1999) and in too narrow a range to allow for the creation of meaningful classes (Pike et al., 1973b; Smith, Carpenter and Shelton, 1978; Devendra and Owen, 1983; Simela et al., 1999). For that reason, a measure of subcutaneous fat depth is not perceived as a useful quality indicator for goat carcasses (Pike et

al., 1973b; Simela et al., 1999) and hence is not employed in some goat carcass classification systems such as the South African one (SAMIC, 2004). In cases where subcutaneous fat is included in goat carcass classification, its assessment is often based on classifications developed for sheep carcasses (e.g. Government of Zimbabwe, 1995). This has resulted in the downgrading of the carcasses because of inadequate fat (Devendra and Owen, 1983; Simela, Ndlovu and Sibanda, 1998). One advantage of the low fat content of chevon is that the actual amount of the undesirable fat that is ingested by consumers per unit of chevon is much lower than for meats that have inherently higher fat content, such as beef and mutton (Teh, 1992).

2.2.4 Meat Juiciness

Lawrie (1998) brings out that juiciness in cooked meat has two organoleptic components. First is the impression of wetness during initial chewing, which is due to the rapid release of meat fluids. Second is the sustained juiciness resulting from the stimulatory effect of fat on salivation. The latter component explains why, for example, meat from young animals gives an initial impression of juiciness but ultimately a dry sensation due to the relative absence of fat (Lawrie, 1998). By the same token good quality meat is juicier than poor quality meat because the former has a higher intramuscular fat content.

Juiciness is related to WHC and marbling. In conjunction with tenderness, it accounts for the overall eating quality and consumers may confuse the two factors when making assessments or comparisons (Varnam and Sutherland, 1995).

In meat research, juiciness is usually determined by sensory evaluation or inferred from measures of water in meat, such as WHC and cooking losses.

2.2.4.1 Juiciness of chevon

Chevon and/or chevon products have been reported to be less juicy than lamb and/or mutton products (Pike et al., 1973a; Schönfeldt et al., 1993b; Tshabalala et al., 2003), a fact that has been attributed to the low fat content of chevon. Within the species, young goats yield juicier chevon, but this depends on the age of the animals under consideration. For example, Schönfeldt et al. (1993b) found that young goats with carcasses ranging from about 10 to 25kg were juicier than the older goats with carcasses ranging from 15 to 30kg. In contrast, Pike et al. (1973b) and

Smith et al. (1978) compared kids with carcasses of 5 to 7kg to yearling goats with carcasses of 12 to 13kg and found the older goats more juicy and palatable. The findings suggests that there is an optimum age/weight at which to slaughter goats to obtain good quality chevon.

2.2.5 Meat Flavour and Aroma

Aroma is a result of the sensory of certain volatile substances by the olfactory organs (Lawrie, 1998). The flavour of meat is attributed to a complex mixture of compounds produced by heating the heterogeneous system containing its precursors (MacLeod and Seyyedain-Ardebili, 1981). It is composed of volatile compounds that give rise to the odour properties; non-volatile or water soluble compounds with taste tactile properties and, potentiators and synergists of flavour (MacLeod and Seyyedain-Ardebili, 1981). The water-soluble fraction of meat provides the basic meaty flavour and aroma while fat provides the species characteristic flavour and aroma, albeit in interaction with the former (Mottram and Edwards, 1983; Moody, 1983; Melton, 1990).

Phospholipids have been specifically implicated in flavour development. The phospholipids appear to provide sufficient lipids for flavour and aroma development while the triacylglycerides seem not to be essential (Mottram and Edwards, 1983) such that there may be no change in flavour with increase in carcass fatness (i.e. increase in triacylglycerides). In fact the effect of the phospholipid fraction may be diluted by the higher concentration of triacylglycerides in fat animals (Fisher et al., 2000), resulting in a weaker aroma and flavour of fatter meat. This is so because the phospholipids content in fat is fairly constant while that of triacylglycerides increases with increase in fatness. PUFA of the n-6 and n-3 series produce different flavours (Kemp, Mahyuddin, Ely, Fox and Moody, 1981; Larick and Turner, 1989; Fisher et al., 2000). Fisher et al. (2000) suggest that it is variation in the absolute concentrations as well as the relative proportions of the different fatty acids that lead to different flavour profiles.

Fats influence the flavour of meat in two ways. One is the oxidation, principally of unsaturated fatty acids (UFA), which yields carbonyl compounds that at one level of concentration produce desirable flavours and at another, undesirable flavours (Moody, 1983). Secondly fats serve as a depot for fat-soluble compounds that volatilise upon heating and strongly affect flavour. Many of the flavour compounds are produced during cooking as a result of reactions such as the Maillard reaction, Strecker degradation, lipid peroxidation and their interactions (Moody, 1983).

2.2.5.1 Flavour and aroma of chevon

Branched chain fatty acids (BCFA) have been specifically implicated in sheep and goat species-related flavour (Wong, Nixon and Johnson, 1975; Johnson, Wong and Birch, 1977; Ha and Lindsay, 1990). Of these fatty acids, 4-ethyloctanoic acid is associated with a powerful goaty odour and has been detected in lamb and mutton (Brennand, 1989 as cited by Madruga, Arruda, Narain and Souza, 2000; Ha and Lindsay, 1990), goat (Ha and Lindsay 1990; Brennand, Ha and Lindsay, 1989) and caprine and ovine cheese (Ha and Lindsay, 1991a). The compound has not been detected in veal, beef, pork, venison (Ha and Lindsay 1990) and bovine cheese (Ha and Lindsay, 1991a). Other BCFA implicated in goat-like flavour are 4-methyloctanoic, 4-methylnanoic (Wong et al., 1975; Brennand, 1989 as cited by Madruga et al., 2000) and 4-ethylheptanoic (Ha and Lindsay, 1990). Alkyloids, pyridines and sulphur containing compounds are other notable flavour compounds that have been identified in chevon and mutton, but were said to be unlikely to play a major role in the development of goat flavour (Ha and Lindsay, 1991b).

In most studies, sensory evaluation of the acceptability, intensity and species specificity of flavour are often reported. Schönfeldt et al. (1993a) evaluated the effect of species, age and fat class on the species specificity and acceptability of chevon and lamb/mutton flavour. They noted that the effects depended on the muscle and the method of preparation used. Where significant differences occurred, sheep flavour was rated more species specific and more acceptable than that of the goats. The flavour of meat from animals with no permanent incisors was more acceptable than that from the older groups, while the flavour of the group with between 1mm and 4mm subcutaneous fat thickness was deemed more acceptable than that of the groups with more or less subcutaneous fat. Other studies have observed similar trends with respect to comparisons of chevon to mutton; that the flavour of chevon is either as acceptable (Babiker et al., 1990; Griffin, Orcutt, Riley, Smith, Savell and Shelton, 1992) or less desirable (Pike et al., 1973a) than that of lamb/mutton.

Within the species age effects have depended on the range of ages under consideration. Amongst Schönfeldt et al.'s (1993a) goats, the younger goats (10 to 25kg carcass) had a more desirable flavour than the older ones (15 to 30kg carcass) but, where very young animals were compared

to older animals, the flavour of the latter was more acceptable (Pike et al., 1973a; Smith et al., 1978; Griffin et al., 1992).

2.2.6 Meat Tenderness

Meat tenderness is rated as the most important attribute of eating quality and is the factor that determines consumers continued interest in meat (Issanchou, 1996; Boleman, Boleman, Miller, Taylor, Cross, Wheeler, Koohmaraie, Shackelford, Miller, West, Johnson and Savell, 1997). Tenderness is defined as the ease of mastication, which involves the initial ease of penetration by the teeth, the ease with which the meat breaks into fragments and the amount of residue remaining after mastication (Lawrie, 1998). The two major determinants of meat tenderness are the content and state of the connective tissue and the structure and state of the myofibrils (Dutson, Hostetler and Carpenter, 1976). The two components are modified to some extent by intramuscular fat and the sarcoplasmic proteins (Lawrie, 1998).

2.2.6.1 Collagen and its contribution to meat tenderness

Connective tissue toughness is often referred to as background toughness because the tissue hardly changes during the standard lengths of meat storage post-mortem (McCormick, 1994). Connective tissue accounts for less than 10% of the total variance in meat tenderness (Harper, 1999). Its contribution to toughness is believed to be a product of the state of connective tissues in the perimysium, which constitutes some 90% of the intramuscular connective tissue (Light, Champion, Voyle and Bailey, 1985). Collagen is the predominant protein of perimysial and endomysial connective tissues, constituting some 1.6 to 14.1% of the dry matter weight of muscle (Purslow, 1999). Collagen characteristics, mainly the content and solubility, are thus the basis for the determination of connective tissue contribution to meat toughness.

In addition to the biochemical methods of determining connective tissue contribution to meat tenderness, rheological methods are also used. In such instances, connective tissue toughness is perceived as the difference between initial and peak force of the Warner-Bratzler deformation curves (Bouton, Harris and Shorthose, 1975). The degree to which the meat is cooked is important in this determination (Warriss, 2000). It has been shown that between 52ºC and 70ºC, collagen shrinks during cooking, which increases the toughness of the meat (Bendall and Restall,

1983). Above 70ºC, collagen gelatinises and the extent to which this happens depends on the length of the cooking time (Bailey and Light, 1989).

2.2.6.2 Myofibrillar contribution to meat tenderness

Myofibrillar contribution to meat tenderness depends on the extent of shortening during rigor development and proteolysis during conditioning (Warriss, 2000). Thus it is determined by the conditions during rigor development and post-mortem tenderisation. The two may be modified by the pre-and post-slaughter effects on the animals or carcasses.

2.2.6.2.1 Pre-slaughter factors

In general, intrinsic pre-slaughter factors (such as species, breed, sex and age) affect tenderness by determining the amount and properties of connective tissue (Lawrie, 1998). They may however, have an effect on tenderness in instances where they determine carcass conformation and fatness, and hence the degree of insulation against cold shortening. Carcass fat performs an important insulatory role in this effect. For beef, a minimum of about 5mm to 6mm subcutaneous cover is necessary to produce tender meat but above that, subcutaneous fat has little effect on changes in tenderness (Tatum et al., 1982; Dolezal et al., 1982; Jones and Tatum, 1994, Dikeman, 1996). For the smaller lamb and goat carcasses subcutaneous fat cover is more crucial because of the greater risk of cold shortening. Smith, Dutson, Hostetler and Carpenter (1976) showed that as subcutaneous fat depth increased from 3.1mm to 7.1mm in lamb carcasses chilled at 1ºC, the carcasses were increasingly able to maintain temperatures that were conducive to autolytic enzyme degradation for longer periods. They sustained less sarcomere length shortening, had lower pHu and tenderness and other meat quality attributes improved. Dikeman (1996) suggests that a minimum of 4mm subcutaneous fat is required to prevent cold shortening in lamb. Goat carcasses barely ever attain 1mm subcutaneous fat cover (Devendra and Owen, 1983; Simela et al., 1999). The impact of chilling should thus be greater on chevon than lamb/mutton carcasses.

Of the extrinsic factors, pre-slaughter stress is of greatest concern in the meat industry. Stress effects are mediated through pre-slaughter depletion of glycogen resulting in high pH meat. Meat toughness increases between pHu 5.5 and 6 and is maximum between pH 5.8 and 6.3 (Jeremiah, Tong and Gibson, 1991; Purchas and Aungsupakorn, 1993; Devine, Wahlgren and Tornberg,

1996; Figure 2.3). According to Yu and Lee (1986), meat is tender at either pHu extreme because, at low pHu, the acidic proteases are active while at the higher end, the neutral calpains are active. The range 5.8 to 6.3 is outside that of the two enzyme systems, and hence there is minimum degradation of muscle proteins.

In most studies, chevon pHu is often around or above 5.8 (Table 2.4). The high pHu is probably due to pre-slaughter stress since goats are excitable. If that is the case, it may be deducible from the GP values. A low GP at slaughter is indicative of prolonged stress prior to slaughter while a high lactate concentration and a low glycogen: lactate ratio is indicative of pre-slaughter stress.

Another possible effect of stress could be that it stimulates the release of a factor that affects calpain and calpastatin levels and/or their kinetics, resulting in reduced proteolytic activity and hence tough meat (Bickerstaffe, 1996). This view is supported by the observation that elevated plasma adrenaline levels increase calpastatin activity and expression, implying that the link between stress and meat toughness may be mediated via the calpain system (Sensky et al., 1996; Parr et al., 2000).

2.2.6.2.2 Post-slaughter factors

Sarcomere shortening is the cause of toughening early post-mortem (Smulders, Marsh, Swartz, Russell and Hoenecke, 1990; Koohmaraie, 1996). Wheeler and Koohmaraie (1994) demonstrated this phenomenon with lamb LTL whose sarcomere length (SL) decreased from 2.24µm at death to 1.69µm 24 hours post-mortem (Figure 2.5). Concomitantly, shear force values increased from 5.09kg to 8.66kg.

Koohmaraie, Doumit and Wheeler (1996) further showed that when sarcomeres were restrained from shortening, no toughening occurred. These findings concur with Marsh and Leet's (1966) observations that most tender meat has SL of 2.0 to 2.5µm, meat of intermediate tenderness 1.7 to 2.0µm and tough meat 1.5 to 1.7µm.

Table 2.4 Some reported ultimate pH values of chevon

Type of goat	Muscle	Mean/range of pHu	Source
Criollo males	*Longissimus*	5.77-6.19	Nuñez Gonzalez et al. (1983)
Criollo males	*Biceps femoris*	5.80-6.10	
Saanen females	Not specified	5.88	Hogg, Catcheside, Mercer and Duganzich (1989)
Saanen males		5.90	
Feral males		5.55	
Unspecified breed castrates	*Iliopsoas*	6.01	Hogg et al. (1992)
Unspecified breed females		6.00	
Boer goat	*Longissimus*	6.04	Swan et al. (1998)
Cashmere		5.70	
Boer x Cashmere		5.78	
Bucks of various breeds	*Longissimus thoracis*	5.6-5.8	Dhanda et al. (1999)
Various breeds intact males	Composite	6.36	Madruga, Arruda and Nascimento (1999)
Various breeds castrates	Composite	6.83	
Boer cross breeds	*Longissimus*	5.8 -6.2	Husain et al. (2000)
Spanish does	*Longissimus*	5.96	Kannan, et al. (2001)
	Semimembranosus	6.07	
	Triceps brachii	6.33	
2yr old Spanish castrates	*Longissimus*	5.7	Kannan, Kouakou, Terrill, Gelaye and Amoah (2003)
≤1 yr Spanish castrates	*Longissimus*	6.1	

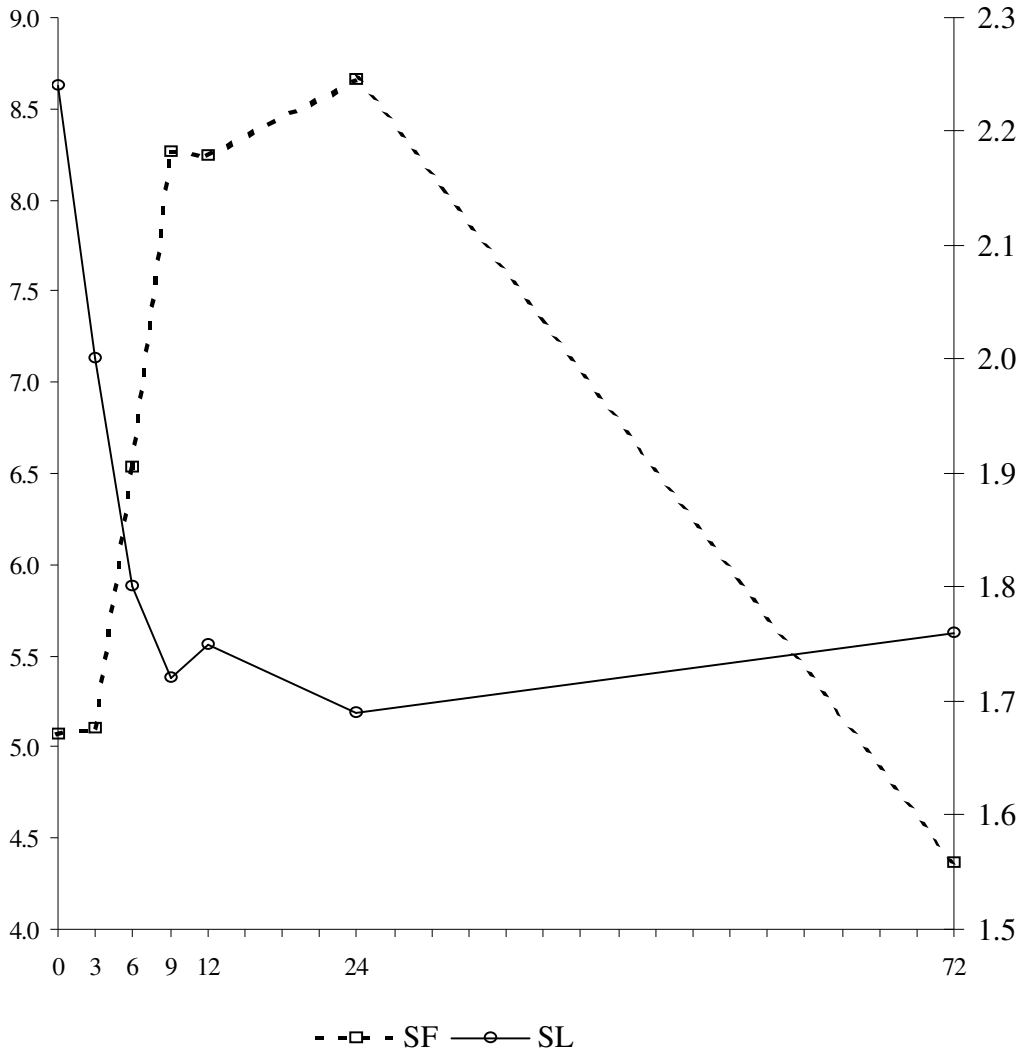

Figure 2.5 Sarcomere length (SL, µm) and shear force (SF, kg) of lamb longissimus thoracis et lumborum at specific times post-mortem (Wheeler and Koohmaraie, 1994)

Wheeler, Shackelford and Koohmaraie (2000) further demonstrated the SL/tenderness relationship with different pork muscles, whereby all muscles with SL greater than or equal to 2.0µm (ST and *M. triceps brachii*) were rated the most tender while those with SL less than 2.0µm (LD, BF and SM) were rated less tender by taste panels. The authors thus concluded that if SL were 2.0µm or more, meat would be tender regardless of collagen content or extent of proteolysis.

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The degree of sarcomere shortening depends on the rates of chilling and post-mortem glycolysis. It is high in slow glycolysing muscles especially if they are subjected to rapid chilling, and low in fast glycolysing muscle (Marsh et al., 1987; Smulders et al., 1990; O'Halloran, Troy and Buckley, 1997b). Therefore any animal and post-slaughter environmental factors that affect the rate of post-mortem chilling and glycolysis will have an impact on the degree of sarcomere contraction.

There is however no unanimity on the relationship between SL and tenderness. Smulders et al. (1990) suggested that the relationship is dependent on the rate of glycolysis, which they measured as the pH at three hours post-mortem (pH_3). These workers reported no relationship between SL and tenderness for meat with $pH_3 \leq 6.3$. Above that, a strong correlation of 0.84 was realised. They thus concluded that sarcomere shortening is a major determinant of tenderness of slow glycolysing muscles. However, the effect of the glycolytic rate on the tenderness/SL relationship has not always been supported by research results (Shackelford, Koohmaraie and Savell, 1994a; O'Halloran et al., 1997b; Koohmaraie et al., 1995a). On the other hand, the impact of fast post-mortem glycolysis in enhancing tenderness is accepted by many research teams (Martin, Murray, Jeremiah and Dutson, 1983; Marsh et al., 1987; Pike, Ringkob, Beckman, Koh and Gerthoffer, 1993; Shackelford et al., 1994a; O'Halloran et al., 1997b). An exception is cases where the rate is so fast that heat shortening occurs (Marsh et al., 1987, Devine, Payne, Peachey, Lowe, Ingram and Cook, 2002). Fast glycolysis may limit tenderness even in the absence of shortening, by reducing calpain activity, and hence ageing potential (Simmons, Singh, Dobbie and Devine, 1996).

Ideally the rate of post-mortem glycolysis should be such that the pH does not drop below 6.2 before the carcass is at 15ºC (Dransfield, 1994a) or below 6.0 before 10ºC (Cornforth et al., 1980) in order to minimise sarcomere shortening and enhance proteolysis. Above these pH/temperature points, muscles have enough energy reserve to contract extensively at rigor mortis. Electrical stimulation is thus employed to expedite energy depletion from muscles and ensure that they enter rigor in a relaxed state.

A team from Texas Agricultural Experimental Station showed that ES improves tenderness not just by preventing cold shortening but by also stimulating an early onset of proteolysis and

causing stretching and tearing myofibrils (Savell et al., 1977; Savell, Smith and Carpenter, 1978a; Savell, Dutson, Smith and Carpenter, 1978b). There are suggestions that ES also causes a reduction of calpastatin activity, and hence an acceleration of proteolysis (Ferguson, Jiang, Hearnshaw, Rymill and Thompson, 2001). Other beneficial effects of ES include improvement of meat colour and flavour, and extension of shelf-life (Martin et al., 1983; Savell, et al., 1977; Savell et al., 1978a; Savell et al., 1978b). These effects have contributed to widespread commendation of ES. It is noted that a rapid decline in pH, and hence high initial muscle energy reserves are necessary for ES to be effective. If animals are stressed such that pre-slaughter glycogen reserves are very low, ES will not improve meat quality (Dutson, Savell and Smith, 1981). Thus, ES carcasses with a high initial pH of 6.7 to 7.1 tend to yield tender meat and require less conditioning time than carcasses with an initial pH of 5.8 to 6.2 (Khan and Lentz, 1973).

The effect of ES on three species is shown in Table 2.5. Notable is that beef and lamb tenderness increased without concomitant increase in SL while there was an increase in both tenderness and SL of chevon. Evidently lamb and beef were not subject to cold shortening under the experimental conditions but the increase in tenderness would have been caused by disruption of myofibrils during ES (Savell et al., 1978a) and enhancement of proteolysis. For goat carcasses, cold shortening may have been a problem and this was prevented by ES.

Toughness of meat that is caused by excessive sarcomere contraction during rigor development is resolved after a period of ageing, supposedly by proteolysis, non-enzymatic degradation of the cytoskeleton (Takahashi, 1996) and the weakening of the actin/myosin interactions (Goll et al., 1995). The state of the actin/myosin interactions post-mortem is not yet fully understood However the apparent increase in SL with ageing, such as the increase from 1.76µm at 24 hours to 1.90µm at 336 hours post-mortem, that was reported by Wheeler and Koohmaraie (1994) suggests that these interactions are slackened during conditioning.

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Table 2.5 The effect of electrical stimulation on goat, lamb and beef loin eating quality

		Stimulated	Non stimulated	*P* level
Goat	Flavour rating	5.4	5.4	Not significant
	Overall tenderness	4.5	3.5	*P*<0.01
	Shear force (kg)	4.74	6.25	*P*<0.01
	Sarcomere length	1.85	1.76	*P*<0.05
	Overall palatability	4.6	3.8	*P*<0.05
Lamb	Flavour rating	6.0	6.0	Not significant
	Overall tenderness	6.7	6.0	*P*<0.01
	Shear force (kg)	2.87	3.82	*P*<0.05
	Sarcomere length	1.83	1.80	Not significant
	Overall palatability	6.0	5.4	*P*<0.05
Beef	Flavour rating	5.1	4.6	*P*<0.01
	Overall tenderness	6.2	5.0	*P*<0.01
	Shear force (kg)	6.4	8.5	*P*<0.01
	Sarcomere length	1.83	1.84	Not significant

Source: Savell et al. (1978a)

As a result of the weakening of inter- and intra-myofibrillar connections during ageing, aged meat yields a high proportion of smaller fragments upon homogenisation than unaged meat (Geesink, 1993). The degree of fragmentation has been found to be highly related to the degree of tenderness and hence most laboratories use the myofibrillar fragmentation index (MFI) as a measure of tenderness. Myofibrillar fragmentation is determined as the turbidity of a homogenised meat sample at 540nm (e.g. Culler, Parrish, Smith and Cross, 1978; Koohmaraie et al., 1991b; Morgan, Wheeler, Koohmaraie, Crouse and Savell, 1993b). The index may however be confounded by sarcocyst infections that commonly occur in muscles of animals raised off the range (Levine, 1985). In such instances measuring the average length of the fragmented myofibres has been found to be a better indicator of tenderness than MFI. Some workers in the past, such as Fukazawa, Briskey, Takahasha and Yasui (1969) have used this approach, though in that case the incidence of the shorter (less than four sarcomere lengths) rather than the longer (greater than five sarcomere lengths) myofibrillar fragments was measured.

The concept of measuring products of proteolysis has been extended to measuring micro-fragments of degradation such as the 30kDa unit arising from the break down of troponin-T by the calpains (Penny, 1980; Ouali, 1990). That measurement is usually accompanied with quantification of the post-mortem changes in the concentration of the calpains.

Of all the laboratory methods of determining meat tenderness, the rheological Warner-Bratzler shear force remains the most popular (Lepetit and Culioli, 1994). By this method the peak force required to cut through a cylindrical block of meat perpendicular to the myofibres is usually determined and this has been observed to accurately reflect myofibrillar tenderness (Bouton et al, 1975). Shear force determinations are often accompanied by sensory evaluations of tenderness. The latter gives an indication of the size of shear force differences that are organoleptically perceivable.

2.2.6.3 Tenderness of chevon

Most studies in the evaluation of goat meat and its palatability have compared the meat to lamb/mutton and/or other meats (e.g. Pike et al., 1973a; Babiker et al., 1990; Griffin et al., 1992; Schönfeldt et al., 1993a; Tshabalala et al., 2003). Tenderness and other palatability values for chevon are often in the acceptable range but lower than values for lamb/mutton (Table 2.6) and beef (Pike et al., 1973a). Shear force values tend to follow similar trends as tenderness ratings but the actual values vary considerably from study to study, depending on pre-slaughter treatment of the animals, post-slaughter handling of the carcasses, the muscle that was used and the method of sample preparation (Table 2.7).

Table 2.6 Average tenderness ratings for chevon compared to lamb/mutton

Source	Tenderness rating		Hedonic scale
	Goat	Sheep	
Pike et al. (1973a)	4.2	7.9	9 point
Schönfeldt et al. (1993a)	2.8	4.8	6 point
Griffith et al. (1992)*	5.5	4.3	8 point
Babiker et al. (1990)	2.8	3.1	5 point
Sheridan, Hoffman and Ferreira (2003)	49.6	83.2	100 point
Tshabalala et al. (2003)	4.3	6.7	9 point

* Untrained consumer panel ratings

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Table 2.7 Some shear force values reported for chevon

Species	Muscle	Carcass handling	Shear sample preparation	Shear force	Source
Angora goat Boer goat	SM SM	ES; Aged for 7d at 1 to 7°C	Defrosted from-20°C; Oven at 160°C to 75°C; 12.5mm∅ cores, Warner Bratzler shear force device	54.05N 60.44N	Schönfeldt et al. (1993a)
Sudanese male desert goats	SM	Conditioned at 34°C then chilled at 7°C for up to 24hrs.	Water bath at 80°C for 1hr 1 x1cm cross section, Warner Bratzler shear force device	5.7kg/cm^2	Babiker and Bello (1986)
Boer goat Cashmere goat Boer x Cashmere goat	SM SM SM	ES; Chilled at 4°C for 20 hours	Defrosted from-20°C; Water bath at 97°C to 75°C internal temperature; 1x1cm cross section, MIRINZ tenderometer	9.1kgF 5.4kgF 8.6kgF	Swan et al. (1998)
Criollo goats (24kg)	LD BF		Water bath to 70°C internal temperature; Warner Bratzler shear force device.	58.45N 54.80N	Nuñez Gonzalez et al. (1983)
Boer, Angora, Saneen and Feral crosses	*Vastus* group	Chilled for 24 hours, temperature not given.	Water bath at 85°C to 70°C internal temperature; 1x1cm cross section; Warner Bratzler shear force device.	4.4kg/cm^2	Dhanda et al. (1999)
Desert goats	SM	Chilled for 24 hrs at 4°C	Defrosted from -10°C; Water bath at 80°C for 1hr; 1x1cm cross section; device not mentioned	4.0kg/cm^2	Babiker et al. (1990)
Saneen x Angora	*M. longissimus*	ES; chilled at 9°C for 24 and 48hrs	Water bath at 85°C to 70°C internal temperature; 1x1cm cross section; MIRINZ tenderometer	8.6kg (24h) 7.6kg (48h)	Hogg et al. (1992)
Spanish kids Spanish yearlings	SM SM	Chilled at 1°C for 48 to 72hrs.	Defrosted from -23°C; Roasted at 175°C to 75°C internal temperature; 12.7mm∅ cores; Warner Bratzler shear force device	8.8kg 5.3kg	Smith et al. (1978)
Boer goats Boer goats	SM	NES; chilled for 24 hours at 4°C	Fresh samples; Water bath at 75°C for 1hour; 12.7mm∅ cores; Warner Bratzler shear force device	11.07kg 14.32kg	Sheridan et al. (2003)

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2.2.7 Factors of Production Quality

At each level of the production-consumption continuum there are several production factors which impact on the final quality of the meat. Some have been discussed in the preceding sections. This section focuses on those that are likely to have critical effect on the quality of chevon; that is nutritional history, physical exercise, peri-mortal treatment and post-slaughter handling.

2.2.7.1 Effect of nutritional history

Nutrition is probably the single important farm-level production factor that influences meat quality. The level of nutrition influences growth rate, final live weight, dressing out percent and carcass fatness, and connective tissue composition and cross-linking (Arbele, Reeves, Judge, Hunsley and Perry, 1981; Miller et al., 1987). Perhaps most critical is the influence of nutrition on muscle glycogen concentration. If the latter is low at slaughter then tenderness, juiciness, flavour, colour and shelf-life of the meat are detrimentally affected (Warner et al., 1998).

Pethick et al. (2000) demonstrated a clear relationship between the level of glycogen in muscle and the intake of metabolisable energy (ME). Wethers and steers that came off a low plane of nutrition consistently had low levels of glycogen on-farm, at slaughter and 48 hours post-mortem than those on high energy diets. In addition, high energy diets reportedly protect slaughter stock from the potential glycogen depleting stressors (Warner et al., 1998; Immonen, Ruusunen, Hissa and Puolanne, 2000a) The protective effect is often large enough to make a difference between normal and dark cutting meat (e.g. pHu values 5.53 on high energy vs. 5.60 on low energy, Warner et al., 1998; pHu value 5.69 on high energy vs. 5.93 on low energy, Immonen et al., 2000a). McVeigh and Tarrant (1982) and Warner et al. (1998) showed that animals that have been on better nutrition prior to slaughter replete their glycogen reserves faster than those coming off poor diets. The inference from these series of works is that animals destined for slaughter should be on a high plane of nutrition so that they have adequate glycogen reserves at slaughter to alleviate the problem of dark cutting (Pethick et al., 2000).

2.2.7.2 Effect of physical exercise

Long term exercise is a factor that is closely linked with extensive production systems for indigenous goats. Daily wandering around in search for food may lead to increased concentration of myoglobin in muscles as well as an increase in the activity of respiratory enzymes and glycogen stores (Lawrie, 1998). Such conditions are conducive to appropriately low pHu post-mortem (Fernandez and Tornberg, 1991; Lawrie, 1998).

Meat from chronically exercised sheep has been reported to be more tender than that from the non-exercised sheep. (Aalhus and Price, 1990; Aalhus, Price, Shand, and Hawrysh, 1991). Aalhus *et al*. (1991) suggested that the advantage of the exercised group could have been a decrease in the proportion of collagen relative to myofibrillar proteins but not exercise-induced changes in collagen metabolism. Shiba, Matsuzaki and Tsuneishi (2000) concur with Aalhus *et al*. (1991). The former observed that exercise did not to have an effect on the collagen properties of most of the goat muscles studied except the *soleus*. On the other hand, studies with rats have shown that continuous exercise impacts on collagen metabolism by retarding the increase of thermal stability (Skalicky and Viidik, 1999, 2000). In contrast to Shiba *et al*. (2000), Skalicky and Viidik (1999) found continuous exercise to be more effective than the intensity and amount of exercise. Therefore, while the effect of exercise on collagen is still not clearly understood, it seems not to have detrimental effects on meat quality.

2.2.7.3 Effects Peri-mortem Treatment

Pre-slaughter stress is the single most influential production factor on glycogen concentration at slaughter, pHu and hence any quality factors that are influenced by pHu. Common pre-slaughter stressors to livestock are poor nutritional status, handling, distance, duration and conditions of travel conditions to the abattoir, inclement temperature, unpropitious hormonal status and social and physical interactions (Price and Tennessen, 1981; Lacourt and Tarrant, 1985; Kenny and Tarrant, 1988; Warriss, 1990; Sanz, et al., 1996; Lahucky, Palaska, Motjo, Zaujec and Huba, 1998). Any animals that have been subjected to these stressors invariably yield meat that has higher pHu values than unstressed groups (Table 2.8).

Table 2.8 Effect of pre-slaughter stress on the ultimate pH taken from the *M. longissimus*

Animal	Stress	Ultimate pH		Source
		Unstressed	Stressed	
Merino wethers	Transport &	5.54	5.64	Gardner et al.
Merino 1st cross wethers	liarage	5.52	5.60	(1999).
Merino 2nd cross wethers		5.54	5.58	
Friesian bulls	Mixing	5.57	6.45	Warriss et al. (1984)
Friesian cross intact & vasectomised bulls & steers	Mixing	5.74	6.04	Mohan Raj et al. (1992)
Heifers of mixed breeds	Oestrous behaviour	5.48	5.92	Kenny and Tarrant (1988)

With time, animals may recover from the travel and mixing stress. However glycogen repletion rates are generally slow in ruminants, taking between three days and two weeks (McVeigh, Tarrant and Harrington, 1982; Warriss, Kestin, Brown and Wilkins, 1984; Lacourt and Tarrant, 1985). The rate depends on the nutritional history, extent of the stress and recovery conditions. The rate of repletion is particularly slow in animals that have been on poor quality diets and/or have been fasting prior to slaughter (McVeigh et al., 1982; Warner et al., 1998). It is thus recommended that slaughter animals be allowed recovery time in liarage so that glycogen reserves may be repleted. For cattle, a 24 hour rest period before slaughter is recommended to allow the animals to recover from the travel, adapt to their new environment and replenish glycogen reserves (Wythes, Shorthose and Powell, 1988).

2.2.7.4 Effects of post-slaughter handling

To produce quality meat, appropriate temperature, airflow and relative humidity must be employed in the chillers (Lawrie, 1998; Varnam and Sutherland, 1995). Chilling must be rapid enough to minimise microbial growth but avert cold shortening. The airflow must be sufficient for even cooling and not excessively dehydrate the carcasses, and humidity must be carefully controlled to reduce bacterial growth on the meat surface. A protocol recommended for sheep is to reduce the temperature rapidly to 12-15°C, hold this temperature for 18 hours followed by a

slow reduction of the temperature to 5°C (Varnam and Sutherland, 1995). Most abattoirs however use a set temperature between 0ºC and 4ºC. Paradoxically, the low temperatures used for chilling are associated with increased incidence of cold shortening, especially with small, poorly insulated carcasses. Consequently innovations to either enhance the rate of glycolysis so as to produce tender meat or mechanically restrict the interdigitation of actin and myosin filaments are recommended for use at these low temperatures. The three commonly researched on-line methods are alternatives to the traditional Achilles tendon carcass suspension, high temperature conditioning and ES.

Alternative carcass suspension works on the premise that the carcass is hung in such a way that high value muscles are stretched and not subject to shortening during chilling. Currently the popular alternatives are Tender stretch, whereby carcasses are hung by the obturator foramen (aitchbone), and Tender cut, whereby bones and connective tissue are cut in the mid loin and the round /sirloin junction of beef carcass sides to enable the weight of the carcass to stretch selected muscles before the onset of rigor mortis (Claus, Wang and Norman, 1997; Beaty, Apple, Rakes and Kreider, 1999). These techniques have been adopted in the beef industry in some countries (Tarrant, 1998; Sørheim et al., 2000).

High temperature conditioning entails holding the carcasses at high temperature for some time immediately post-slaughter before moving them into the chillers. This is so that glycolysis occurs at the high temperatures and by the time the carcasses are chilled, glycolysis would have advanced beyond the stage where cold shortening may occur. The criticism against high temperature conditioning is that it causes delays in the slaughter line and has a high risk of microbial contamination.

Electrical stimulation is widely acclaimed because it not only improves tenderness but seems to improve other quality attributes such as colour, reduced incidence of heat ring and flavour (Savell et al., 1978a and b). The effects of ES are clearly demonstrated in Table 2.5, whereby tenderness of the three meat types was considerably improved, whether through expediting of glycolysis or other effects.

CHAPTER 2

2.2.8 Implication of Smallholder Production Systems on Chevon Quality

In southern Africa, drastic changes in smallholder goat production systems are unlikely in the foreseeable future unless there are drastic changes in the land tenure systems (Cronjé, 1999) and marketing opportunities (Panin and Mahabile, 1998; Seleka, 2001). Until such changes occur, the goats coming off the developing agricultural sector will continue to be of the assortment that is subjected to seasonal fluctuations in rangeland nutrition (Sibanda, 1992) and walk long distances daily in search for food. The seasonality of rangeland quality has been shown to result in good quality carcasses in post rainy season and poor quality carcasses in the dry to early rain seasons (Simela, et al., 1998). The foregoing therefore suggests that in order to supply the meat markets with chevon of acceptable quality, the slaughter stock should be correctly selected from the existing flocks. In addition, carcass handling and classification should take into consideration the lean nature of goat carcasses.

2.3 SENSORY EVALUATION OF MEAT QUALITY

The sensory properties of a food impact on consumers' appreciation of the food and determine their perception of its acceptability and quality (Chambers IV and Bowers, 1993). Sensory properties are pivotal in this respect because consumers need to be entirely satisfied with the sensory properties before other elements become relevant (Chamber IV and Bowers, 1993; Issanchou, 1996). There have been several investigations to determine the sensory attributes that drive acceptance of food. Most have concluded that acceptability of meat can be predicted from tenderness/texture, juiciness and flavour (Horsefield and Taylor, 1976, Parrish, Boles, Rust and Olson, 1991). Studies in the United Sates of America have identified tenderness as the most important factor influencing the acceptability of beef (Morgan, Savell, Hale, Miller, Griffin, Cross and Shackelford, 1991; Boleman et al., 1997) and that juiciness and flavour have a greater effect on consumer satisfaction as toughness increases (Miller, Carr, Ramsey, Crockett and Hoover, 2001).

Laboratory techniques have been developed to quantitatively assess the palatability attributes. While laboratory methods provide technical, precise and reliable information about a product, the results do not tell whether or not the food would be acceptable to consumers. Therefore,

consumer studies are used to determine the range of quantitative values that are acceptable as well as the degree of liking or preference for a product (Muñoz and Chambers IV, 1993).

The sensory test that is carried out to determine whether or not consumers like a product is that of acceptance, which is defined as a positive attitude after the tasting experience and is directly measured on a hedonic scale (Baker, Wong Hahn, and Robins, 1994). It may be determined as an overall measure or for individual sensory attributes (Meilgaard, Civille and Carr, 1991). The test may be accompanied by a food action rating test, which requires the consumers to estimate their intended frequency of consumption of the product (Penfield and Campbell, 1990). The latter test is essential because consumers tend to be realistic when they evaluate or predict actions. As such a measure of consumption intent is considered more sensitive and action-orientated than the hedonic tests (Penfield and Campbell, 1990). A complimentary test, when several products are being evaluated, is an indication of whether or not consumers prefer one product to others. Preference determination is useful because it is possible for consumers to show a strong preference for a sample but not want to consume it frequently or to reject it for other reasons than not liking it (Penfield and Campbell, 1990).

A number of studies have been conducted on the palatability and acceptability of chevon but in most instances the studies have employed trained taste panels. In most of them, chevon and chevon products were rated as high quality (Breukink and Casey, 1989; Schönfeldt et al., 1993a and b; Tshabalala et al., 2003). Despite these outcomes, indications are that consumers perceive chevon as tough and smelly (USAID/South Africa and ARC, 1998a; Mahanjana and Cronjé, 2000). The latter findings are however based on surveys rather than on sensory evaluations. It has been shown that sometimes consumer biases against chevon may be unfounded. In a blind test carried out to determine the overall appeal rate of chevon versus beef, 42% of the consumers preferred chevon, 38% beef and 20% were indifferent between the two meats (Teh, 1992). Thus sensory evaluations help to highlight the disparities and parallelisms between consumer conceptions and tastes.

CHAPTER 2

2.4 SUMMARY

Substantial research has been conducted on goat production systems, productivity, carcass and meat yield. However few studies ever link animal and carcass characteristics to the quality of the meat. Details of how handling of goats, carcases and chevon throughout the production to consumption continuum are necessary in order o determine points at which measures to optimise quality may be instated.

Due to the increase in the segment of consumers that are conscientious fat content and quality in meat, it may be that the low carcass fat of chevon will be its primary selling point in the meat market. Paradoxically, the leanness of goat carcasses predisposes them to dehydration, fast chilling and slow glycolysis under normal chilling conditions in commercial abattoirs. Inappropriate handling of the lean carcasses may therefore be one of the reasons that chevon is perceived as poor quality meat. Much improvement can be made in animal handling prior to slaughter to ensure that the animals are fit to produce quality meat. However, with ever increasing concerns about food safety, it is unlikely that adjustment will be made to the chilling protocols used in abattoirs. Coupled with the view that smallholder goat production will barely change in the near future, the challenge is to select from the existing flocks, goats that will yield carcasses that process well during primary chilling in order to ensure a quality product. Achieving a technologically sound goat carcass, tied with knowledge of the nutritional value of chevon, would facilitate defining carcasses, and hence goats are acceptable to consumers.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 THE EXPERIMENTAL GOATS

A flock of goats was purchased from an auctioneer who buys goats from all over South Africa. The goats were kept at the Hatfield Experimental Farm, University of Pretoria prior to slaughter. The flock ranged from recently weaned kids to 6-teeth castrates and intact males and full-mouthed females. On arrival at the farm, the goats were vaccinated against pulpy kidney and pasteurellosis, and were dosed against major internal parasites. They were separated into males and females in two adjacent pens. Suckling kids were held in the same pen as the does. The goats were provided a maintenance diet of Silgro® ewe and lamb pellets fed at ca. 0.3% of total animal weight per pen. The pellets were formulated to provide 130g/kg crude protein, 34.9% non-protein nitrogen, 150g/kg crude fibre, 25g/kg crude fat, 15g/kg calcium and 3g/kg phosphorus. Clean water and *Eragrostis curvula* hay were available ad libitum.

The goats were divided into two groups for slaughter, which, as much as was possible, consisted of goats from all age and sex groups. One group were the non-conditioned goats, which were slaughtered within three months of purchase. Pre-slaughter conditioned goats were slaughtered between six and 10 months of purchase. All goats were slaughtered when they were at least 25kg live weight. As is typical of goats from smallholder producers (Simela, 1996), there were very few milk- and 2-teeth goats that weighed 25kg or more in the market. The majority of the young goats, especially the females, were about 13–15kg and hence for this study, they were raised to at least 25kg before slaughter. Consequently most of the 2-teeth goats were slaughtered in the pre-slaughter conditioned state.

In total 89 goats were slaughtered. The distribution of the slaughtered stock by age class (based on dentition), sex and pre-slaughter conditioning is shown in Table 3.1.

Chronological age of the goats was estimated from their dentition based on the findings of Horgan, King and Kurth (1988) and Singh and Saini (1998). According to these authors, the first pair of permanent incisors erupts at 15 to 17 months, the second at 20 to 26 months, the third at 24 to 26 months and the fourth pair at 28 to 30 months in medium and large goats. The age range at which each set of permanent incisors erupts is however very wide within and amongst the breeds,

especially for the later sets (Horgan et al., 1988; Singh and Saini, 1998). Nonetheless, dentition serves as a guideline for the estimation of the age of goats raised by smallholder farmers, which would otherwise be impossible to estimate since the farmers do not keep such records. Moreover dentition is said to be a more precise estimation of physiological age than methods such as degree of ossification of cartilage or the appearance of some bones of thoracic and lumbar vertebrae (Price, 1982).

Table 3.1 Distribution of experimental goats by age (dentition) class, sex and pre-slaughter conditioning

Age class (dentition)	Pre-slaughter conditioning	Castrates	Female	Males	Total
0-teeth	Non-conditioned	6	1	3	10
	Conditioned		3	4	7
2-teeth	Non-conditioned	7		1	8
	Conditioned	7	13	4	24
4–6 teeth	Non-conditioned	9	7	4	20
8-teeth	Non-conditioned		11		11
	Conditioned		9		9
Total	Non-conditioned	22	19	8	49
	Conditioned	7	25	8	40
Grand total		29	44	16	89

NB: Incisors were considered in pairs. Thus if one of the first pair of incisors had erupted then the goat was considered 2-teethed; if one of the second pair had erupted then the goat was taken as 4-teethed, etc.

Non-conditioned – slaughtered within three months of purchase

Conditioned - slaughtered between six and ten months of purchase

The delineation of the age classes using dentition was in line with the current ruminant carcass grading system in South Africa, which defines classes, A, AB, B and C as animals with milk teeth, one to two permanent incisors, three to six permanent incisors and more than six incisors, respectively.

CHAPTER 3

All the goats were slaughtered at the abattoir of the Animal Nutrition and Animal Products Institute (ANAPI) of the Agricultural Research Council (ARC) at Irene. In the morning of the day prior to slaughter, animals were randomly selected for slaughter from the different age and sex groups with a pre-slaughter conditioning group. The goats intended for slaughter were weighed and their chest girths were measured. They were held in a separate enclosure but had their daily ration of feed and water. During the mid afternoon, the slaughter animals were taken to the abattoir, which was a drive of about 30km (20 minutes). They were held in lairage overnight for about 17 hours with clean water ad libitum but no feed.

During slaughter, the goats were stunned using 300V applied across the head, at the base of the ears and behind the eyes. Judging from the research conducted on pigs (Wotton, Wilkins and Whittington, 2003), this voltage should have been well beyond the threshold necessary to break down the initial impedance and promote an effective and immediate stun.

A subset of four castrated males with 4-to-6 permanent incisors and nine does with full mouth were electrically stimulated immediately after exsanguination, with 220V, for one minute at a pulse of 12.5 per second. Electrically stimulated goats were taken from both the non-conditioned and pre-slaughter conditioned groups.

The dressed carcass comprised of the body after removing the skin, the head at the occipito-atlantal joint, the fore-feet at the carpal-metacarpal joint the hind feet at the tarsal-metatarsal joint and the viscera. The kidneys and kidney knob and channel fat (KKCF) were part of the dressed carcass. They were only removed after the chilled carcass had been weighed.

3.2 SAMPLING AND SAMPLE STORAGE

Within 10 minutes of slaughter, two samples of the *M. longissimus thoracis* (LT) of about 20g each were cut from the left side of the carcasses and immediately frozen in liquid nitrogen, put in marked self-sealing polythene bags and stored at –70ºC for myofibre typing (MFT), calpastatin and glycolytic potential (GP) determinations. The LT samples were collected from all 89 goats while *M. semimembranosus* (SM) samples for myofibre typing and calpastatin analyses were taken from 27 randomly selected goats for comparative purposes with LT samples. Several samples were cut from the goat that was slaughtered last and retained for the extraction of m-

calpain, which was to serve as reference for calpastatin analysis. This carcass was not included in further analyses.

After skinning and evisceration, omental fat was removed from the viscera of each goat and weighed separately.

At 24 hours post-mortem, *M longissimus lumborum* (LL) and SM samples were cut from each side of the carcass and weighed. Any fat (subcutaneous and/or intermuscular) that was attached to these muscles was separated and weighed. Samples for myofibrillar fragmentation length (MFL) and sarcomere length (SL) determinations were cut from the proximal end of the SM. Similar samples were cut from the cranial end of the LL muscle. All the samples (including the remainder of each muscle) were vacuum packed. Samples from the left side of each carcass were immediately frozen at –20ºC. Muscles from the right side of each carcass were aged for a further 72-hours and then stored at –20ºC.

The 96-hour ageing period was selected on the basis of the outcome from the surveys conducted in Zimbabwe, in which most of the goat carcasses in the commercial market were sold within four to five days after slaughter. Further to that, Kannan, Chawan, Kouakou and Gelaye (2002a) showed that there is no significant improvement in chevon tenderness beyond the first 96 hours of refrigerated storage.

3.3 CARCASS MEASUREMENTS

Immediately after removing GP, MFT and calpastatin samples, initial pH (pH_0) and temperature were measured on the left LT and SM within 15 minutes after slitting the throat of each animal. Subsequent readings were taken at three, six and 24 hour post-mortem and the pH readings are designated pH_3, pH_6 and pH_{24}/pHu, respectively. Hot carcass weight (HCW) was measured prior to washing and chilling. The carcasses were chilled at 2–4ºC for up to 24 hours post slaughter (about 23 hours in the chillers). Thereafter they were weighed to obtain cold carcass weight (CCW). All the KKCF and the kidneys were then removed. The KKCF was weighed, vacuum-packed and stored at –20ºC. Buttock circumference was measured according to Fisher and de Boer (1994) and then the carcass was split in half along the dorso-ventral plane. The right side was weighed and carcass dimensions (carcass depth, carcass length and side length) were measured as

prescribed by Fisher and de Boer (1994). Thereafter the side was jointed along the lines shown in Figure 3.1 into neck, fore limb, ventral trunk, dorsal trunk and hind limb.

The dorsal trunk was further split between the 12th and 13th ribs and the area of the LT was traced out on the surface of the 12t^{h} rib. The muscle area was later measured from the tracing using a visual image analyser (VIA, Kontron, Germany).

Each joint was dissected into the separable tissues; lean, bone, intermuscular and subcutaneous fat as defined by Fisher and de Boer (1994). Each tissue was weighed separately for each joint. The weights of the SM and of the LL samples and their fat were added to the weights of the hind limb and dorsal trunk, respectively.

Dressing out percentage and chilling losses were calculated as follows:

$$\text{Dressing out (\%)} = \frac{CCW}{Liveweight} \times 100 \qquad \text{Chilling losses (\%)} = \frac{HCW - CCW}{HCW} \times 100$$

Other variables that were calculated were the proportions of the dissectible tissues within the joints and within the right half carcass as well as the proportions of the joints within the side.

3.4 HISTOLOGICAL AND HISTOCHEMICAL ANALYSES

The SL and MFL of LL and SM samples aged for 24 and 96 hours where determined. MFT was carried out from LT and SM samples that were ultra frozen at -70°C immediately post slaughter.

3.4.1 Sarcomere Length

Portions of about 3g were cut out from the core of the frozen samples and prepared according to Hegarty and Naudé (1970). The frozen samples were homogenised in about 15ml of distilled water using an ultra Turrax blender at low speed. A few droplets of the homogenate were mounted on a slide, covered with a cover slip and immediately viewed under a microscope attached to a VIA, at a magnification of 100x. The SL were determined as the average sarcomere length of a hundred 5-sarcomere long sections taken randomly in VIA fields (Figure 3.2).

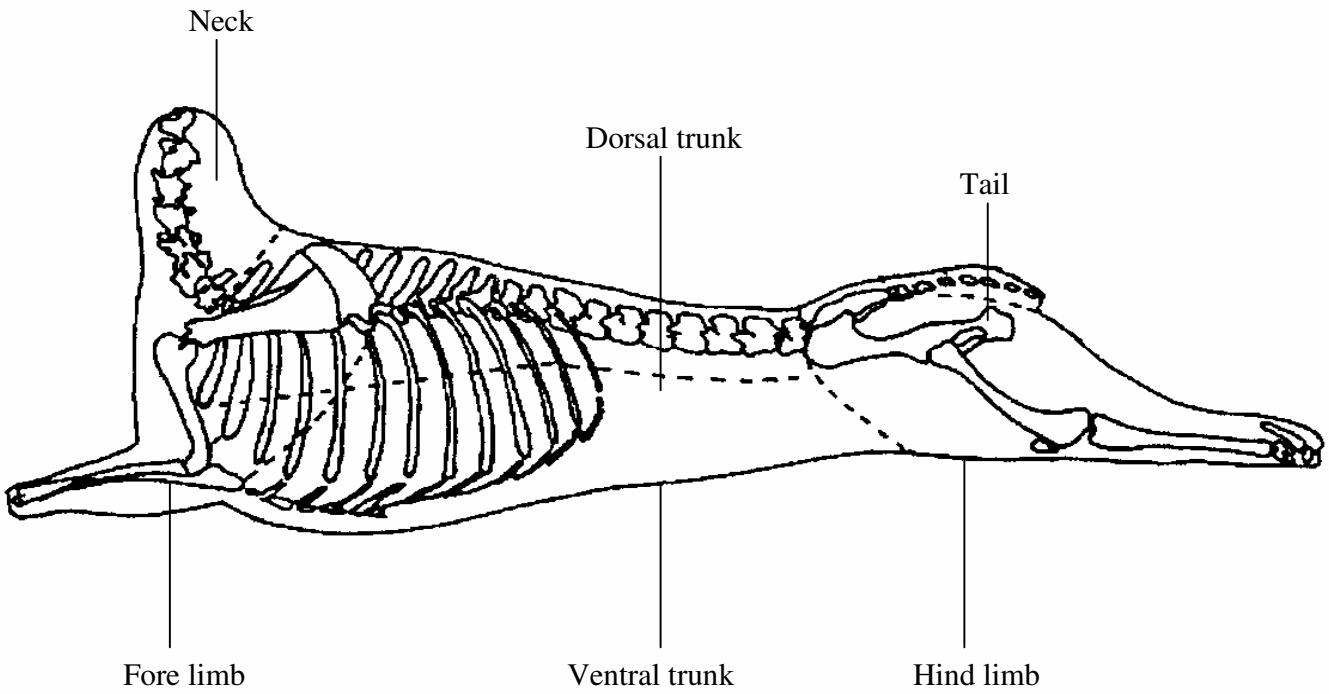
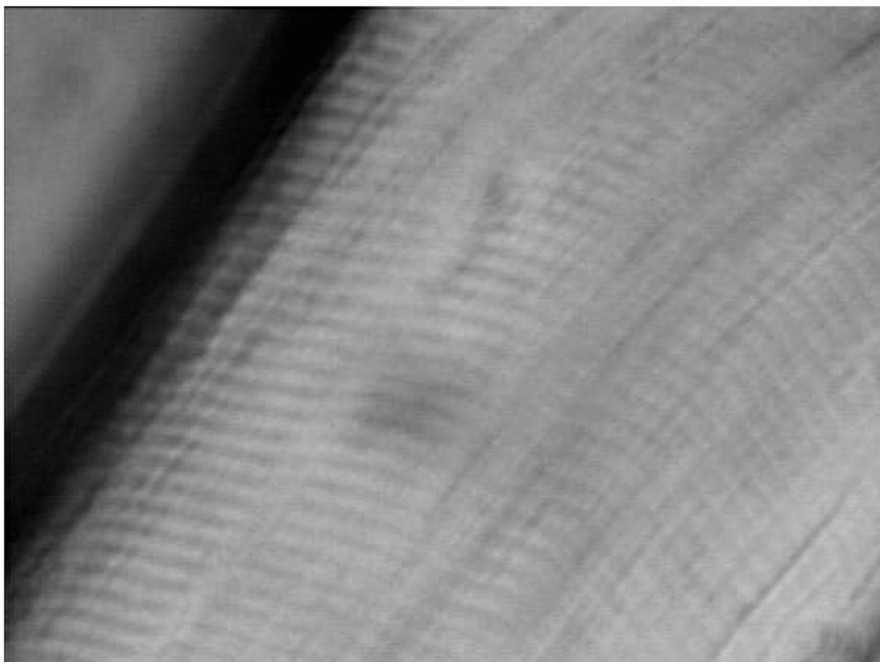


Figure 3.1 Diagram showing the joining lines for the goat carcasses (Casey, 1982)

i)



ii)

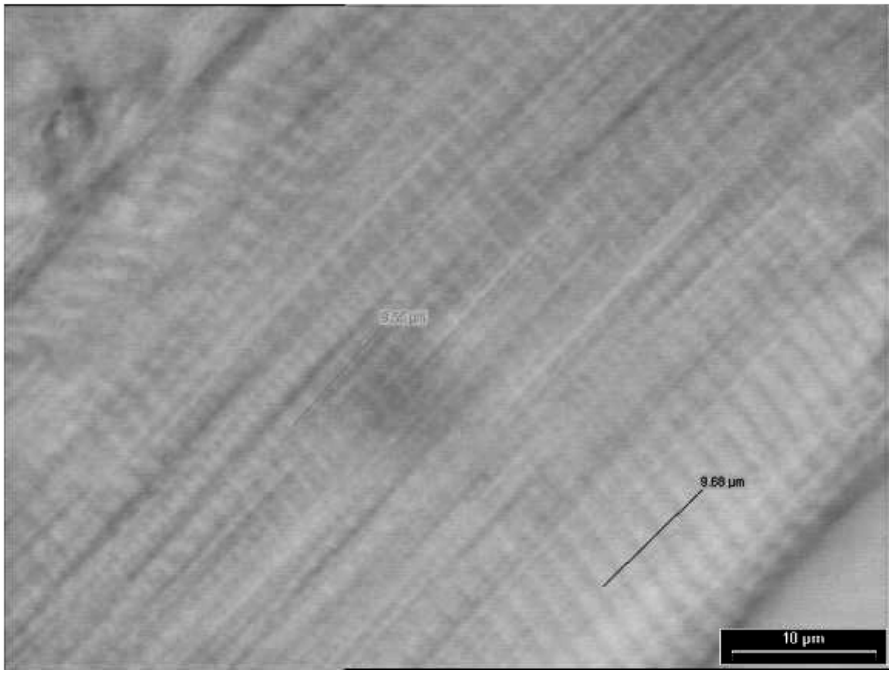


Figure 3.2 Illustrations of fields of (i) *M. longissimus lumborum* and (ii) *M. semimembranosus* samples prepared for sarcomere length determination as viewed under the visual image analyser (100 x magnification)

3.4.2 Myofibrillar Fragment Length

A sub sample of about 3g was cut from the interior of the frozen samples, blended in a cold potassium phosphate extraction buffer and prepared according to Culler et al. (1978). MFLs were determined according to Heinze and Bruggemann (1994). The methods involved the extraction of the myofibres in the buffer solution and under cold conditions (~4°C) in order to arrest any further proteolysis. Droplets of the extracted MFL solution were mounted on a slide, covered and viewed at a magnification of 40x under a microscope attached to the VIA. Myofibrillar fragment lengths were determined as the average length of the first 50 myofibrils that were longer than five sarcomeres and were in clear focus in VIA fields (Figure 3.3).

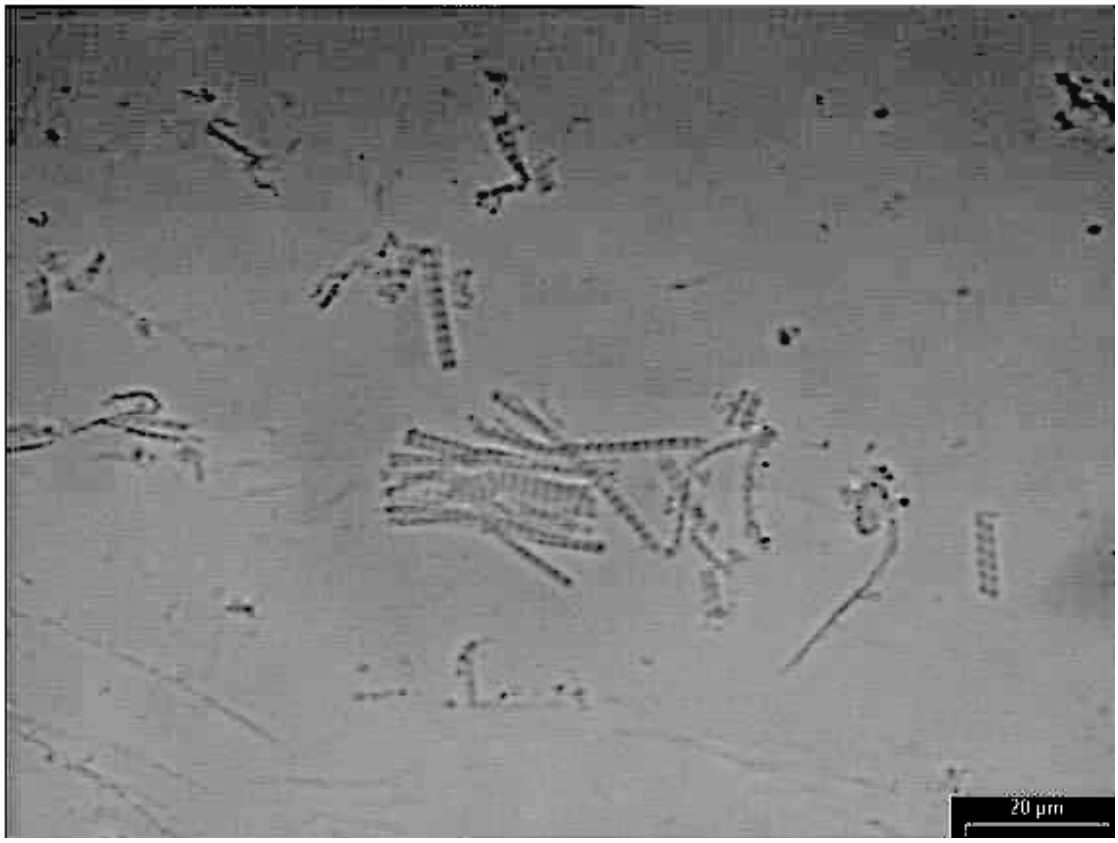


Figure 3.3 An illustration of a field of myofibrillar fragments as viewed under the visual image analyser at a magnification of 40x (*M. longissimus lumborum* sample aged for 96 hours)

3.4.3 Myofibre Typing

Sample blocks of about 50mm^2 cross sectional area were sectioned on a cryostat at -25°C to a thickness of 12µm. The sections were mounted on slides, stained for succinate dehydrogenase activity using nitroblue tetrozolium (Barka and Anderson, 1963), covered with cover slips and viewed under the microscope attached to the VIA at a magnification of 10x. From the VIA fields, the myofibres were classified as red, intermediate or white depending on intensity of the staining (Figure 3.4). The myofibre areas were determined as the average area of 50 fibres of each type. Additionally, the proportion of each myofibre type was estimated as the percent count of each MFT in five randomly selected fields.

3.5 PHYSICAL MEAT CHARACTERISTICS

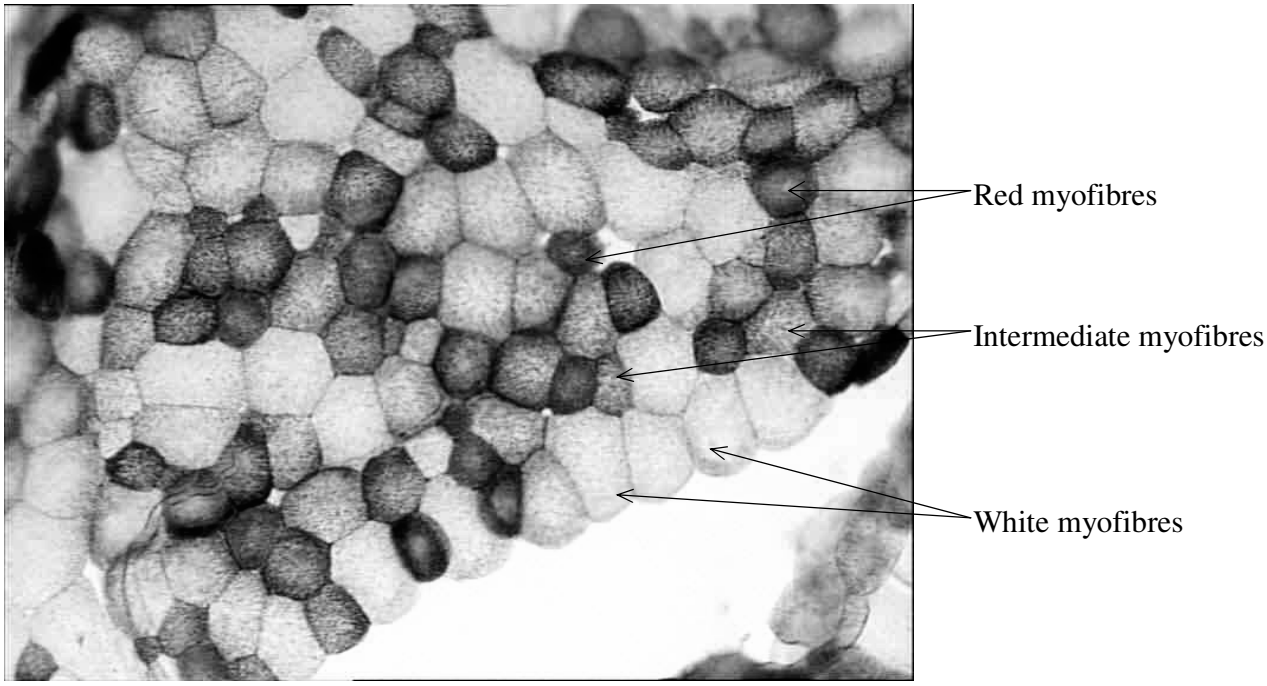
The physical parameters that were measured were the meat colour, cooking losses and shear force.

3.5.1 Colour, Cooking Losses and Shear Force

Samples of *M. semimembranosus* from both ageing periods were defrosted overnight at 2–4°C. Thereafter the vacuum seal was broken and a layer of about 0.5cm was cut off from the proximal end of the muscle to expose a fresh surface. The muscle was then wrapped in oxygen permeable polythene film and left to bloom for three hours at 2–4ºC with light. Subsequently, CIE L*, a* and b* values were determined on the cut surface with a Minolta chromameter, Model CR200 (Minolta, Japan). The chromameter was standardised against a white calibration tile that was wrapped in the same polythene cling film used for the meat samples. The calibration CIE values were L* 97.81, a*-5.56 and b* + 7.38. Three replicate measurements were taken per sample with special effort to avoid areas of connective tissue and intramuscular fat.

Following colour measurements, blocks of about 6 x 6 x 2.5cm (averaging 78.5g) were cut out, weighed and boiled in sealed polythene bags in a water bath at 76ºC for one hour. The temperature and cooking time were pre-determined in an earlier trial using mutton samples. The bags were then cooled under running water at room temperature for 30 minutes and stored in the chiller at about 2–4ºC overnight (Honikel, 1998).

i)



ii)

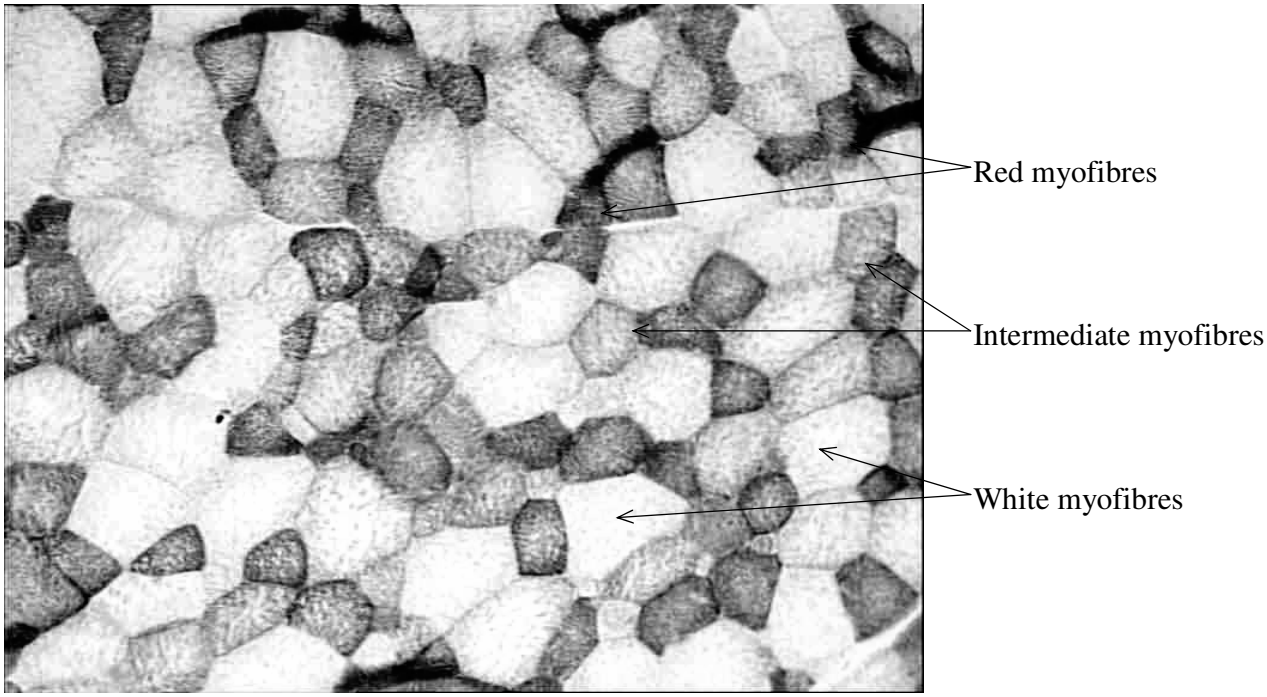


Figure 3.4 Illustrations of fields of (i) *M. longissimus thoracis* and (ii) *M. semimembranosus* muscles prepared for myofibre typing as viewed under the VIA (10x magnification)

The following day each sample was patted dry with a paper towel and weighed. Thereafter, as many cores as possible of 12.7mm diameter were cut out parallel to the myofibres. Each core was sheared perpendicular to the myofibres using a Warner Bratzler device fitted to an Instron Universal Testing Machine, Model 1011 (Instron Ltd, England), at a crosshead speed of 200mm per second (Honikel, 1998). The cores were sheared at one to three different points depending on their length and the number of cores obtained per sample. Toughness was taken as the average maximum force (Newtons) that was required to shear through cores of a sample.

The recommendation is that 10 cores should be sheared once for each sample (Boccard et al., 1981). However, goat SM were small such that only two to four cores that were about 3–6cm long could be obtained per sample. Therefore the longer cores were sheared two to three times.

Cooking losses were calculated as the percent weight loss of the sample after it had been cooked and dried with a paper towel.

3.6 BIOCHEMICAL ANALYSES

3.6.1 Glycolytic Potential, ATP and Creatine Phosphate

Samples for glycolytic potential (GP) were extracted from 3g of each of the 89 ultra frozen LT samples using perchloric acid, as described by Dalrymple and Hamm (1973). Glycogen concentration was determined as glycosyl units after hydrolysis with α-amyloglucosidase and correction for glucose concentration in the extract according to the method of Keppler and Decker (1974). Concentrations of ATP, glucose-6-phosphate and creatine phosphate were determined in the perchloric acid extracts according to Lamprecht, Stein, Heinz and Weisser (1974) and lactate concentration according to Gutmann and Wahlefeld (1974). Glycolytic potential was calculated according to Monin and Sellier's (1985) formula, as follows:

$$GP = 2([\text{glycogen}] + [\text{glucose}] + [\text{glucose-6-phosphate}]) + [\text{lactate}]$$

3.6.2 Calpastatin

Calpastatin concentration was determined using the boiling method described by Shackelford, Koohmaraie, Cundiff, Gregory, Rohrer and Savell (1994b) with some modifications. Frozen

samples of about 3g were homogenised for about 20 seconds in 12ml of the extraction buffer (100 mM Tris, 5 mM EDTA, with 15µl β-mercaptoethanol, pH 8.3, 4°C), using an ultra Turrax blender at high speed (13 500 revolutions per minute). The homogenates were centrifuged at 10 000 RCF for 15 minutes using a Sorvall Super T21 tabletop centrifuge (Sorvall™). The supernatant of each sample replicate was decanted into a measuring cylinder and made up to 20ml with the extraction buffer. For each sample, a 500µl aliquot was set aside for protein determination while the rest was transferred to bosilicate tubes and boiled in a water bath at 95°C for 15minutes. The samples were then cooled in an ice water bath for 15 minutes. After cooling, the coagulated protein was resuspended with a glass rod and the mixture was transferred to centrifuge tubes and centrifuged in one step at 4 000 RCF for at least 10 minutes.

Following centrifugation, the volume of the supernatant was determined and recorded for subsequent calculation of calpastatin activity. Calpastatin activity was determined according to the method of Koohmaraie (1990b). Azo-casein was used as the substrate for m-calpain and absorbance was determined at 366nm (Dransfield, 1996). The m-calpain used was extracted from goat meat samples that were set aside for that purpose. One Unit of calpastatin activity was defined as the amount that inhibited one Unit of m-calpain activity. A Unit of m-calpain activity was defined as the increase in absorbance of 1.0 per hour at 25°C determined at 366nm.

The Buiret method (Gornall, Bordawell and David, 1949 as cited by Bailey, 1967) was used to determine the extractable protein content. Calpastatin activity was expressed either as Units per gram sample or Units per milligram of protein (specific activity).

3.6.3 Fatty Acids

Fatty acid composition of LL samples that were aged for 24 hours and stored at -20°C was determined according to the method outlined by Webb (1994) and modified by Steenkamp (2000).

About 10g were cut from frozen meat samples, chopped into small pieces and stored in 20ml of chloroform with 0.01% butylated hydroxytoluene (BHT) to inhibit oxidation. The meat sample in chloroform was quantitatively transferred to a 50 ml boiling tube and a further 10ml of chloroform with BHT added. The sample was then boiled in a water bath at 60°C for about 15

minutes, until all chloroform had evaporated. Then a known volume of 10 to 15ml of chloroform was added and the meat sample was crushed with a glass rod to extract all the lipids from it. A 1ml aliquot was then taken for transesterification and determination of fatty acids concentration. A 5ml portion of the lipids in chloroform was kept aside for the determination of lipid concentration in the extract.

Transesterification was carried out at 60°C for 30 minutes (Steenkamp, 2000). Fatty acid concentration was determined using a Varian 3300 gas chromatograph equipped with a Varian 3300 integrator (Varian, California) as outlined by Webb (1994). The gas chromatography (GC) programme was as follows:

Initial column temperature:	150°C
Initial holding time:	2 minutes
Final column temperature	200°C
Rate:	5°C per minute
Holding time:	13 minutes
Injector temperature:	230°C
Detector temperature:	240°C
Range:	11

Prior to running the samples in the GC, a standards solution containing methyl esters of fatty acids known to occur in meat and in known concentrations was prepared and injected in order to determine and check the retention times of the different fatty acids.

The concentration of each fatty acid in the sample was determined by the following formulae:

$$\text{Fatty acid concentration (µg/g lipid)} = \frac{PAsa}{PAst} \times [FA]st \text{ µg/ml} \times \frac{1}{[Lipid]} \text{ g/ml}$$

$$\text{Fatty acid in meat (µg/g)} = [\text{lipid}] \text{ g/ml} \times \frac{extract}{sampleweight} \times [\text{fatty acid}] \text{ µg/g lipid}$$

Where PAsa = peak area in sample; PAst = peak area in standard; [Lipid] = lipid concentration in extract; [FA]st = fatty acid concentration in standard; extract = volume of lipid extract (ml); sample weight = weight of meat sample (g) from which lipids were extracted.

3.6.4 Amino Acids

The Pico.Tag method for amino acid determination (Bidlingmeyer, Cohen and Travin, 1984) was employed on 12 freeze-dried and defatted LL samples. The method involved three steps, which were the hydrolysis of the fat free meat sample with hydrochloric acid to yield free amino acids; derivatisation with phenylisothiocyanate to produce phenyltiocarbomyl amino acids. These derivatives were then separated by reverse column high pressure liquid chromatography and detected using a Water Associates Model 440 absorbance detector set at 254nm.

The objective of this analysis was to give an indication of the amino acid composition of chevon and hence the small number of samples used.

3.6.5 Crude Nitrogen and Crude Fat

Crude protein and crude fat were determined from freeze dried portions of the 45 LL samples that were used in the sensory evaluation. The conventional Association of Official Analytical Chemists (AOAC) methods were used for these analyses (AOAC, 1990).

3.7 SENSORY EVALUATION

Samples of LL muscle that were aged for 96 hours were used for sensory evaluations. The evaluation was conducted in two series. In the first series, LL of castrated (n=15) and female (n=15) goats with two to six permanent incisors were used. In the second series LL samples of male kids with no permanent incisors (n=6) and does with a full mouth (n=9) were used. In each of the series the goat samples were compared to mutton LL samples cut from twelve loins of ewes with four to six permanent incisors. The loin samples were obtained from a commercial retailer, from carcasses that were hung in the chillers for 48 hours. The samples were vacuum-packed and stored frozen at –20ºC for sensory analysis.

3.7.1 Preparation of Samples for Sensory Evaluation

Meat samples were taken from the -20°C deep freezer 24 hours before each session and thawed in a refrigerator at 4–5°C. Each thawed sample was weighed individually to determine cooking time. The samples were then salted slightly and roasted in an oven at 165°C until an internal temperature of 73°C was reached. The temperature was measured using a distance thermometer.

After roasting, each sample was weighed, allowed to set for one minute before it was cut into 4mm thick slices. Small samples were cut out because the goat LL were small.

3.7.2 Sensory Panels and Sensory Evaluation

A panel of 193 consumers who had previously eaten and had no objections to chevon, lamb/mutton were recruited on a voluntary basis through telephonic or personal contact. The profile of the panel in terms of population category (black or white), gender (male or female), age (21–30, 31–40, >40) and level of education (primary, secondary, tertiary) was recorded. The distribution of panellists of the first and second series of sensory analysis by these categories is shown in Table 3.2.

Table 3.2 Distribution of the consumers by population category, gender, age and level of education within the first and second series of sensory analysis

		Series I	Series II
Number of consumers per series		84	109
% per population category	Black	48%	77%
	White	52%	32%
% per gender group	Female	55%	38%
	Male	45%	62%
% per age group	21–30 years	44%	37%
	31–40 years	23%	31%
	> 40 years	33%	32%
% per level of education group	Primary	11%	29%
	Secondary	23%	38%
	Tertiary	67%	33%

There were 84 consumers in the first and 109 in the second series of analysis. No Indians or Muslims were included in the study because the goats had not been slaughtered according to their religious requirements. Two 15-minute sessions were conducted once a week under controlled conditions in a sensory evaluation laboratory.

The meat samples were randomly allotted and served to the consumer panel while still warm, to be evaluated in sequence according to an incomplete balanced block design. Three sensory tests were conducted in sequence. First the panellists rated the acceptability of flavour, aroma and tenderness on a five point hedonic scale, ranging from "extremely acceptable" (5), "acceptable" (4), "neutral" (3), "not acceptable" (2) to "extremely unacceptable" (1) (Bosman, van Aardt, Vorster, and Drewnowski, 1997). Secondly, they indicated the meat sample they preferred, if any. Finally the panellists indicated their consumption intent for each sample using a 5-point food action scale with response categories "eat it very often – everyday" (5), "eat it often – once a week" (4), "eat it occasionally – once a month" (3), "eat it only when no other food is available" (2) and "never eat it" (1). Panellists rinsed their mouths with water before and between tasting the samples (Bosman et al., 1997). At the end of each session, the panellists each received a slice of an apple to clean their mouths and a glass of fruit juice and a bar of chocolate for their participation.

3.8 STATISTICAL ANALYSIS

3.8.1 Live Animal, Carcass and Meat Quality Characteristics

General linear models (GLM) procedures of SAS (1996) were used to test the effects of sex, age classes and pre-slaughter conditioning (Table 3.2) and first order interaction effects on live animal, carcass and meat quality characteristics.

Pre-analysis tests were carried out for each of the variables. Where the data for a variable were not normally distributed, the rank transformation was performed and the transformed variable was used in the GLM analysis. For first order interaction effects sex was nested in age and age nested in pre-slaughter conditioning since not all sexes occurred in all age groups and not all age groups were represented in both pre-slaughter conditioning groups (Table 3.2). Where F-tests were significant ($P<0.05$), Scheffé's test was used to compare means.

3.8.1.1 Live animal and carcass characteristics

The main and first order interaction effects as described above were tested on slaughter weight, chest girth, carcass weights, carcass losses, carcass dimensions, carcass joint and tissue composition. The results of these analyses are presented in Chapter 4.

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3.8.1.2 Meat quality of chevon

The effects sex, age, pre-slaughter conditioning and first order interaction effects on the pH and temperature profiles, myofibre proportions and areas, MFL, SL, glycolytic metabolite concentrations and calpastatin concentration of the LTL muscle were tested as described in §3.8.1. The main effects and interaction effects on the pH and temperature profiles, myofibre proportions and areas, MFL, SL, cooking losses, shear force and colorimetric values of the SM muscle were similarly tested.

Pearson's correlations between the myofibre areas and proportions and meat quality traits were computed for each muscle. Furthermore, correlations between hot carcass weight, total carcass fat content and all the meat quality variables were investigated for each muscle. The effects of early post-mortem pH (pH_3) and ultimate pH (pHu= pH_{24}) on meat quality were further investigated for the variables that significantly correlated to these parameters.

Delineation of pH_3 groups was based on the concept that carcasses should attained a pH of 6.2 or less before the temperature drops below 15°C (Honikel et al., 1983) or a pH of 6 or less before 10°C (Cornforth et al., 1980). Carcass temperature averaged 13°C after three hours in this study, and hence it was taken that a pH of about 6.1 should have been attained by that time. Therefore the carcasses were divided into the following groups:

- $pH_3 < 6.1$
- $6.1 \leq pH_3 \leq 6.3$
- $pH_3 > 6.3$

Carcass in the $pH_3 < 6.1$ group were considered to be glycolysing at a fast enough rate to avert cold shortening. The second group were considered intermediate and the third slow and susceptible to cold shortening (Honikel et al., 1983).

Carcasses were further grouped as follows, based on pHu:

- pHu <5.8
- 5.8 ≤ pHu ≤ 6.0
- pHu >6.0

The assumption was that muscles with pHu of less than 5.8 would have normal quality characteristics. Those with pH_{24} between 5.8 and 6 would be tougher and darker and above 6, the muscles would have the dark cutting condition (Figure 2.3).

Where meat quality traits significantly correlated to pH_3 or pHu, Kruskal Wallis one-way ANOVA was performed to test the effects of pH group and compare the means (BMDP, 1983). The Kruskal Wallis' test is used if normality assumptions are not justified but the populations from which the samples are drawn have the same general shape, though possibly different medians (Steyn, Smit, du Toit & Strasheim, 1994).

Additionally, LTL and SM myofibre properties (SL, MFL, myofibre type areas and proportions and calpastatin activity) were compared using the Wilcoxon rank sum test (BMDP, 1983). The same test was used to compare the effects of 24-hour and 96-hour chilling on SL, MFL, cooking losses, shear force and colour parameters. The Wilcoxon rank sum test has similar assumptions to the Kruskal Wallis' test but is used to compare two samples (Steyn et al., 1994).

Results of these analyses are presented in Chapter 5.

3.8.1.3 Effects of electrical stimulation on chevon quality

The Wilcoxon ranked sum test (BMDP, 1983) was used to compare carcass and meat quality characteristics of non-stimulated (NES) and electrically stimulated (ES) carcasses. The LTL and SM meat quality characteristics were no significant different between females and castrates. Furthermore the carcass characteristics of the two sexes were similar. Consequently, data of the two sexes were pooled for each muscle and the overall effects of ES on meat quality tested. The results are presented in Chapter 6.

3.8.2 Fatty Acid and Amino Acid Composition of Chevon

Means and standard deviations were computed for the proportions and concentrations of all fatty acids detected in the meat samples. GLM procedures as described in §3.8.1 were used to test the effects of sex, age, pre-slaughter conditioning and first order interactions on the fatty acid proportions and concentrations. The analysis was carried out on fatty acids that were detected in at least 70% of the samples.

Means and standard deviations of the amino acid concentration in defatted lean of milk-teethed kids, 2-to-4 teeth castrates and females and mature does were computed. Kruskal Wallis' test (BMDP, 1983) was used to test for the effects of the four goat groups on the amino acid content and to compare means. The results of these analyses are presented in Chapter 7.

3.8.3 Sensory Evaluation

Comparisons of carcass and LTL meat quality characteristics were made between the goat classes in each of the two series using Wilcoxon's ranked sum test. Kruskal-Wallis' test was used to compare cooking losses of the mutton and chevon samples in each of the series.

The main effects of gender, age, population category and level of education of the consumers' ratings of aroma, tenderness, flavour and overall acceptability were tested using GLM procedures of SAS (SAS, 1996). Overall acceptability was calculated as the average of the ratings of the three sensory attributes for each consumer. GLM procedures were also used to compare the sensory ratings and overall acceptability of each meat type. Where the F-test was significant, Tukey's test was used for the comparison of means.

Kruskal Wallis test was use to compare consumption intent scores of different consumer categories as well as for the different meat types within each category. Medians and percentiles of consumption intent are presented. Spearman's correlations between hedonic scores and consumption intent were computed.

Multiple comparisons of proportions was performed to compare preference for each of the meats within each series (Millers, 1981). Stepwise discriminant analysis was performed to determine the sensory attributes that drove preference.

The results of these analyses are presented in Chapter 8.

CHAPTER 4

4 LIVE ANIMAL AND CARCASS CHARACTERISTICS OF SOUTH AFRICAN INDIGENOUS GOATS

4.1 INTRODUCTION

The acceptability of a carcass lies in its perceived value, which includes the potential meat yield of the carcass (Kempster, 1983; Chrystall, 1998) and the eating quality of the meat (Chrystall, 1998). To processors, wholesalers and the producers to some extent, the value of the carcass lies mainly in its potential saleable meat yield (Chrystall, 1998). Traits such as the weight and conformation of the live animal and of the carcass as well as fat distribution within the carcass are therefore of great importance in the early stages of meat production. The proportion of high value cuts also plays an important role in as much as it reflects the amount of high quality meat that may be obtained from the carcass.

Although live animal and carcass attributes are principally concerned with the quantity of saleable meat that can be obtained from the carcass, they also have significant implications on the technological value of the carcass. These attributes influence the biochemical and physiological processes in meat during slaughter and chilling, and hence the resultant quality of the meat. Therefore, early identification of animal characteristics that affect meat quality is beneficial for the production of meat of acceptable quality.

The purpose of this chapter is to describe the carcasses of the sample of South African indigenous goats that were used to evaluate chevon quality in the subsequent chapters.

4.2 RESULTS

4.2.1 Live Animal and Carcass Characteristics

The effects of sex, age and pre-slaughter conditioning on the live animal and carcass characteristics of the South African indigenous goats are presented in Tables 4.1 to 4.3.

4.2.1.1 Effect of sex on the live animal and carcass characteristics

Male goats were significantly bigger (P<0.0001) than the females (Table 4.1). Live weights of intact and castrated males were on average 5.44kg heavier and the chilled carcasses 2.32kg heavier than those of the females. Losses during dressing and chilling did not vary with sex (P>0.05). The overall mean DO% and chilling losses were respectively 40.55 ± 4.41% and 2.67 ± 1.03%.

Intact males had the largest frames, reflected by the broader chests (P<0.01) and longer carcasses (P=0.0001). The three sex classes however had similar LT area, whose overall mean was 10.79 ± 3.44cm^2. They also had similar internal fat content (P>0.05), whose overall means were 727±561g omental fat and 461±341g KKCF.

4.2.1.2 Effect of age on live animal and carcass characteristics

All weight and linear measurements increased significantly (P<0.01) with animal age as was expected (Table 4.2). The overall increases in live weight and carcass weights were 53% and 43%, respectively between the milk- and 8-teeth groups. Corresponding increases in chest girth, chest depth, carcass length, side length and buttock circumference were 18%, 13%, 13%, 15% and 15%, respectively. Dressing out percentages were not significantly affected by the age of the goats, though there was a tendency for the values to decrease with age (P=0.087). Chilling losses were highest for the 2-teeth group (P<0.05) but similar across all other age groups (P>0.05). Internal fat content increased significantly with the age of the goats (P<0.0001) such that the 8-teeth group had about twice as much omental and KKCF as the amounts occurring in the goats with up to two permanent incisors.

4.2.1.3 Effect of pre-slaughter conditioning on live animal and carcass characteristics

The goats that were conditioned prior to slaughter were bigger than the non-conditioned group (Table 4.3). The mean live weight of the former group was 4kg heavier (P=0.0004) and their carcasses were 3.6kg heavier (P=0.0001) than those of the non-conditioned goats. The carcasses of the pre-slaughter conditioned goats lost less weight during dressing (5.85% units) and chilling (0.93% units) compared to those of the non-conditioned group (P<0.0001).

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Table 4.1 Effect of sex on live animal and carcass characteristics of South African indigenous goats (means ± S.D.)

	Sex			*P*- value
	Castrates	Females	Intact males	
N	29	44	15	
Slaughter weight (kg)	36.03 ± 6.47[b]	31.41 ± 5.87[a]	37.66 ± 7.17[b]	<0.0001
Hot carcass weight (kg)	15.19 ± 3.62[b]	13.20 ± 2.84[a]	15.89 ± 3.90[b]	0.0023
Cold carcass weight (kg)	14.86 ± 3.55[b]	12.86 ± 2.84[a]	15.49 ± 3.88[b]	0.0021
Dressing out percentage	40.79 ± 3.66	40.99 ± 4.46	40.88 ± 5.50	0.9772
Chilling out percentage	2.15 ± 0.89	2.69 ± 1.06	2.62 ± 1.26	0.0979
Chest girth (cm)	78.20 ± 5.99[b]	74.75 ± 5.21[a]	79.52 ± 6.82[b]	0.0032
Chest depth (cm)	28.52 ± 1.94[a]	28.15 ± 1.67[a]	29.81 ± 1.58[b]	0.0035
Carcass length (cm)	69.80 ± 3.77[a]	67.48 ± 4.11[a]	72.66 ± 4.51[b]	<0.0001
Side length (cm)	63.69 ± 4.31	62.54 ± 4.10	64.29 ± 2.30	0.1956
Buttock circumference (cm)	52.83 ± 4.51	51.59 ± 4.32	53.00 ± 4.58	0.4793
M. longissimus thoracis area (cm^2)	12.24 ± 3.05	11.07 ± 3.19	12.39 ± 4.57	0.2118
Omental fat (g)	845 ± 376	739 ± 619	678 ± 438	0.2859
Kidney knob and channel fat (g)	547 ± 249	493 ± 368	455 ± 298	0.3458

[a, b] Means within a row with different superscripts differ significantly ($P < 0.05$)

Table 4.2 Effect of age on live animal and carcass characteristics of South African indigenous goats (means ± S.D.)

	Age class				*P*-value
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
N	16	32	20	20	
Slaughter weight (kg)	27.83 ± 3.81[a]	33.07 ± 5.66[b]	36.59 ± 6.39[c]	42.65 ± 3.92[d]	<0.0001
Hot carcass weight (kg)	12.06 ± 2.58[a]	14.11 ± 3.23[b]	15.58 ± 3.15[bc]	17.29 ± 2.84[c]	<0.0001
Cold carcass weight (kg)	11.81 ± 11.43[a]	13.69 ± 3.18[b]	15.22 ± 3.10[bc]	16.91 ± 2.88[c]	<0.0001
Dressing out percentage	42.15 ± 5.99	41.02 ± 3.36	41.37 ± 2.90	39.02 ± 4.34	0.0868
Chilling out percentage	2.24 ± 1.38[a]	3.04 ± 0.56[b]	2.40 ± 1.06[a]	2.28 ± 1.23[a]	0.0250
Chest girth (cm)	71.05 ± 3.44[a]	75.49 ± 4.74[b]	79.33 ± 6.89[c]	84.09 ± 2.39[d]	<0.0001
Chest depth (cm)	27.18 ± 1.68[a]	28.16 ± 1.70[b]	29.28 ± 1.53[c]	30.68 ± 0.99[d]	<0.0001
Carcass length (cm)	66.26 ± 3.73[a]	68.60 ± 4.22[b]	70.11 ± 3.07[b]	74.96 ± 3.22[c]	<0.0001
Side length (cm)	59.72 ± 2.48[a]	62.03 ± 3.31[b]	63.59 ± 3.72[b]	68.68 ± 2.43[c]	<0.0001
Buttock circumference (cm)	48.56 ± 3.36[a]	51.19 ± 3.76[b]	54.16 ± 5.36[c]	55.99 ± 3.10[c]	0.0001
M. longissimus thoracis area (cm^2)	11.10 ± 3.94	11.05 ± 3.35	12.50 ± 2.30	12.94 ± 3.07	0.3345
Omental fat (g)	553 ± 382[a]	554 ± 423[a]	711 ± 229[a]	1 197 ± 716[b]	<0.0001
Kidney knob and channel fat (g)	402 ± 302[ab]	357 ± 275[a]	533 ± 161[b]	700 ± 445[c]	<0.0001

[a, b, c] Means within a row with different superscripts differ significantly ($P < 0.05$)

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Table 4.3 Effect of pre-slaughter conditioning on live animal and carcass characteristics of South African indigenous goats (means ± S.D.)

	Pre-slaughter conditioning		
	Non-conditioned	Conditioned	*P*- value
N	49	39	
Slaughter weight (kg)	31.85 ± 6.08	35.88 ± 5.86	0.0004
Hot carcass weight (kg)	12.49 ± 2.86	16.06 ± 2.70	<0.0001
Cold carcass weight (kg)	12.11 ± 2.81	15.72 ± 2.66	<0.0001
Dressing out percentage	37.91 ± 3.61	43.86 ± 2.78	<0.0001
Chilling out percentage	3.08 ± 1.05	2.15 ± 0.73	<0.0001
Chest girth (cm)	75.52 ± 6.08	77.58 ± 5.13	0.0088
Chest depth (cm)	28.52 ± 1.93	28.47 ± 1.61	0.2305
Carcass length (cm)	68.43 ± 3.65	69.58 ± 4.64	0.0624
Side length (cm)	62.33 ± 4.44	63.86 ± 3.40	0.0280
Buttock circumference (cm)	51.47 ± 4.97	52.68 ± 3.70	0.0065
M. longissimus thoracis area (cm^2)	8.99 ± 2.32	13.82 ± 2.83	<0.0001
Omental fat (g)	314 ± 245	1 238 ± 716	<0.0001
Kidney knob and channel fat (g)	228 ± 162	741 ± 286	<0.001

Chest girth, side length and buttock circumference of the carcasses of the pre-slaughter conditioned goats were all significantly greater than those of the non-conditioned goats ($P<0.05$) by about 2.5% each. Other measurements; carcass length and chest depth, were not affected by pre-slaughter conditioning ($P>0.05$). Notable differences between the two conditioning groups were the LT area and fat content ($P<0.0001$). The LT area, omental fat and KKCF values for the pre-slaughter conditioned group were, respectively, 54%, 294% and 225% greater than the values of the non-conditioned group. Thus, the effect of pre-slaughter conditioning was to increase the overall size of the goats and the fat content, and to reduce the losses during dressing and chilling.

4.2.1.4 Interaction effects of sex, age and pre-slaughter conditioning on live animal and carcass characteristics

Table 4.4 summarises the first order interaction effects of sex, age and pre-slaughter conditioning on live animal and carcass characteristics with significant effects ($P<0.05$) highlighted. Significant interaction effects of pre-slaughter conditioning and sex are illustrated in Figure 4.1. Dressing out percentages of the pre-slaughter conditioned goats were higher than for the non-conditioned goats ($P<0.05$), more so for the intact males than the castrates and females (Figure 4.1i). However, the values within each conditioning group did not differ significantly ($P>0.05$). Conversely, chilling losses from the carcasses of the conditioned females and intact males were significantly lower ($P<0.05$) than those of the non-conditioned ones (Figure 4.1ii). Chilling losses from the carcasses of the castrates were not significantly affected by pre-slaughter conditioning ($P>0.05$). Non-conditioned females and pre-slaughter conditioned intact males had the broadest chests ($P<0.05$), which were significantly broader than those of the non-conditioned castrates (Figure 4.1iii).

The interaction effects of age and sex on DO% and chest depth are illustrated in Figure 4.2. Whereas the DO% of the females and intact males declined significantly with the age of the goats ($P<0.05$), that of the castrates was not significantly affected by age ($P>0.05$). Chest depth measurements for all three sexes increased with the age of the goats (Figure 4.2ii). The increases were significant for the castrates and females ($P<0.05$) but not the intact males ($P>0.05$).

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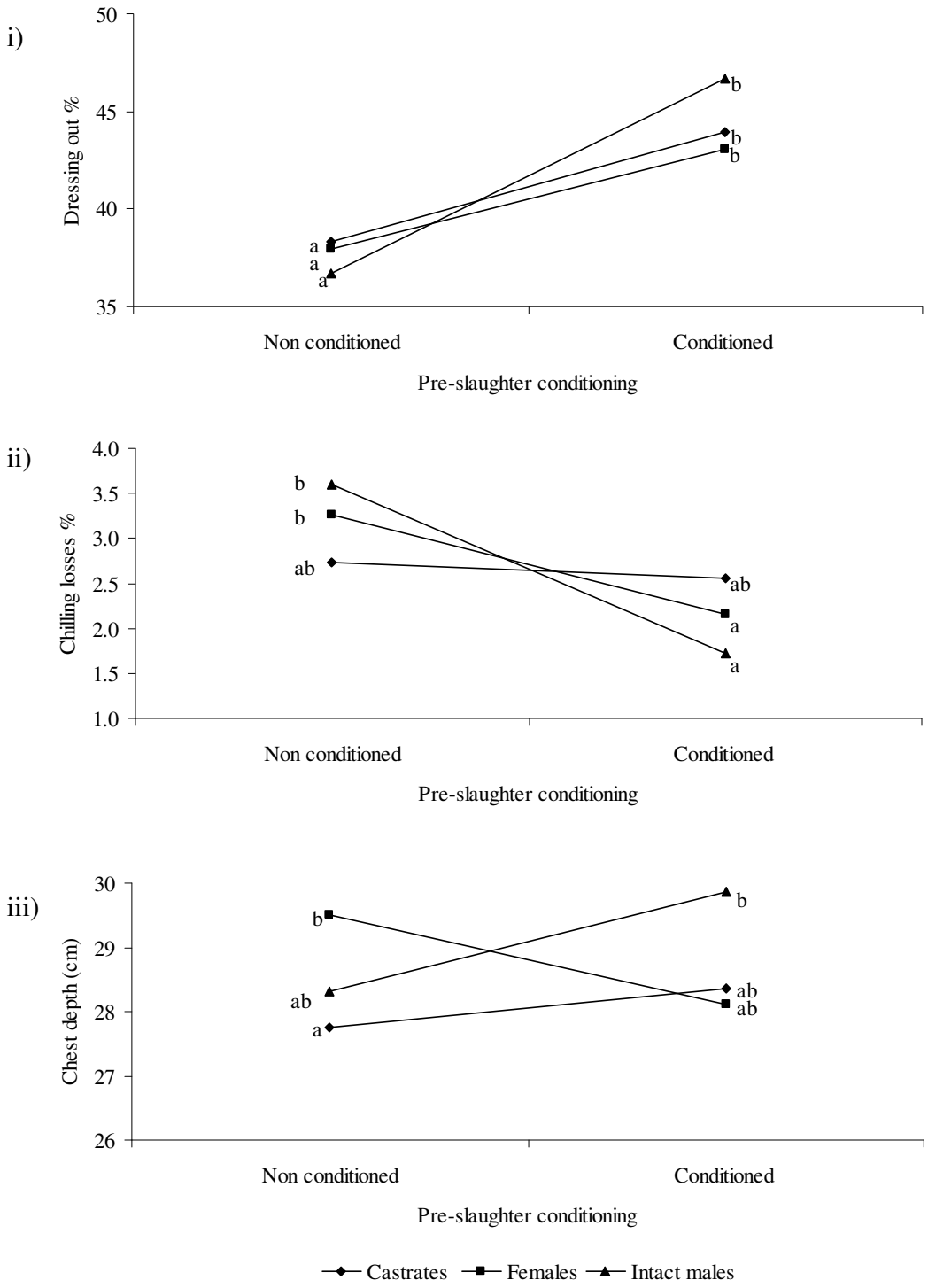
Table 4.4 *P*-values of the first order interaction effects of sex, age and pre-slaughter conditioning on live animal and carcass characteristic of South African indigenous goats

	Interaction effect		
	Age(sex)[1]	Sex*pre-slaughter conditioning	Pre-slaughter conditioning(age)[2]
Slaughter weight (kg)	0.6376	0.7093	0.2805
Hot carcass weight (kg)	0.5354	0.3667	0.3557
Cold carcass weight (kg)	0.5308	0.3178	0.37498
Dressing out percentage	**0.0015**	**0.0023**	0.0588
Chilling out percentage	0.3893	**0.0134**	0.1522
Chest girth (cm)	0.1329	0.4396	0.2011
Chest depth (cm)	**0.0267**	**0.0276**	0.3790
Carcass length (cm)	0.3474	0.0597	0.3754
Side length (cm)	0.4995	0.5700	0.4099
Buttock circumference (cm)	0.6811	0.1703	0.5716
M. longissimus thoracis area (cm^2)	0.2156	0.3121	0.5227
Omental fat (g)	0.5786	0.5630	0.3071
Kidney knob and channel fat (g)	0.1048	0.4429	0.4007

NB: 1- sex effects were nested in age effects (§ 3.8.1 refers)

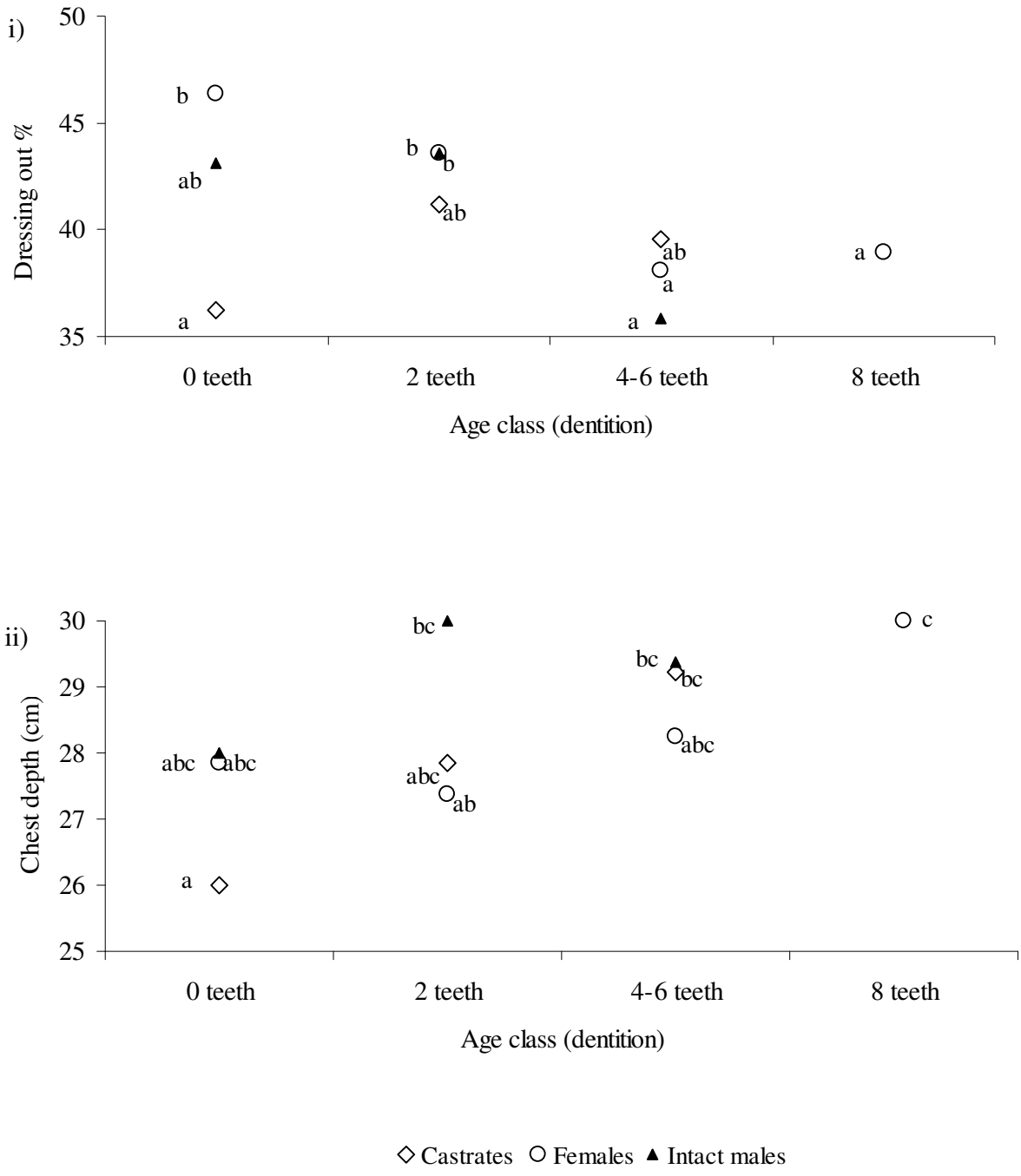
2- Age effects were nested in conditioning effects (§ 3.8.1 refers)

Significant interaction effects ($P<0.05$) are in bold face



NB Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$)

Figure 4.1 The effects of the interaction between pre-slaughter conditioning and sex on i) dressing out percentage, ii) chilling losses percentage, and iii) chest depth (cm)



NB Points within a graph with different letters 'a' or 'b' or 'c' differ significantly ($P<0.05$)

Figure 4.2 The effects of the interaction between age and sex on i) dressing out percentage and ii) chest depth (cm)

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4.2.2 Carcass Composition

Means and standard deviations of the weights and proportions of each joint and weights and proportions of dissectible tissues in the right half of each carcass are presented for each sex (Tables 4.5–4.8), age (Tables 4.10–4.13) and pre-slaughter conditioning group (415–4.18) In addition the proportions of each dissectible tissue in the joints are presented (Tables 4.9, 4.14 and 4.19). Significant first order interaction effects are evaluated (Figures 4.3 and 4.4).

4.2.2.1 Effect of sex on carcass composition

The weights of all the joints were significantly affected ($P<0.01$) by the sex of the goats (Table 4.5). Intact males typically had the heaviest necks, which were 1.3 times and 1.5 times the weights of those of the castrates and females, respectively. The variation of the weights of the rest of the joints followed a similar trend compared to the variation in the weights of entire carcasses with sex. That is, the weights of the joints from the intact and castrated males were similar but those from the female carcasses were lighter ($P<0.05$).

On average the intact males had a significant 2.4% units more weight in the neck and about 1.5% units less weight in the hind limb compared to the females and castrates *(*$P<0.01$, Table 4.6). Fore limb, dorsal trunk and ventral trunk percentages did not differ significantly amongst the sexes ($P>0.05$). Overall mean proportions of the joints were 19.08±1.39%, 20.74±1.58% and 18.31±2.42%, respectively.

Female goats had the least lean content ($P<0.001$) amongst the three sexes (Table 4.7) while the intact and castrated males had similar quantities ($P>0.05$). The bone weights of the three sexes differed significantly ($P<0.0001$). Intact males had the heaviest bones which were, respectively 1.1 and 1.3 times heavier than the bones of the castrates and females.

The amount of intermuscular fat in the carcass was not significantly affected by the sex of the goats ($P>0.05$). However, the females and castrates yielded about 1.5 times as much subcutaneous fat as the intact males ($P=0.003$). Total fat yield from castrated males was greatest and that from intact males the least ($P=0.032$). Meat yield did not differ significantly with the sex of the goats ($P>0.05$). Means for the indices were 2.95±0.38 lean/bone and 3.67±0.68 lean-and-fat/bone ratios.

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Table 4.5 Effect of sex on joint weights (kg) of the right carcass halves of South African indigenous goats (means ± S.D.)

	Sex			*P*-value
	Castrates	Females	Males	
N	29	44	15	
Neck	812 ± 207[b]	684 ± 164[a]	1 037 ± 386[c]	<0.0001
Fore limb	1 311 ± 305[b]	1 109 ± 214[a]	1 337 ± 263[b]	0.0007
Dorsal trunk	1 418 ± 354[b]	1 246 ± 334[a]	1 518 ± 418[b]	0.0061
Ventral trunk	1 335 ± 364[b]	1 113 ± 370[a]	1 365 ± 484[b]	0.0166
Hind limb	2 052 ± 480[b]	1 747 ± 329[a]	2 034 ± 417[b]	0.0030

[a, b] Means within the same row with different superscripts differ significantly ($P<0.05$)

Table 4.6 Effect of sex on joint proportions (%) in the right carcass halves of South African indigenous goats (means ± S.D.)

Characteristic	Sex			*P*-value
	Castrates	Females	Males	
N	29	44	15	
Neck	11.69 ± 1.33[a]	11.66 ± 1.24[a]	14.04 ± 1.79[b]	0.0001
Fore limb	19.08 ± 1.03	18.93 ± 1.39	18.71 ± 1.69	0.6438
Dorsal trunk	20.33 ± 1.56	20.98 ± 1.59	20.79 ± 1.06	0.2809
Ventral trunk	19.04 ± 2.02	18.65 ± 2.49	18.15 ± 2.66	0.4408
Hind limb	29.85 ± 1.46[b]	29.77 ± 1.87[b]	28.31 ± 2.14[a]	0.0048

[a, b] Means within the same row with different superscripts differ significantly ($P<0.05$)

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Table 4.7 Effect of sex on tissue content (g) and meat yield indices of the right carcass halves of South African indigenous goats (means ± S.D.)

Characteristic	Sex			*P*-value
	Castrates	Females	Intact males	
N	29	44	15	
Lean	4 273 ± 1 018[b]	3 600 ± 766[a]	4 772 ± 1 259[b]	0.0001
Bone	1 405 ± 246[b]	1 239 ± 168[a]	1 556 ± 255[c]	<0.0001
Intermuscular fat	808 ± 284	696 ± 461	666 ± 398	0.1661
Subcutaneous fat	380 ± 208[b]	315 ± 173[b]	224 ± 129[a]	0.0033
Total carcass fat	1 188 ± 469[b]	1 011 ± 613[ab]	890 ± 494[a]	0.0321
Lean/bone	3.04 ± 0.31	2.90 ± 0.41	3.07 ± 0.44	0.4767
Lean-and-fat/bone	3.89 ± 0.52	3.72 ± 0.73	3.64 ± 0.70	0.7209

[a, b] Means within the same row with different superscripts differ significantly ($P<0.05$)

Table 4.8 Effect of sex on proportions of the dissectible tissues (%) in the right carcass halves of South African indigenous goats (means ± S.D.)

Characteristic	Sex			*P*-value
	Castrates	Females	Intact males	
N	29	44	15	
Lean	62.11 ± 2.96[a]	61.37 ± 4.92[a]	65.95 ± 2.66[b]	<0.0001
Bone	20.89 ± 2.60	21.45 ± 3.36	22.25 ± 3.79	0.2837
Intermuscular fat	10.99 ± 2.85[b]	11.22 ± 5.23[b]	8.11 ± 4.46[a]	0.0037
Subcutaneous fat	5.13 ± 2.25[b]	5.14 ± 2.07[b]	2.69 ± 1.53[a]	<0.0001
Total carcass fat	16.12 ± 4.63[b]	16.36 ± 6.85[b]	10.81 ± 5.20[a]	<0.0001

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

The percentages of lean, intermuscular fat and subcutaneous fat in the right carcass half were significantly affected ($P<0.01$) by the sex of the goats (Table 4.8) but bone percentages were not ($P>0.05$). Lean percentage was highest in the intact males whose mean was on average 4.21% units greater than the means of the females and castrates. Both the intermuscular and subcutaneous fat percentages were highest in the female and least in the intact male carcasses ($P<0.01$). Intact males had about 1.4 times less intermuscular fat and nearly two times less subcutaneous fat that the castrates and females. Consequently intact males' total carcass fat percentage was 6.2% units lower than the values for the castrates and females.

Within each joint (Table 4.9), the proportion of lean was generally highest in the intact males ($P<0.01$) but castrates and female goats had similar proportions. The proportion of bone in each joint (except the hind limb) was similar amongst the three sex groups ($P>0.05$). The hind limb bone percentage of intact males was a significant 2.03% units greater than that of the females ($P<0.05$) while that of the castrates did not differ from either the intact males or the females ($P>0.05$).

Intermuscular fat proportions in the fore limb, dorsal trunk and hind limb all differed significantly with the sex of the goats ($P<0.05$). The highest percentages were in the joints of the female and castrated goats. Ventral trunk intermuscular fat percentage was not affected by the sex of the goats ($P>0.05$).

Subcutaneous fat percentage in all the joints was significantly affected by the sex of the goats ($P<0.05$). Within each of the joints, the females and castrates had similar proportions of subcutaneous fat, which were about twice as much as that in the same depots of the intact males. The three sex groups all significantly differed in hind limb subcutaneous fat percentage ($P<0.0001$). Castrates had the highest proportion of 4.68% and intact males the least by a factor of 2.2.

Table 4.9 Effect of sex on proportions of the dissectible tissues (%) within joints of the right carcass halves of South African indigenous goats (means ± S.D.)

	Sex			
	Castrates	Females	Intact males	*P*-value
N	29	44	15	
Lean: Neck	60.84 ± 5.13[a]	56.10 ± 6.74[a]	67.13 ± 4.04[b]	<0.0001
Fore limb	64.17 ± 1.94[a]	64.63 ± 4.29[a]	68.43 ± 3.86[b]	0.0002
Dorsal trunk	57.17 ± 3.62[a]	56.19 ± 6.47[a]	60.84 ± 4.22[b]	0.0075
Ventral trunk	57.19 ± 8.21[a]	55.54 ± 7.55[a]	61.62 ± 5.64[b]	0.0038
Hind limb	68.25 ± 2.26[a]	69.02 ± 3.77[ab]	70.77 ± 2.80[b]	0.0373
Bone: Neck	20.51 ± 4.36	23.01 ± 4.96	20.52 ± 4.87	0.0800
Fore limb	22.14 ± 3.10	21.75 ± 3.23	23.27 ± 3.24	0.2442
Dorsal trunk	26.42 ± 5.23	26.78 ± 5.00	27.60 ± 5.32	0.6973
Ventral trunk	15.69 ± 2.96	15.84 ± 4.92	17. 43 ± 6.00	0.4227
Hind limb	19.90 ± 2.34[a]	20.61 ± 2.46[ab]	21.93 ± 2.63[b]	0.0172
Intermuscular fat: Neck	14.27 ± 4.41[b]	14.65 ± 7.93[b]	10.70 ± 6.04[a]	0.0174
Fore limb	8.91 ± 3.25[b]	9.28 ± 5.85[b]	4.96 ± 3.59[a]	0.0049
Dorsal trunk	10.26 ± 3.71[b]	10.45 ± 6.29[b]	6.86 ± 4.41[a]	0.0106
Ventral trunk	17.90 ± 6.01	19.20 ± 9.35	15.38 ± 9.19	0.1567
Hind limb	6.60 ± 2.06[b]	6.19 ± 2.19[b]	4.39 ± 2.10[a]	0.0021
Subcutaneous fat: Neck	3.36 ± 3.14[b]	4.68 ± 3.60[b]	1.26 ± 1.39[a]	0.0061
Fore limb	4.04 ± 1.91[b]	3.72 ± 1.86[b]	2.47 ± 1.80[a]	0.0272
Dorsal trunk	5.04 ± 2.83[b]	5.79 ± 4.00[b]	3.15 ± 1.80[a]	0.0163
Ventral trunk	8.04 ± 5.62[b]	8.49 ± 5.22[b]	4.28 ± 4.24[a]	0.0297
Hind limb	4.68 ± 1.86[c]	3.57 ± 2.38[b]	2.17 ± 1.13[a]	<0.0001

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

4.2.2.2 Effect of age on carcass composition

The weights of all the joints increased significantly ($P<0.01$) with age of the goats (Table 4.10). The 2- and 4-to-6 teeth groups tended to have joints of similar weights ($P<0.05$). Percentages of the neck, fore limb and dorsal trunk were similar amongst ($P>0.05$) the goats in the different age classes (Table 4.11). Percentage of the ventral trunk was lowest in the 2-teeth group and conversely that of the hind limb was highest in the same group ($P<0.01$). The rest of the age classes had similar proportions of the two joints.

Except for subcutaneous fat, all tissue weights significantly increased ($P<0.001$) with the age of the goats (Table 4.12). However, the yield indices, lean/bone and lean-and-fat/bone, were not affected by the age of the goats.

The highest proportions of lean were in the 2-teeth and the 4-to-6 teeth groups ($P=0.008$), which had about 64% lean (Table 4.13). The milk-teeth kids had the lowest proportion of about 62%. The proportions of bone and subcutaneous fat were not significantly affected by the age of the goats ($P>0.05$). However, intermuscular and total carcass fat percentages tended to be lowest in the 2-to-6 teeth groups and highest in the full mouth group ($P<0.05$).

Within the fore limb, dorsal trunk, and hind limb, the percentage of lean varied significantly ($P<0.01$) with the age of the goats (Table 4.14). As was the case within the entire right half carcasses, the percentages tended to be higher for the 2-to-6 teeth groups and lower for the milk-teeth and full mouth groups. Intermuscular fat percentages of the neck and fore limb were not significantly affected by age ($P>0.05$). However, the dorsal trunks of the 8-teeth group had significantly the highest percentage intermuscular fat ($P=0.006$). The mean intermuscular fat percentage in the 8-teeth group averaged 3.98% units more than the younger goats. In the ventral trunk and hind limb, the 2-to-6 teeth groups generally had lower intermuscular fat percentages than the milk- and 8-teeth groups ($P<0.05$).

Only the subcutaneous fat percentage of the hind limb was significantly affected by the age of the goats ($P=0.002$). The proportion was lowest in the younger goats with up to 2-teeth (average of 2.75%) and increased to 4.74% in the 8-teeth group.

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Table 4.10 Effect of age on joint weights (kg) of the right carcass halves of South African indigenous goats (means ± S.D.)

	Age class				*P*-value
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
N					
Neck	712 ± 239[a]	817 ± 298[ab]	865 ± 188[bc]	982 ± 160[c]	0.0043
Fore limb	1 037 ± 180[a]	1 219 ± 245[b]	1 324 ± 260[bc]	1 430 ± 239[c]	<0.0001
Dorsal trunk	1 135 ± 230[a]	1 349 ± 350[b]	1 418 ± 306[b]	1 675 ± 348[c]	<0.0001
Ventral trunk	1 056 ± 334[a]	1 112 ± 358[a]	1 343 ± 332[b]	1 571 ± 445[c]	<0.0001
Hind limb	1 627 ± 295[a]	1 908 ± 374[b]	2 035 ± 413[bc]	2 208 ± 355[c]	0.0001

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

Table 4.11 Effect of age on the joint proportions (%) in the right carcass halves of South African indigenous goats (means ± S.D.)

	Age class				*P*-value
Characteristic	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
N					
Neck	12.63 ± 1.60	12.47 ± 1.87	12.23 ± 1.56	12.52 ± 1.20	0.8691
Fore limb	18.81 ± 1.35	19.26 ± 1.26	19.21 ± 1.12	18.34 ± 1.51	0.0918
Dorsal trunk	20.41 ± 1.09	21.01 ± 1.27	20.06 ± 1.73	21.31 ± 1.61	0.0771
Ventral trunk	18.70 ± 2.69[b]	17.06 ± 1.71[a]	19.16 ± 2.42[b]	19.55 ± 2.94[b]	0.0047
Hind limb	29.45 ± 1.63[ab]	30.20 ± 2.20[b]	29.33 ± 1.10[ab]	28.27 ± 2.14[a]	0.0055

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

Table 4.12 Effect of age on dissectible tissue content (g) and meat yield indices of the right carcass halves of South African indigenous goats (means ± S.D.)

	Age class				*P*-value
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
N	16	32	21	19	
Lean	3 428 ± 770[a]	4 141 ± 1 008[b]	4 451 ± 992[bc]	4 841 ± 807[c]	0.0002
Bone	1 210 ± 200[a]	1 374 ± 242[b]	1 440 ± 229[b]	1 575 ± 124[c]	<0.0001
Intermuscular fat	632 ± 328[a]	542 ± 299[a]	707 ± 251[a]	1 013 ± 567[b]	<0.0001
Subcutaneous fat	252 ± 158	283 ± 179	327 ± 142	364 ± 201	0.1630
Total carcass fat	884 ±475[a]	825 ± 436[a]	1 034 ± 353[a]	1 377 ± 752[b]	0.0002
Lean/bone	2.83 ± 0.38	3.01 ± 0.26	3.09 ± 0.36	3.07 ± 0.54	0.2745
Lean-and-fat/bone	3.56 ± 0.70	3.61 ± 0.43	3.81 ± 0.53	3.95 ± 0.94	0.5332

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

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Table 4.13 Effect of age on the proportions of dissectible tissues (%) in the right carcass halves of South African indigenous goats (means ± S.D.)

	Age class				*P*-value
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
N	16	32	21	19	
Lean	61.82 ± 4.21[a]	64.68 ± 3.46[c]	63.94 ± 2.97[bc]	62.13 ± 5.81[ab]	0.0077
Bone	22.23 ± 3.38	21.91 ± 1.91	21.13 ± 3.02	20.86 ± 4.32	0.4740
Intermuscular fat	10.83 ± 4.45[bc]	8.09 ± 3.27[a]	9.56 ± 3.27[ab]	11.94 ± 6.43[c]	0.0009
Subcutaneous fat	4.32 ± 2.32	4.29 ± 2.15	4.54 ± 1.96	4.14 ± 2.12	0.9293
Total carcass fat	15.15 ± 6.54[b]	12.38 ± 4.74[a]	14.10 ± 4.51[ab]	16.08 ± 8.25[b]	0.0266

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

Table 4.14 Effect of age on the proportions of the dissectible tissues (%) within joints of the right carcass halves of South African indigenous goats (means ± S.D.)

	Age class				
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	*P*-value
N					
Lean: Neck	58.65 ± 5.57	60.87 ± 6.64	62.67 ± 6.10	63.23 ± 7.66	0.0667
Fore limb	63.17 ± 3.68^{a}	67.07 ± 3.14^{b}	66.47 ± 3.32^{b}	66.26 ± 4.42^{b}	0.0016
Dorsal trunk	56.83 ± 5.71^{ab}	60.54 ± 4.19^{c}	59.06 ± 4.06^{bc}	55.82 ± 7.67^{a}	0.0064
Ventral trunk	58.25 ± 7.94	58.35 ± 7.08	59.37 ± 6.47	56.50 ± 7.63	0.5126
Hind limb	68.39 ± 2.60^{a}	71.39 ± 2.77^{b}	69.48 ± 2.74^{ab}	68.13 ± 4.34^{a}	0.0033
Bone: Neck	22.60 ± 5.54	22.00 ± 4.01	20.59 ± 4.70	20.20 ± 4.80	0.3801
Fore limb	23.73 ± 3.37^{b}	23.08 ± 2.59^{b}	21.04 ± 3.19^{a}	21.70 ± 4.06^{ab}	0.0366
Dorsal trunk	27.71 ± 5.38	26.48 ± 3.50	27.18 ± 4.69	26.35 ± 6.11	0.7956
Ventral trunk	15.51 ± 3.78	17.10 ± 2.49	16.40 ± 5.23	16.27 ± 6.61	0.7204
Hind limb	21.69 ± 2.25	20.70 ± 1.87	20.74 ± 2.49	20.11 ± 2.98	0.2773
Intermuscular fat: Neck	13.76 ± 5.40	12.04 ± 5.16	12.36 ± 4.52	14.67 ± 9.64	0.2269
Fore limb	8.61 ± 4.77	5.69 ± 4.76	7.82 ± 4.12	8.75 ± 6.20	0.0887
Dorsal trunk	9.03 ± 3.74^{a}	7.56 ± 5.16^{a}	8.14 ±3.04^{a}	12.03 ± 7.16^{b}	0.0059
Ventral trunk	19.46 ± 8.65^{b}	14.55 ± 7.00^{a}	16.40 ± 5.98^{ab}	19.56 ± 11.11^{b}	0.0213
Hind limb	6.33 ± 2.28^{b}	4.52 ± 1.79^{a}	5.52 ± 2.34^{ab}	6.53 ± 2.43^{b}	0.0055
Subcutaneous fat: Neck	3.70 ± 3.09	4.21 ± 3.91	3.15 ± 2.80	1.33 ± 2.40	0.0723
Fore limb	3.81 ± 1.94	3.35 ± 1.80	3.92 ± 2.17	2.56 ± 1.54	0.1695
Dorsal trunk	5.34 ± 4.39	3.97 ± 3.50	5.09 ± 1.78	4.25 ± 3.82	0.4170
Ventral trunk	6.13 ± 3.56	8.87 ± 5.48	6.44 ± 5.87	6.30 ± 4.71	0.2826
Hind limb	3.01 ± 1.53^{ab}	2.50 ± 2.10^{a}	3.63 ± 1.39^{bc}	4.74 ± 2.84^{c}	0.0015

$^{a, b, c}$ Means within the same row with different superscripts differ significantly (P<0.05)

4.2.2.3 Effect of pre-slaughter conditioning on carcass composition

All the carcass joints of the pre-slaughter conditioned goats were significantly bigger (P<0.0001) than those of the non-conditioned ones (Table 4.15). The ratios of the conditioned to the non-conditioned goat joints were 1.35, 1.20, 1.37, 1.41 and 1.20 for the neck, fore limb, dorsal trunk, ventral trunk and hind limb, respectively. The percentages of the neck and dorsal trunk were similar (P>0.05) between the two conditioning groups (Table 4.16). However, the fore and hind limb proportions were greater in the carcasses of the non-conditioned goats (P<0.001), while the ventral trunk percentage was greater in the carcasses of the pre-slaughter conditioned goats (P<0.0001).

All dissectible tissues of the carcasses of the pre-slaughter conditioned goats were significantly heavier (P<0.05) than those of the non-conditioned ones (Table 4.17). The yield indices were improved by conditioning (P<0.01). The lean/bone was 1.1 times higher and the lean-and-fat/bone ratio 1.25 times higher in the carcasses of the pre-slaughter conditioned compared to those of the non-conditioned goats.

The lean and bone percentages were higher in the carcasses of the non-conditioned goats (P<0.0001) while all carcass fat proportions were higher (P<0.0001) in the carcasses of the goats that were conditioned prior to slaughter (Table 4.18). Within each joint, the lean and bone percentages were consistently higher (P<0.05) in the non-conditioned goats (Table 4.19). Conversely, intermuscular fat percentages were consistently higher (P<0.01) in the joints of the pre-slaughter conditioned goats. Subcutaneous fat percentage was not as variable as the other tissues. Only that of the dorsal trunk and the hind limb was significantly increased by pre-slaughter conditioning (P<0.0001).

4.2.2.4 Interaction effects of sex, age and pre-slaughter conditioning on carcass composition

There were significant interaction effects of age and pre-slaughter conditioning, and sex and pre-slaughter conditioning on some of the carcass composition variables. These are illustrated in Figures 4.3 and 4.4. None of the age by sex effects were significant (P>0.05).

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Table 4.15 Effect of pre-slaughter conditioning on joint weights (kg) of the right carcass halves of South African indigenous goats (means ± S.D.)

	Pre-slaughter conditioning		
	Non-conditioned	Pre-slaughter conditioned	*P*-value
N	49	39	
Neck	667 ± 160	903 ± 269	<0.0001
Fore limb	1 104 ± 234	1 324 ± 220	<0.0001
Dorsal trunk	1 139 ± 273	1 559 ± 314	<0.0001
Ventral trunk	1 000 ± 339	1 413 ± 324	<0.0001
Hind limb	1 723 ± 369	2 072 ± 342	0.0001

Table 4.16 Effect of pre-slaughter conditioning on proportions of the joints (%) in the right carcass halves of South African indigenous goats (means ± S.D.)

	Pre-slaughter conditioning		
	Non-conditioned	Pre-slaughter conditioned	*P*-value
N	49	39	
Neck	11.87 ± 1.39	12.27 ± 1.89	0.7698
Fore limb	19.69 ± 1.18	18.31 ± 1.25	0.0008
Dorsal trunk	20.23 ± 1.60	21.39 ± 1.30	0.7081
Ventral trunk	17.48 ± 2.43	19.35 ± 2.00	<0.0001
Hind limb	30.72 ± 1.44	28.66 ± 1.94	0.0004

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Table 4.17 Effect of pre-slaughter conditioning on tissue content (g), and yield indices of the right carcass halves of South African indigenous goats (means ± S.D.)

	Pre-slaughter conditioning		
	Non-conditioned	Pre-slaughter conditioned	*P*-value
N	49	39	
Lean	3 692 ± 874	4 367 ± 945	0.0004
Bone	1 295 ± 204	1 401 ± 224	0.0111
Intermuscular fat	397 ± 254	1 000 ± 337	<0.0001
Subcutaneous fat	202 ± 132	434 ± 162	<0.0001
Total carcass fat	599 ± 363	1 434 ± 439	<0.0001
Lean/bone	2.84 ± 0.39	3.10 ± 0.33	0.0097
Lean-and-fat/bone	3.30 ± 0.58	4.14 ± 0.48	<0.0001

Table 4.18 Effect of pre-slaughter conditioning on proportions of the tissues (%) in joints of the right carcass halves of South African indigenous goats (means ± S.D.)

	Pre-slaughter conditioning		
Characteristic	Non-conditioned	Pre-slaughter conditioned	*P*-value
N	49	39	
Lean	65.52 ± 2.88	59.88 ± 4.26	<0.0001
Bone	23.46 ± 3.08	19.44 ± 1.74	<0.0001
Intermuscular fat	6.76 ± 3.11	13.72 ± 3.77	<0.0001
Subcutaneous fat	3.42 ± 1.74	6.00 ± 1.96	<0.0001
Total carcass fat	10.18 ± 4.33	19.72 ± 4.74	<0.0001

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Table 4.19 Effect of pre-slaughter conditioning on proportions of dissectible tissues in the joints of the right carcass halves of South African indigenous goats (means ± S.D.)

	Pre-slaughter conditioning		
	Non-conditioned	Pre-slaughter conditioned	*P*-value
N	49	39	
Lean: Neck	63.14 ± 5.32	55.85 ± 6.71	0.0091
Fore limb	66.89 ± 3.06	64.03 ± 3.96	0.0018
Dorsal trunk	60.79 ± 4.27	54.73 ± 5.93	0.0014
Ventral trunk	62.96 ± 5.93	51.30 ± 5.59	<0.0001
Hind limb	70.31 ± 2.63	68.62 ± 3.75	0.0227
Bone: Neck	24.17 ± 4.51	19.55 ± 3.62	0.0009
Fore limb	23.91 ± 3.38	20.49 ± 2.19	0.0012
Dorsal trunk	29.83 ± 4.74	23.56 ± 3.19	0.0005
Ventral trunk	18.24 ± 4.91	14.23 ± 2.97	0.0023
Hind limb	21.81 ± 2.52	19.31 ± 1.80	0.0025
Intermuscular fat: Neck	8.26 ± 4.40	19.01 ± 4.87	<0.0001
Fore limb	5.45 ± 3.44	10.62 ± 5.52	0.0005
Dorsal trunk	5.67 ± 3.05	13.34 ± 5.58	<0.0001
Ventral trunk	11.20 ± 6.04	23.19 ± 6.61	<0.0001
Hind limb	4.96 ± 2.22	6.60 ± 1.99	0.0051
Subcutaneous fat: Neck	3.35 ± 3.11	4.34 ± 3.42	0.5472
Fore limb	3.08 ± 1.87	4.08 ± 1.77	0.2226
Dorsal trunk	2.78 ± 1.59	7.14 ± 3.79	<0.0001
Ventral trunk	6.35 ± 5.00	9.64 ± 5.36	0.2202
Hind limb	2.34 ± 1.39	4.72 ± 2.34	<0.0001

Pre-slaughter conditioned intact males and castrates had significantly heavier necks than their non- conditioned counterparts but the females were not affected (P=0.010, Figure 4.3i). The means for the castrates, females and intact males were respectively 635±177, 689±151and 700±130g for the non-conditioned goats and 933±111, 789±162 and 1281±343g for the pre-slaughter conditioned goats. Both fore limb (P=0.035) and dorsal trunk (P=0.0497) lean percentages were lower for the pre-slaughter conditioned compared to the non-conditioned goats (Figure 4.3ii and iii). The difference in the proportion of lean between the conditioning groups was significant for the females (P<0.05) but not the male sexes (P>0.05). The fore limb lean percentages for the castrates, females and intact males were 65.69±2.03, 67.52±3.32 and 68.68±3.77 for the non-conditioned goats and 64.50±1.35, 62.92±3.89 and 67.54±4.17 for the pre-slaughter conditioned goats, respectively. The corresponding dorsal trunk mean lean percentages were, respectively 60.94±3.71, 59.81±4.16, 62.72±5.67, and 57.52±1.66, 52.35±6.09 and 60.45±0.90.

The neck (P=0.030) and dorsal trunk (P=0.046) were heavier in the pre-slaughter conditioned than the non-conditioned goats (Figure 4.4i and ii). Pre-slaughter conditioning led to significantly heavier necks of the 2-teeth group (P<0.05) but not those of the milk, and 8-teeth groups (P>0.05). The neck weight means for the non-conditioned goats were similar (P>0.05) and were 600±90, 621±158, 689±188 and 724±137g for milk-, 2-, 4-to-6 and 8-teeth goats. The means for the conditioned goats were 861±325, 909±301 and 914±123g for the milk-, 2- and 8-teeth goats, respectively.

The dorsal trunks of the pre-slaughter conditioned 8-teeth goats were significantly heavier than those of all the non-conditioned younger goats and of the conditioned milk-teeth goats (P<0.05). The dorsal trunk weight means were 1000±122, 1062±214, 1159±306 and 1297±290g for the milk-, 2-, 4-to-6 and 8-teeth non-conditioned goats and 1253±290, 1561±293 and 1755±234g for the milk-, 2- and 8-teeth conditioned goats, respectively.

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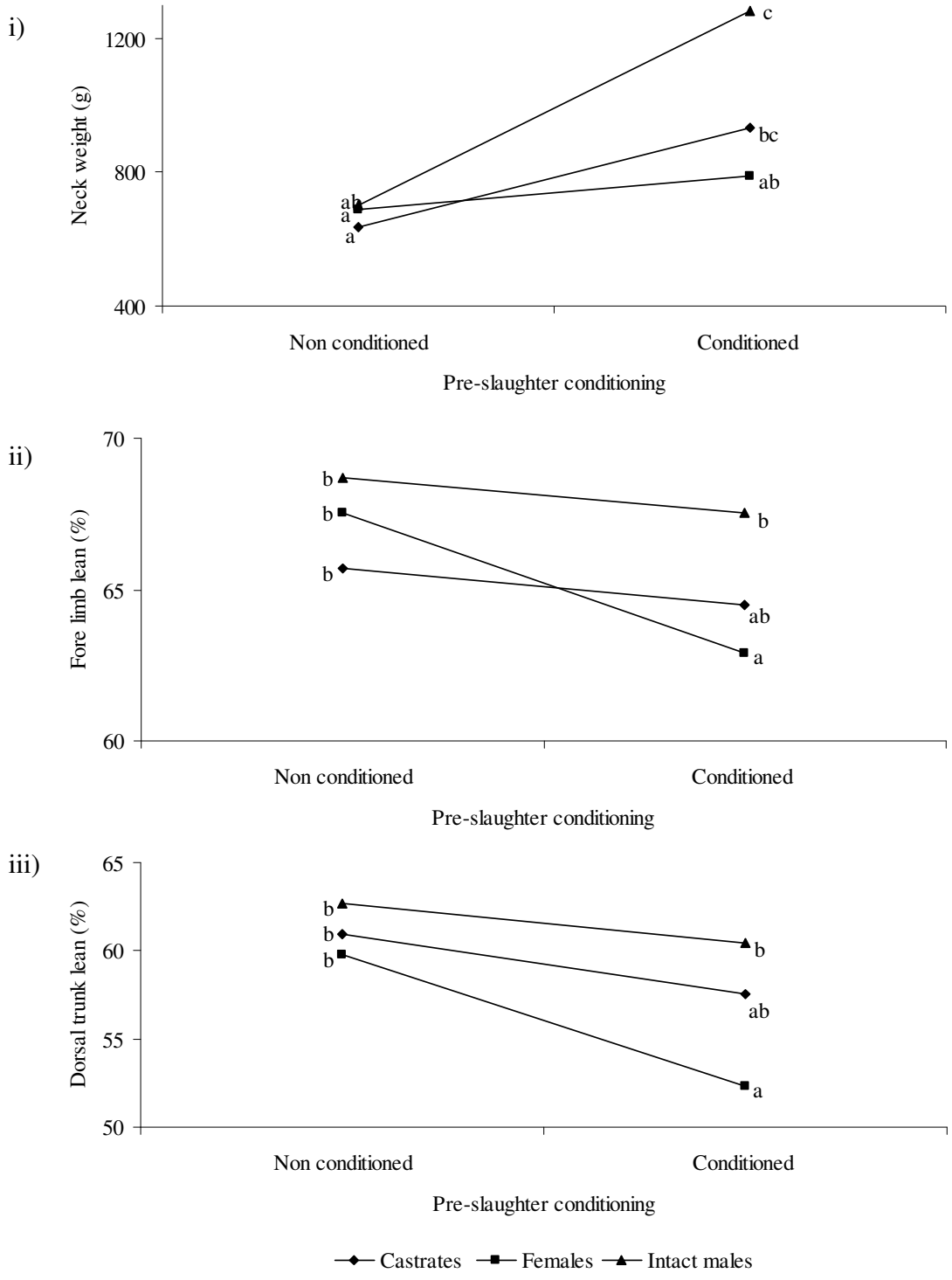
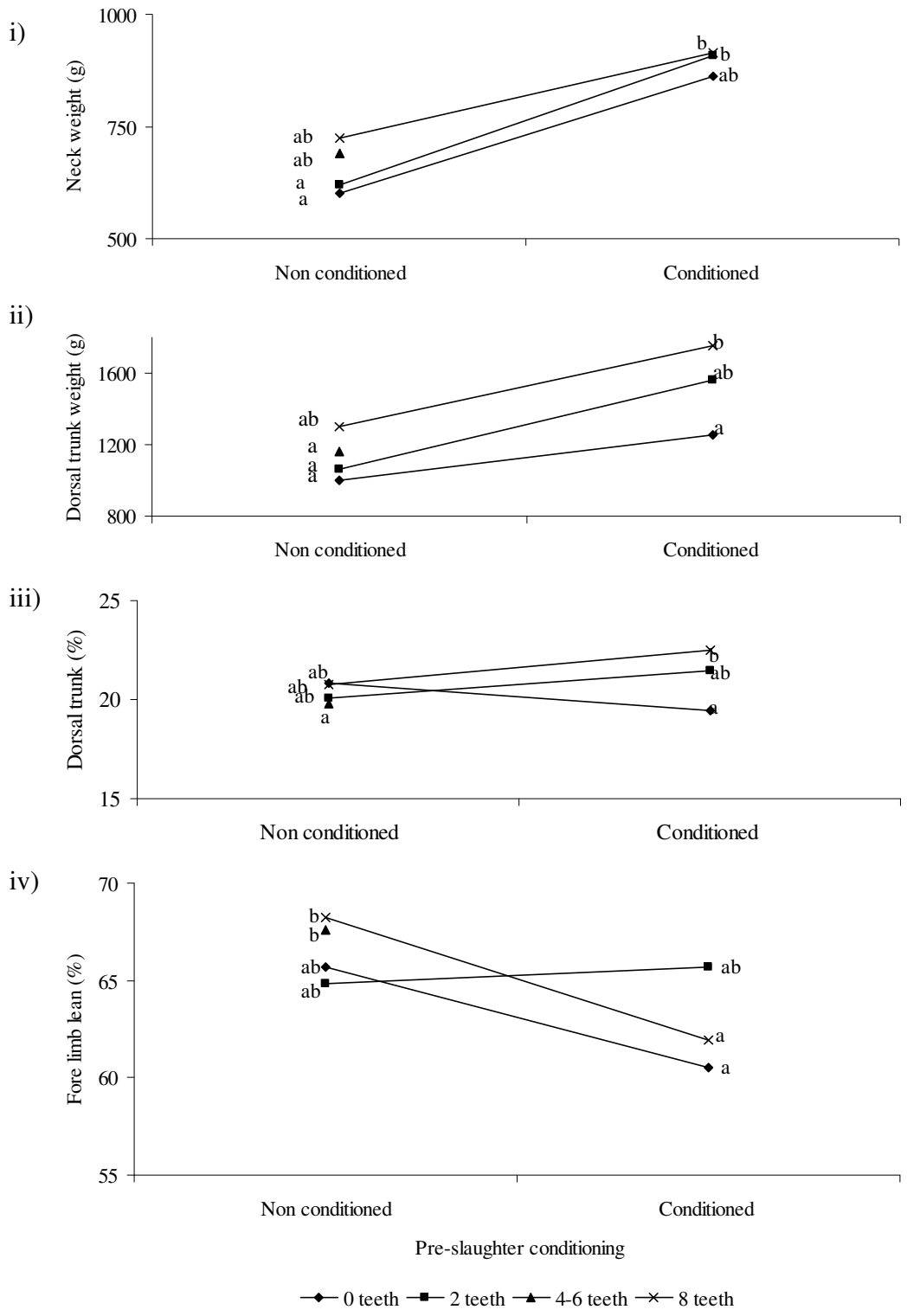


NB Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$)

Figure 4.3 Pre-slaughter conditioning and sex interaction effects on (i) neck weight (g), (ii) fore limb lean %, and (iii) dorsal trunk lean (%)



NB Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$)

Figure 4.4 Pre-slaughter conditioning and age interaction effects on (i) neck weight (g), (ii) dorsal trunk weight (%), (iii) dorsal trunk (%), and (iv) fore limb lean (%)

The proportions of the dorsal trunk were similar (P>0.05) for all the age groups in the non-conditioned group (Figure 4.4iii) and comprised approximately 20.3% of the right half carcass. Amongst the pre-slaughter conditioned goats, the percentage of the dorsal trunk in the milk-teeth kids was significantly smaller than in the 8-teeth group (P=0.033). The mean percentages for pre-slaughter conditioned milk-, 2- and 8-teeth goats were 19.46±0.67, 21.47±1.03 and 22.49±0.72, respectively. Fore limb lean percentages tended to decline (P=0.038) with pre-slaughter conditioning of the milk and 8-teeth goats (Figure 4.3iv). The difference in the proportions of this tissue between the non-conditioned and pre-slaughter conditioned groups was significant for the 8-teeth group only (P<0.05). The mean fore limb lean percentages for the non-conditioned goats were 65.66±1.95, 64.8±1.81 and 67.62±3.32, 68.20±3.26 for the milk, 2, 4-to-6 and 8-teeth goats, respectively. Those for the pre-slaughter conditioned goats were 60.54±3.77, 65.69±3.48 and 61.94±2.96% for the milk, 2 and 8-teeth goats, respectively.

4.3 DISCUSSION

4.3.1 Live Animal and Carcass Characteristics

Live weight and chest girth have been used in several studies to define the size of small ruminants (e.g. Owen, 1975; Mukherjee, Singh and Mishra, 1981, 1986; Simela et al., 2000a; Atta and El Khidir, 2004). The live weight, chest girth and carcass measurements of the goats used in this study compare well to other breeds in the region, namely the Tswana goats of Botswana (Fisher, Frost, Owen and Norman, 1976; Owen and Norman, 1977) and the Matebele goats of Zimbabwe (Simela et al., 2000a). For example, the reported mean chest girth for castrated Matebele goats ranged from 59.8cm to 83.3cm between the milk- and 8-teeth stages (Simela et al., 2000a). The average live weight of these castrates when they are marketed in the commercial sector ranged from a stipulated minimum of 25kg (Hatendi, 1993) to about 41kg at the 6-teeth stage (Simela et al., 2000a). Side length and chest depth measurements of carcasses of mixed sex ranged from 57.0cm and 27.7cm at the milk-teeth stage to 66.2 and 31.4cm at the 6-to-8 teeth stage (Simela, Ndlovu and Sibanda, 1999). The corresponding carcass weights were 12.5kg, 13.3kg, 16.3kg and 19.7kg, respectively for the milk, 2-, 4- and 6-to-8 teeth groups (Simela et al., 1999).

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The side length and chest depth for the Tswana castrated goats ranged from 55.3cm and 25.9cm at the milk-teeth stage to 64.4cm and 31.1cm at the six-teeth stage (Owen and Norman, 1977), respectively. The corresponding range of live weights was 24kg to 41kg and the carcass weights of the milk-, 2-, 4- and 6-teeth castrates were 9.89kg, 11.69kg and 13.87kg and 17.67kg, respectively. Corresponding measurements in this study (Tables 4.1 to 4.3) compare well to these reported values.

In essence the South African indigenous goats are of the same type as the large goats of southern Africa that are described by Mason (1981). Due to their size, many researchers are of the opinion that these large southern African goat breeds have a high potential for commercial chevon production.

The mean dressing out percentages varied between 38% and 44%, which generally agrees with the values reported for various goat breeds worldwide (Devendra and Owen, 1983, Kadim, Mahgoub, Al-Ajmi, Al-Maqbaly, Al-Saqri and Ritchie, 2004) as well as the large southern African goats (Owen and Norman, 1977; Simela, Gumede, Ndlovu and Sibanda, 2000c). For the latter breeds, Owen and Norman (1977) obtained values ranging from 43.1% for milk-teeth kids to 48.3% for full-mouthed castrated Tswana goats. Full mouthed females had a DO% of 39.7%. Simela et al. (2000c) obtained values ranging from 42.3% to 46.8% for Matebele goats weighing from 25kg to over 45kg. One abattoir that slaughtered goats in Zimbabwe used an estimation of about 42% (Hatendi, 1993).Therefore, the DO% values that were observed in the present study are in line with what is observed in commercial slaughter situations.

A large source of the variation in DO% is the gut contents which may account for as much as 26% of the live weight of the animal (Owen et al., 1983). Post-weaning gut contents are particularly affected by the diet of the goats prior to slaughter. Gaili, Ghanem and Mukhtar (1972) noted that after 24 hours off feed but with access to water, unfattened goats averaged 18% gut content whereas those off a fattening diet averaged 8.8%. The goats employed in the current study were weighed prior to feeding, 24 hours after the last feeding session in order to minimise differences in live weight due to gut content.

In addition to heavier carcasses and increased carcass fat, a higher plane of nutrition also typically results in a higher DO% (Devendra and Owen, 1983; Oman, Waldron, Griffin and Savell, 1999) as was observed herein. According to Hogg et al. (1992), fattened goats are expected to dress out 2–3% more than those coming off pastures. Such a difference occurred between the non-conditioned and pre-slaughter conditioned groups of this study. Further to this, the intact males proved more productive in response to pre-slaughter conditioning in that the increase in their dressing out percentage and decrease in the chilling losses were greater than those of the castrates or the females (Figure 4.1).

Chilling losses in this study averaged less than the 3% that is usually estimated for chevon (Government of Zimbabwe, 1995) and beef (Offer et al., 1984) carcasses. In Simela et al. (2000b) such low chilling losses were associated with CCW of 16.9kg and above. In this study the lower values may have been due to that the goats were generally in good condition at slaughter. However when the goats were separated into non-condition and pre-slaughter conditioned groups, the advantages of improved nutrition were evident in the 30% decrease in chilling losses.

4.3.2 Joint and Tissue Composition of the Carcasses

The tissue distribution of the goat carcasses in this study averaged 63% lean, 22% bone, 10% intermuscular fat and 5% subcutaneous fat. These values are within the ranges that have been reported for other goat breeds (Devendra and Owen, 1983; Kirton, 1988; Simela et al., 1999; refer to § 2.2.3.1). Low carcass fat is one of the main attractions to chevon production. However the low and rather invariable subcutaneous fat cover is a particular cause for concern in commercial chevon production since it is often well below the levels considered necessary for effective carcass chilling, without the risk of cold shortening (Smith et al., 1976; Dikeman, 1996). The low subcutaneous cover has also contributed to the downgrading of goat carcasses in a number of commercial enterprises, particularly where the classification/grading schedules that are employed are based on those of lamb and mutton (Pike et al., 1973b; Simela et al., 1999). Several scientists (Devendra and Owen, 1983, Kirton, 1988; Prasad and Kirton, 1992; Simela et al., 1998) have emphasised this misconception and recommended well-researched classification systems that are indicative of the possible end use of the carcass rather than nominal carcass

quality. Such an approach would better cater for diverse consumer populations with different expectations, such as occurs in South Africa.

Typically, the intact males tended to yield leaner carcasses with less cavity fat than the females. Such a trend has been observed amongst cattle, whereby steers reportedly have 40% more omental and kidney fat, 71% more subcutaneous fat and 26% more intermuscular fat than bulls (Brännäng, 1971 as cited by Pearson, 1990). In this study the castrated and intact males differed significantly in carcass fat content. Castrates attained percentages of intermuscular and subcutaneous fat that were 41% and 91% greater than the respective percentages in the intact males. Pearson (1990) also discussed the differences in the proportion of the quarters within beef carcasses: bulls reportedly have some 2.5% more fore quarter than steers. Similar differences were obtained in this study when just the neck and hind limbs were compared; the intact males had about 2.4% units more neck and 1.5% units less hind limb than the castrates. Therefore, the tissue distributions of the goats were typical of the trends with the sexes.

The lean carcasses, coupled with the faster growth of the intact males (Louca, Ecomides and Hancock, 1977; Allan and Holst, 1989; Aregheore, 1995) are the basis for the drive to produce young intact males in preference to castrates and females. However, at sexual maturity and beyond, meat from intact males is believed to have an unacceptably strong odour (Norman, 1991), which leads to the downgrading of their carcasses. A further deterrent to the production of males could be that they have a lower proportion of the western-style high value hind quarter (Table 4.6) than the castrates and females. However the preferred carcass weights would affect the extent that the differing joint proportions influence the value of the carcass. Furthermore, the impact of the effect of sex on the proportions of the joints within the carcass will also depend on the relative importance of these joints or the cuts arising from them to the consumers.

No standards have been set for the presentation of chevon to consumers to date. However, in a chevon industry survey carried out in Zimbabwe, indications were that most consumers that purchase chevon from retail outlets prefer cuts and joints. Unfortunately that study did not delve further into the nature of the preferred cuts and joints. The general trend in commercial chevon production is to use similar cuts to lamb (Wilson, 1992). The effectiveness of this in marketing chevon is debatable since the two species differ in distribution of joints within the carcass as well

as the dissectible tissues within the joints (Casey, 1982). In lamb the western-style high value cuts are associated with the loin region (dorsal trunk) and the hind limb. The composition of the hind limb of goats seems suitable for the production of high value cuts in that it has a low fat and high lean content. Although the dorsal trunk also has a low fat content, it tends to be bony. This is attested to by the high bone (27%) and low lean content (58%) of the cut as well as the relatively small LT areas, especially when compared to sheep (Gaili et al., 1972; Riley, Savell, Johnson, Smith and Shelton, 1989). The implications of this are that the rib and loin cuts from goat carcasses would not be as meaty as similar cuts derived from the dorsal trunk of sheep.

An additional consideration in the jointing of goat carcasses is the classification of the cuts according to their perceived value to consumers. Previous research shows that the preference for the cuts varies with cultural backgrounds. Whereas in most of the western world, cuts from the hind limb and the dorsal region are of prime value and the breast region is of low value, a high preference for the breasts has been shown in some studies conducted in Africa and Asia (Wilson, 1992; Prasad and Kirton, 1992). An understanding of the market needs within each country is therefore essential for the development of a market for chevon.

A previously reported phenomenon with unimproved goats is that there is little variation in the lean/bone index with sex and age (Simela et al., 1999). This phenomenon is in line with the fact that goats are relatively late maturing and hence age-related changes in the proportions of tissues do not occur until a late stage (Owen et al., 1978). This has been demonstrated by the relatively high growth coefficients for lean, bone and fat, particularly when compared to those of sheep. Owen et al. (1978) reported Tswana goat lean, bone and fat growth coefficients of 1.1697, 0.7756 and 1.9947 respectively. Corresponding values for Boer goats reported by Casey (1982) were 1.0754, 0.7685 and 1.9877 whereas the average values for the sheep breeds were 0.9112, 0.6959 and 2.0962 for lean, bone and fat, respectively. The meat yield indices, including the *M. longissimus* area, are however increased by improved nutrition (Gaili et al., 1972; Mtenga and Kitaly, 1990; Johnson and McGowan, 1998; Oman et al., 1999). The increases would obviously be more evident and consequential in young growing animals than in old goats, and amongst the former, in intact males than in castrates and females (Louca et al., 1977; Allan and Holst, 1989).

CHAPTER 4

4.4 SUMMARY

The results of this chapter showed that the indigenous goats of South Africa belong to the large breeds that are considered to have a high potential for chevon production. These goats have a high lean and low fat content that is typical of most goat breeds. The intact males seemed particularly suited for high chevon yield because they were heavy, had a high lean and low fat content and losses during dressing and chilling were reduced by improved nutrition. Goats between the two- and six-teeth stages were high yielding because they had heavy carcasses with weights that were comparable to goats in the eight teeth group. Additionally, the two-to-six teeth groups yielded proportionately more lean, more so in the joints that are considered as of high value, the hind limb and dorsal trunk.

Within the goat carcasses, the hind limb seems most ideal for the high lean, low fat, high value cuts. The dorsal trunk was bony and yielded less lean, which may not make it a high value cut in terms of saleable meat yield.

Pre-slaughter conditioning improved the overall size of the goats. It also reduced the losses from the goats during slaughter and chilling. Although pre-slaughter conditioning reduced the percentage of lean and increased that of fat, it also improved the meat yield indices.

CHAPTER 5

5 MEAT QUALITY CHARACTERISTICS OF CHEVON

5.1 INTRODUCTION

In section 2.2, various meat quality characteristics were reviewed with highlights of results that have been reported for chevon. Acceptably, substantial research has been conducted on goat carcass and meat quality. In all this however, little attention has been paid to the biochemical and physiological changes taking place in the meat immediately post-mortem. This is despite the fact that it has been established that these changes are a reflection of the effects of the peri- and post-mortem treatments and are crucial in the determination of the ultimate quality of meat.

The aims of this chapter are to look at meat quality characteristics of chevon, particularly in relation to the immediate post-mortem metabolic status, pH changes as well as the histological characteristics. The objective is to identify the group of goats (age, sex, and/or pre-slaughter conditioning) that yield chevon of acceptable quality.

5.2 RESULTS

The results are presented for the *M. longissimus thoracis et lumborum* (LTL) and *M. semimembranosus* (SM) followed by a brief comparison of the two muscles and a report on effects on chevon quality.

5.2.1 Post-mortem pH, Temperature, Histological, Histochemical, Proteolytic and Metabolic Properties of Chevon as Determined from the *M. Longissimus Thoracis et Lumborum*

5.2.1.1 Effects of sex, age and pre-slaughter conditioning on pH and temperature

The effect of age, sex and pre-slaughter conditioning on the mean LT pH and temperature are presented in Tables 5.1 to 5.3 and illustrated in the corresponding figures. Muscle pH and temperature profiles of the three sexes (Table 5.1, Figure 5.1) were similar ($P>0.05$). The carcasses dropped from a mean temperature of 36.21 ± 1.97°C to 3.67 ± 3.58°C and a mean initial pH of 6.54 ± 0.29 to a mean pHu of 5.93 ± 0.14.

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Table 5.1 Effect of sex on pH and temperature (°C) profiles (means ± S.D.) of the *M. longissimus thoracis* of South African indigenous goats

Parameter	Time post-mortem	Sex			*P*-value
		Castrates	Females	Intact males	
pH	15 min	6.55 ± 0.35	6.52 ± 0.25	6.55 ± 0.32	0.4132
	3 hours	6.37 ± 0.20	6.27 ± 0.27	6.31 ± 0.38	0.3528
	6 hours	6.17 ± 0.20	6.15 ± 0.26	6.15 ± 0.34	0.5414
	24 hours	5.90 ± 0.13	5.95 ± 0.16	5.91± 0.09	0.9752
Temp (°C)	15 min	35.90 ± 2.08	36.28 ± 1.78	36.53 ± 2.27	0.9438
	3 hours	12.55 ± 4.61	14.21 ± 4.26	12.53 ± 4.98	0.2257
	6 hours	7.50 ± 4.55	9.32 ± 4.11	8.09 ± 4.07	0.2940
	24 hours	3.50 ± 4.13	4.13 ± 3.54	2.87 ± 2.73	0.4031

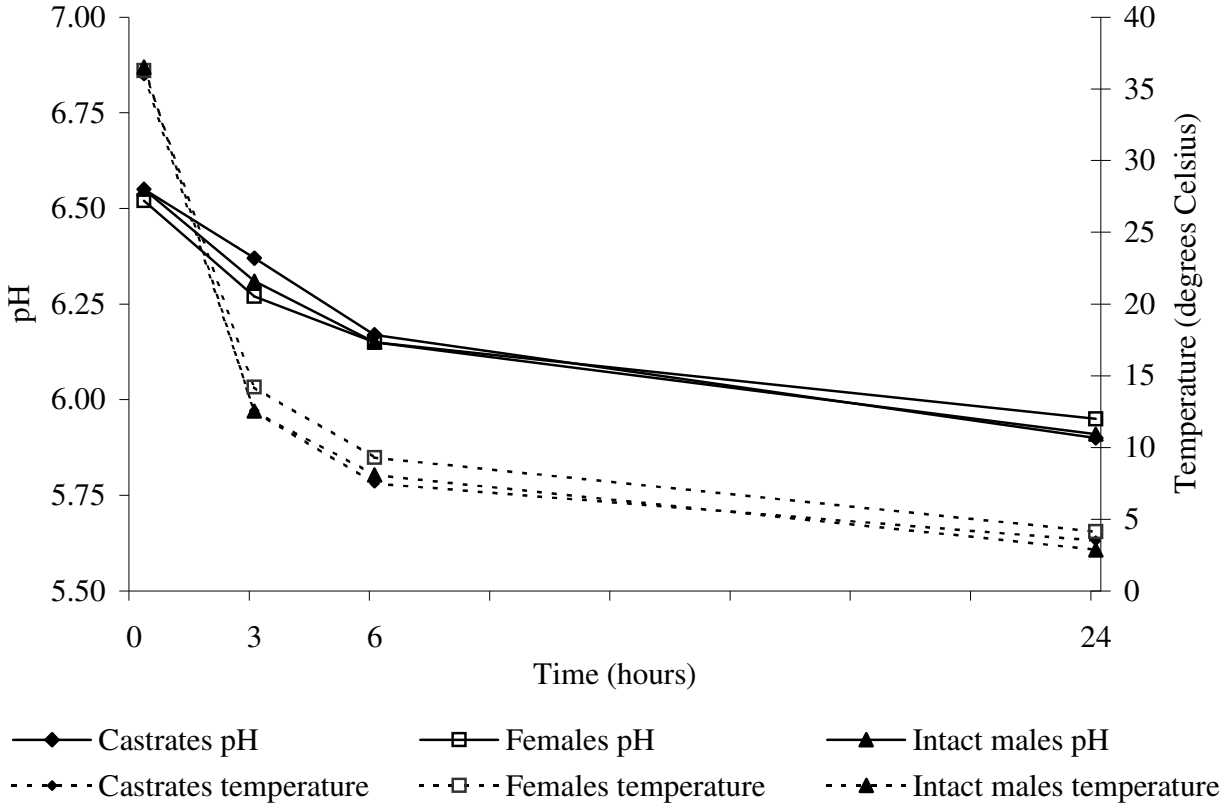

Figure 5.1 Effect of sex on pH and temperature (°C) profiles of the *M. longissimus thoracis* of goat South African indigenous goats

Age had a significant effect ($P \leq 0.045$) on all mean pH readings (Table 5.2, Figure 5.2). The 2-teeth group had the lowest pH throughout the first 24 hours post-mortem. The 8-teeth group had the highest pHu of 6.03±0.19, which significantly differed from that of the 2-teeth group ($P=0.042$) by 0.15 units. The rate of temperature decline of the LT was slowest for the 2-teeth group such that by three hours post-mortem the group had a reading (mean = 16.33±4.05) that was significantly higher ($P=0.010$) than the other three age groups (mean = 11.05±3.45). At six hours post-mortem, the range of the age group mean temperatures was 6.52°C and the 2-teeth group mean was highest, the milk-teeth and 8-teeth groups intermediate and the 4-to-6 teeth group mean lowest ($P=0.026$). By 24 hours post-mortem, the four age groups had similar temperature readings ($P>0.05$), whose mean was 3.67°C±3.59.

Initial pH was not affected ($P=0.413$) by pre-slaughter conditioning of the goats (Table 5.3, Figure 5.3). However, early post-mortem rate of pH decline differed between the two groups such that at three hours post mortem the non-conditioned group had a mean pH that was 0.29 units higher than that of the pre-slaughter conditioned group ($P=0.081$). By six hours post mortem the difference was 0.30 and was statistically significant ($P=0.020$). Nonetheless, pHu values were similar ($P=0.436$) between the two groups (Table 5.3). Except for the initial reading, the mean LT temperature of the pre-slaughter conditioned group was consistently higher than that of the non-conditioned group throughout the 24-hour period ($P<0.0001$).

5.2.1.2 Effects of sex, age and pre-slaughter conditioning on histological, histochemical, metabolic and proteolytic characteristics

Many of the histological, histochemical, metabolic and proteolytic parameters that were determined on the LTL did not significantly vary with sex, age or pre-slaughter conditioning. The overall means for all the traits are thus presented (Table 5.4) but the trends of the main effects can be discerned from Tables 5.5 to 5.7.

Myofibre properties did not significantly ($P>0.05$) vary with the sex of the goats (Table 5.5). Therefore female, castrate and intact male goats in this study had similar SL, MFL and MFT areas and proportions. The averages were 1.79µm and 1.76µm SL, and 18.3µm and 16.9µm MFL at 24 and 96 hours post-mortem, respectively. The myofibres averaged 27% red, 33% intermediate and 40%.

Table 5.2 Effect of age on pH and temperature (°C) profiles (means ± S.D.) of the *M. longissimus thoracis* of South African indigenous goats

Parameter	Time post-mortem	Dentition group				*P*-value
		0 teeth	2 teeth	4-to-6 teeth	8 teeth	
pH	15 min	6.56 ± 0.27^{ab}	6.41 ± 0.24^{a}	6.75 ± 0.35^{b}	6.59 ± 0.25^{ab}	0.0121
	3 hours	6.43 ± 0.23^{b}	6.16 ± 0.25^{a}	6.49 ± 0.21^{b}	6.36 ± 0.29^{ab}	0.0285
	6 hours	6.22 ± 0.17^{b}	5.99 ± 0.17^{a}	6.34 ± 0.28^{b}	6.28 ± 0.29^{b}	0.0447
	24 hours	5.94 ± 0.10^{ab}	5.88 ± 0.12^{a}	5.94 ± 0.13^{ab}	6.03 ± 0.19^{b}	0.0417
Temp (°C)	15 min	36.19 ± 2.61	36.56 ± 1.53	36.35 ± 1.78	35.05 ± 2.08	0.0840
	3 hours	11.49 ± 3.96^{a}	16.33±4.05^{b}	10.01 ± 1.43^{a}	11.83 ± 4.45^{a}	0.0103
	6 hours	6.92 ± 3.54^{ab}	11.43 ± 3.59^{c}	4.91 ± 1.78^{a}	7.03 ± 4.11^{b}	0.0263
	24 hours	3.02 ± 3.01	5.97 ± 3.50	2.06 ± 1.33	2.13 ± 2.40	0.3471

$^{a, b, c}$ Means within the same row with different superscripts differ significantly (P<0.05)

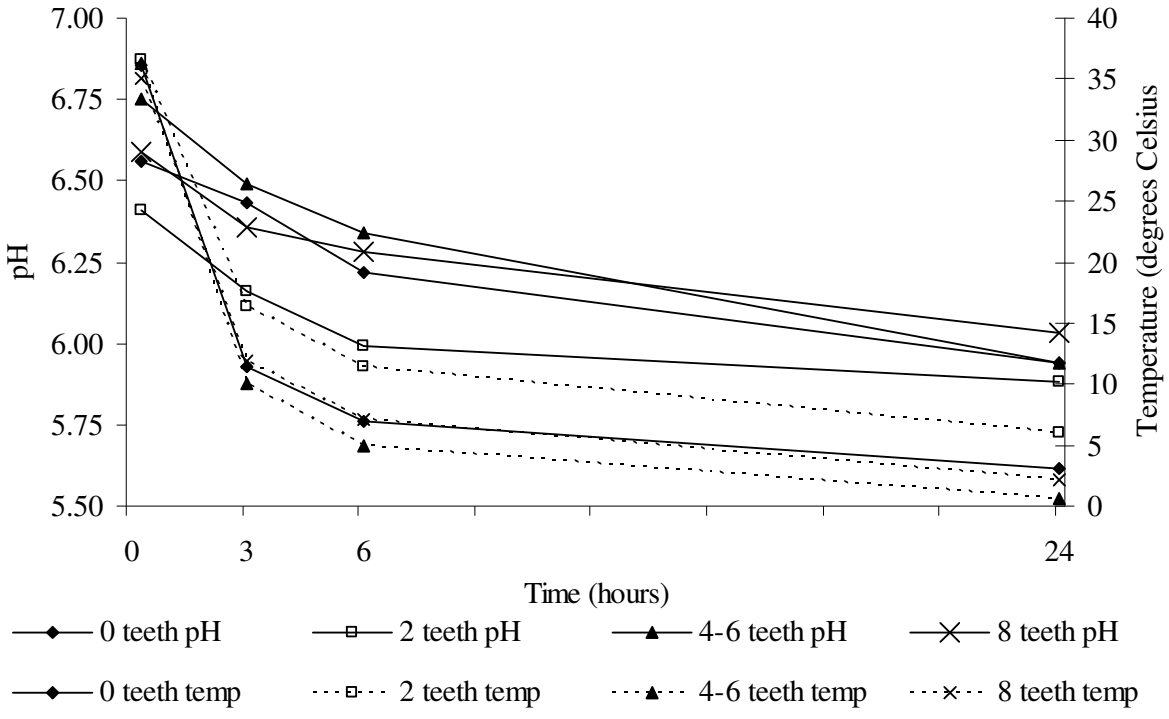

Figure 5.2 Effect of age on pH and temperature (°C) profiles of the *M. longissimus thoracis* of South African indigenous goats

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Table 5.3 Effect of pre-slaughter conditioning on pH and temperature (°C) profiles (means ± S.D.) of the *M. longissimus thoracis* of South African indigenous goats

Parameter	Time post-mortem	Pre-slaughter conditioning		*P*-value
		Non-conditioned	Conditioned	
pH	15 minutes	6.63 ± 0.31	6.43 ± 0.24	0.1433
	3 hours	6.45 ± 0.22	6.16 ± 0.25	0.0809
	6 hours	6.29 ± 0.24	5.99 ± 0.16	0.0202
	24 hours	5.93 ± 0.12	5.92 ± 0.16	0.4356
Temperature	15 minutes	35.56 ± 2.36	36.96 ± 1.02	0.0922
(°C)	3 hours	9.52 ± 1.84	17.82 ± 1.78	<0.0001
	6 hours	4.87 ± 1.69	12.72 ± 1.63	<0.0001
	24 hours	0.82 ± 1.20	7.02 ± 2.32	<0.0001

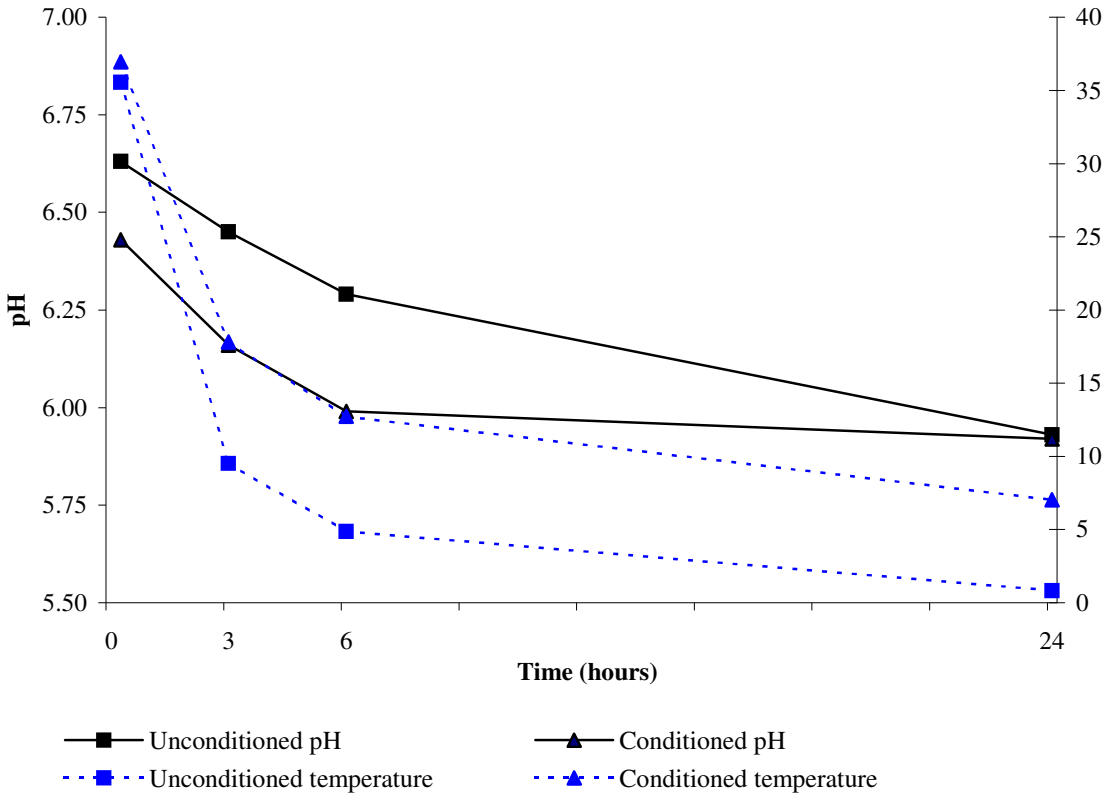

Figure 5.3 Effect of pre-slaughter conditioning on pH and temperature (°C) profiles of the *M. longissimus thoracis* of South African indigenous goats

Table 5.4 Overall means (± S.D.) and range of values of the histological, histochemical metabolic and proteolytic attributes of chevon that were determined on the *M. longissimus thoracis et lumborum* of South African indigenous goats

Characteristics	Mean ± S.D.	Minimum	Maximum
N	74		
Histological and histochemical:			
Sarcomere length (µm) 24hr	1.79 ± 0.15	1.23	2.21
Sarcomere length (µm) 96hr	1.76 ± 0.12	1.31	2.11
MFL‡ (µm) 24hr	18.30 ± 2.27	14.72	25.55
MFL (µm) 96hr	16.92 ± 2.18	14.09	24.70
Red myofibre area (μm^2)	1 790 ± 594	775	3 702
Intermediate myofibre area (μm^2)	2 302 ± 567	1 288	3 622
White myofibre area (μm^2)	3 057 ± 722	1 824	5 224
% Red myofibres	27.29 ± 3.63	20.69	35.13
% Intermediate myofibres	32.69 ± 3.21	26.88	40.82
% White myofibres	40.02 ± 4.70	29.54	49.57
Metabolic and proteolytic:			
Glycolytic potential (µmol/g)	101.74 ± 23.21	56.29	153.81
Lactate (µmol/g)	30.19 ± 10.57	8.88	75.16
Glycogen (µmol/g)	32.82 ± 11.39	8.84	59.75
Lactate %	15.37 ± 5.57	6.04	31.07
Glycogen %	31.60 ± 6.28	14.40	42.20
Glucose (µmol/g)	1.70 ± 0.53	0.76	3.37
Glucose-6-phosphate (µmol/g)	1.25 ± 0.69	0.29	4.00
ATP (µmol/g)	5.17 ± 0.74	2.36	6.75
Creatine phosphate (µmol/g)	3.74 ± 1.16	1.86	9.73
Calpastatin activity (U/g sample)	3.18 ± 0.81	1.23	5.01
Extractable protein (mg/g sample)	52.78 ± 8.88	35.02	89.72
Calpastatin specific activity (U/mg	0.061 ± 0.023	0.023	0.127

‡ MFL = Myofibrillar fragment length

Table 5.5 Effect of sex on chevon histological, histochemical, metabolic and proteolytic attributes (means ± S.D.) that were determined on the *M. longissimus thoracis et lumborum* of South African indigenous goats

Characteristics	Sex			*P*-value
	Castrates	Females	Intact males	
N	24	35	15	
Histological and histochemical:				
Sarcomere length (µm) 24hr	1.79 ± 0.13	1.78 ± 0.19	1.81 ± 0.19	0.4318
Sarcomere length (µm) 96hr	1.77 ± 0.17	1.75 ± 0.14	1.77 ± 0.16	0.9471
MFL‡ (µm) 24hr	18.31 ± 2.58	17.96 ± 2.04	19.03 ± 1.82	0.5280
MFL (µm) 96hr	16.67 ± 2.06	16.97 ± 2.21	17.19 ± 2.27	0.7487
Red myofibre area (µm^2)	1 581 ± 368	1 897 ± 648	1 869 ± 691	0.1439
Intermediate myofibre area (µm^2)	2 139 ± 387	2 397 ± 596	2 342 ± 696	0.1236
White myofibre area (µm^2)	2 839 ± 500	3 179 ± 801	3 120 ± 788	0.1002
% Red myofibres	27.97 ± 3.80	27.31 ± 3.45	26.27 ± 3.75	0.1501
% Intermediate myofibres	33.30 ± 2.84	32.28 ± 3.54	32.93 ± 3.02	0.8474
% White myofibres	38.72 ± 5.10	40.42 ± 4.61	40.09 ± 4.15	0.3821
Metabolic and proteolytic:				
Glycolytic potential (µmol/g)	105.48 ± 23.18	95.45 ± 22.03	109.48 ± 23.99	0.1324
Lactate (µmol/g)	30.39 ± 10.37	28.88 ± 9.12	32.69 ± 12.53	0.7493
Glycogen (µmol/g)	34.53 ± 10.92	30.58 ± 10.84	35.05 ± 12.88	0.2676
Lactate %	14.80 ± 4.72	15.74 ± 5.92	15.43 ± 5.47	0.6265
Glycogen %	32.17 ± 6.20	31.31 ± 6.62	31.34 ± 5.33	0.8425
Glucose (µmol/g)	1.67 ± 0.52	1.70 ± 0.56	1.74 ± 0.39	0.9527
Glucose-6-phosphate (µmol/g)	1.35 ± 0.69^b	1.01 ± 0.67^a	1.61 ± 0.83^c	0.0286
ATP (µmol/g)	5.21 ± 0.63	5.27 ± 0.94	4.91 ± 0.53	0.2207
Creatine phosphate (µmol/g)	3.62 ± 0.79	3.97 ± 1.68	3.43 ± 0.89	0.9200
Calpastatin activity (U/g sample)	3.11 ± 0.96	3.13 ± 0.85	3.11 ± 1.14	0.5102
Extractable protein (mg/g)	52.41 ± 10.47	54.95 ± 11.31	48.73 ± 6.09	0.1895
Calpastatin specific activity‡‡	0.062 ± 0.024	0.060 ± 0.023	0.064 ± 0.022	0.2919

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

‡ MFL = Myofibrillar fragment length; ‡‡ units = U/mg protein

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Amongst the glycolytic metabolites, the initial glucose-6-phosphate content of the LT was significantly different amongst all the sex groups (P=0.029). Glucose-6-phosphate was lowest in the LT of the females by 0.34µmol/g and 0.60µmol/g less than the content in the LT of castrates and intact males, respectively. The concentrations of the rest of the energy metabolites (glycogen, lactate, ATP and creatine phosphate) did not vary with the sex of the goats (Table 5.5). Neither did calpastatin activity (P=0.510), extractable protein content (P=0.190) nor specific calpastatin activity (P=0.292).

There were no significant (P>0.05) age effects on the histological and histochemical parameters measured on the LTL (Table 5.6). Sarcomeres of the 2-teeth group were however numerically longer than those of the other age groups by up to 0.16 and 0.19µm at 24 and 96 hours post-mortem, respectively. The group also had a mean GP content that was a noticeable 15.65µmol/g higher than that of the 8-teeth group. These trends in SL and GP were in line with the variations in early post-mortem temperature and pHu, respectively.

Of the energy metabolites, only creatine phosphate significantly varied with the age of the goats (P=0.030). The range for the age group means was 0.64µmol/g. The metabolite was lowest in the 4-to-6 teeth group and highest in milk teethed kids, implying a higher peri-mortem energy utilisation by former group. ATP concentration was not significantly affected by the age of the goats (P>0.05).

Calpastatin activity (P=0.274), specific activity (P=0.102) and the extractable protein content (P=0.069) did not differ significantly amongst the age groups.

Pre-slaughter conditioning also had no significant effect on most parameters except for the SLs, the proportion of intermediate myofibres and initial calpastatin activity (Table 5.7). At 24 and 96 hours post-mortem, respectively, the sarcomeres of the pre-slaughter conditioned goats were 0.19µm and 0.17µm longer than those of the non-conditioned goats (P=0.0002). The latter group had a lower proportion of the intermediate myofibres (P=0.041) though by only 1.3%, and a 0.54U/g sample lower initial calpastatin activity (P=0.020). However, when calpastatin activity was expressed as a proportion of the extractable protein, the pre-slaughter conditioning effects were annulled (P=0.1904).

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Table 5.6 Effect of age on chevon histological, histochemical, metabolic and proteolytic attributes (means ± S.D.) that were determined on the *M. longissimus thoracis et lumborum* of South African indigenous goats

Characteristics	Dentition group				*P*-value
	0 teeth	2 teeth	4–6 teeth	8 teeth	
N	16	32	16	10	
Histological and histochemical:					
Sarcomere length (µm) 24hr	1.75 ± 0.17	1.86 ± 0.15	1.70 ± 0.18	1.77 ± 0.16	0.7529
Sarcomere length (µm) 96hr	1.72 ± 0.15	1.84 ± 0.12	1.67 ± 0.12	1.68 ± 0.18	0.4851
Myofibre fragment length (µm) 24hr	18.21 ± 2.01	18.44 ± 2.33	18.81 ± 2.23	17.21 ± 1.98	0.6756
Myofibre fragment length (µm) 96hr	16.54 ± 1.59	17.22 ± 2.48	16.64 ± 2.35	16.94 ± 1.58	0.8892
Red myofibre area (μm^2)	1 545 ± 443	1 908 ± 653	1 715 ± 613	1 875 ± 521	0.2457
Intermediate myofibre area (μm^2)	2 130 ± 545	2 449 ± 558	2 135 ± 544	2 321 ± 607	0.5691
White myofibre area (μm^2)	2 903 ± 700	3 132 ± 719	3 043 ± 828	3 068 ± 682	0.4596
% Red myofibres	27.59 ± 2.94	27.69 ± 3.91	26.46 ± 4.09	26.76 ± 3.25	0.4056
% Intermediate myofibres	33.51 ± 3.67	33.03 ± 2.99	32.02 ± 3.68	31.42 ± 2.24	0.5081
% White myofibres	38.90 ± 3.93	39.28 ± 4.94	41.52 ± 4.99	41.82 ± 4.14	0.1364
Metabolic and proteolytic:					
Glycolytic potential (µmol/g)	98.34 ± 22.51	106.07 ± 21.35	104.85 ± 25.80	90.42 ± 25.35	0.7866
Lactate (µmol/g)	29.67 ± 13.03	31.68 ± 10.99	30.31 ± 6.50	26.51 ± 7.04	0.2275
Glycogen (µmol/g)	31.03 ± 10.61	34.08 ± 10.58	34.75 ± 13.86	29.48 ± 11.74	0.7779
Lactate %	15.43 ± 5.56	15.24 ± 5.44	15.53 ± 6.01	15.43 ± 4.96	0.6384
Glycogen %	31.06 ± 6.34	31.71 ± 6.01	31.90 ± 6.81	31.71 ± 5.64	0.6602
Glucose (µmol/g)	1.64 ± 0.37	1.82 ± 0.64	1.57 ± 0.36	1.59 ± 0.36	0.3181
Glucose-6-phosphate (µmol/g)	1.66 ± 0.93	1.29 ± 0.72	0.95 ± 0.47	0.88 ± 0.44	0.1951
ATP (µmol/g)	5.26 ± 0.63	5.33 ± 0.86	4.92 ± 0.54	4.92 ± 0.90	0.5655
Creatine phosphate (µmol/g)	4.04 ± 1.70^{b}	3.68 ± 1.26^{ab}	3.40 ± 1.05^{a}	3.89 ± 0.98^{ab}	0.0296
Calpastatin activity (U/g sample)	3.29 ± 0.82	3.23 ± 0.91	2.43 ± 0.81	3.40 ± 1.05	0.2735
Extractable protein (mg/g sample)	52.32 ± 9.85	56.68 ± 11.29	49.50 ± 8.02	46.33 ± 5.33	0.0688
Calpastatin specific activity (U/mg protein)	0.064 ± 0.019	0.059 ± 0.021	0.051 ± 0.022	0.075 ± 0.029	0.1021

[a, b] Means within the same row with different superscripts differ significantly ($P<0.05$)

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Table 5.7 Effect of the pre-slaughter conditioning on chevon histological, histochemical, metabolic and proteolytic attributes (means ± S.D.) that were determined on the *M. longissimus thoracis et lumborum* of South African indigenous goats

Characteristics	Pre-slaughter conditioning		*P*-value
	Non-conditioned	Conditioned	
N	40	34	
Histological and histochemical:			
Sarcomere length (µm) 24hr	1.70 ± 0.13	1.89 ± 0.16	0.0002
Sarcomere length (µm) 96hr	1.68 ± 0.14	1.85 ± 0.11	0.0002
Myofibre fragment length (µm) 24hr	18.48 ± 2.59	18.09 ± 1.66	0.3970
Myofibre fragment length (µm) 96hr	16.64 ± 1.88	17.24 ± 2.42	0.6310
Red myofibre area (μm^2)	1 630 ± 537	1 958 ± 612	0.0761
Intermediate myofibre area (μm^2)	2 113 ± 544	2 502 ± 528	0.1468
White myofibre area (μm^2)	2 881 ± 697	3 243 ± 709	0.1259
% Red myofibres	27.34 ± 3.85	27.24 ± 3.44	0.1524
% Intermediate myofibres	32.07 ± 2.95	33.34 ± 3.38	0.0412
% White myofibres	40.59 ± 5.03	39.43 ± 4.33	0.7566
Metabolic and proteolytic:			
Glycolytic potential (µmol/g)	101.133 ± 24.34	102.41 ± 22.44	0.5171
Lactate (µmol/g)	29.02 ± 6.63	31.50 ± 13.23	0.9225
Glycogen (µmol/g)	33.23 ± 12.15	32.37 ± 10.58	0.2360
Lactate %	15.10 ± 4.89	15.66 ± 5.98	0.1467
Glycogen %	31.92 ± 5.65	31.23 ± 6.57	0.2328
Glucose (µmol/g)	1.66 ± 0.45	1.75 ± 0.57	0.7800
Glucose-6-phosphate (µmol/g)	1.17 ± 0.67	1.34 ± 0.82	0.7233
ATP (µmol/g)	4.97 ± 0.60	5.40 ± 0.89	0.6169
Creatine phosphate (µmol/g)	3.53 ± 0.86	3.97 ± 1.63	0.6944
Calpastatin activity (U/g sample)	2.86 ± 0.90	3.40 ± 0.91	0.0203
Extractable protein (mg/g sample)	48.67 ± 6.33	52.36 ± 11.89	0.2029
Calpastatin specific activity (U/mg protein)	0.060 ± 0.023	0.063 ± 0.024	0.1904

5.2.1.3 Interaction effects of sex, age and pre-slaughter conditioning on histological, histochemical, metabolic and proteolytic characteristics

The *P*-values of the first order interaction effects are shown in Table 5.8, in which significant effects are highlighted.

Amongst the non-conditioned goats, females, castrates and intact males had myofibres of similar size (Figure 5.4). Amongst the pre-slaughter conditioned goats, intact males had the thickest myofibres, which were consistently and significantly thicker ($P<0.05$) than those of the intact males and castrates but not the females ($P>0.05$) of the non-conditioned group for all three myofibre types. Thus, only myofibre sizes of intact males significantly increased with pre-slaughter conditioning. The relative percentage difference in red, intermediate and white myofibre areas between the non-conditioned and pre-slaughter conditioned intact males were respectively, 76, 58 and 38.

There were significant age and sex interaction effects on the proportions of white ($P=0.028$) but not of red and intermediate myofibres ($P>0.05$; Figure 5.5). Within each sex group, age had no significant effect on the white myofibre proportions ($P>0.05$). However, the trend was an upsurge of white myofibre population between the milk- (mean = 39.10±2.72%) and 2-teeth (mean = 44.40±4.42%) stages of intact males, but the proportion subsequently declined (40.41±4.13% at the 4-to-6 teeth stage). Changes in white myofibre proportions of castrates were in the reverse order to that of intact males while in females, the proportion tended to increase mainly between the milk teeth (mean = 34.57±4.88%) and 2-teeth (40.41±4.08%) stages and not much thereafter (means = 40.79±5.20% and 41.82±4.14% at 4-to-6 and 8-teeth stages, respectively). Within the 2-teeth group, intact males had the greatest proportion of white myofibres which differed significantly ($P<0.05$) from that of the castrates (mean = 36.40±4.06%) but not that of the females.

Within the non-conditioned group, calpastatin activity of the three sexes did not differ significantly ($P>0.05$) (Figure 5.6). The activity did not vary significantly with pre-slaughter conditioning amongst the females and castrates but it almost doubled between intact males of the non-conditioned and pre-slaughter conditioned groups ($P<0.05$).

Table 5.8 *P*-values of the first order interaction effects of sex, age and pre-slaughter conditioning on pH, histological, histochemical, metabolic and proteolytic attributes that were determined on the ***M.*** *longissimus thoracis et lumborum* of South African indigenous goats

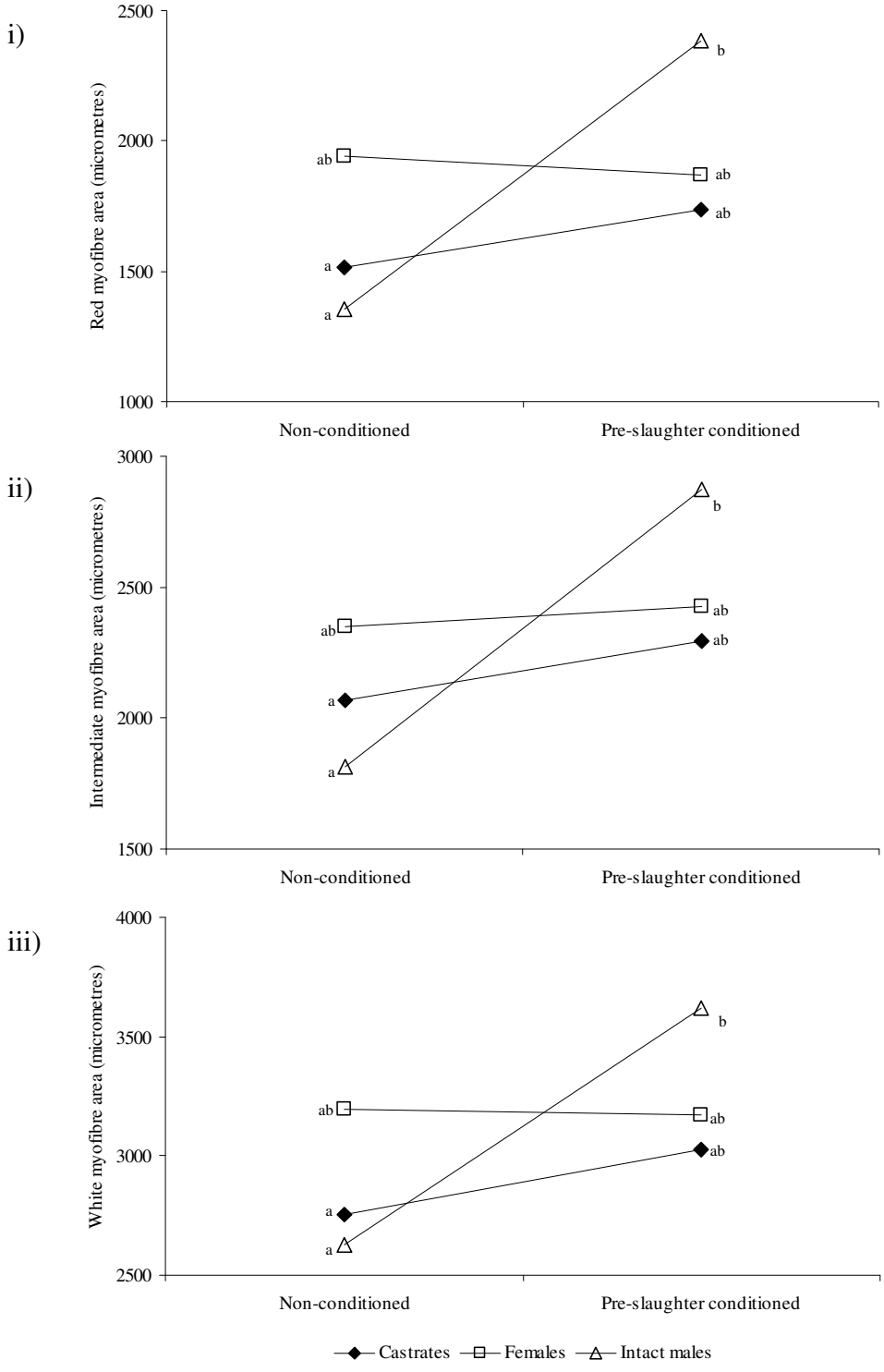
	Interaction effects		
	Age(sex)[1]	Sex*conditioning	Conditioning(age)[2]
pH_0	0.5674	0.0864	0.1517
pH_3	0.2276	0.6477	0.5105
pH_6	0.1240	0.8042	0.3424
pH_{24}	0.8736	0.5614	0.5967
Sarcomere length (µm) 24hr	0.8006	0.3531	0.6065
Sarcomere length (µm) 96hr	0.9018	0.6301	0.9243
MFL‡ (µm) 24hr	0.5302	0.5182	0.6066
MFL (µm) 96hr	0.2787	0.2172	0.5601
Red myofibre area (μm^2)	0.5811	0.0231	0.3740
Intermediate myofibre area (μm^2)	0.4745	0.0089	0.1468
White myofibre area (μm^2)	0.3174	0.0278	0.2842
% Red myofibres	0.1226	0.3516	0.2898
% Intermediate myofibres	0.1577	0.4886	0.5129
% White myofibres	0.0278	0.1947	0.6758
Glycolytic potential (µmol/g)	0.9318	0.4765	0.3412
Lactate (µmol/g)	0.2967	0.8590	0.5933
Glycogen (µmol/g)	0.5389	0.2770	0.2083
Lactate %	0.1512	0.1261	0.0620
Glycogen %	0.2405	0.2055	0.1078
Glucose (µmol/g)	0.4355	0.8374	0.8271
Glucose-6-phosphate (µmol/g)	0.8190	0.3596	0.2646
ATP (µmol/g)	0.2355	0.0385	0.0830
Creatine phosphate (µmol/g)	0.2381	0.0455	0.1538
Calpastatin activity (U/g sample)	0.6634	0.0127	0.8276
Calpastatin activity (U/mg protein)	0.9147	0.0267	0.4874
Extractable protein (mg/g sample)	0.5515	0.4404	0.1412

NB ‡ MFL = Myofibrillar fragment length;

1- Sex effects were nested in age effects (refer to § 3.8.1)

2- Age effects were nested in conditioning effects (refer to § 3.8.1)

Significant interaction effects ($P<0.05$) are in bold face



NB: Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$).

Figure 5.4 Pre-slaughter conditioning and sex interaction effects on i) red, ii) intermediate and iii) white myofibre areas

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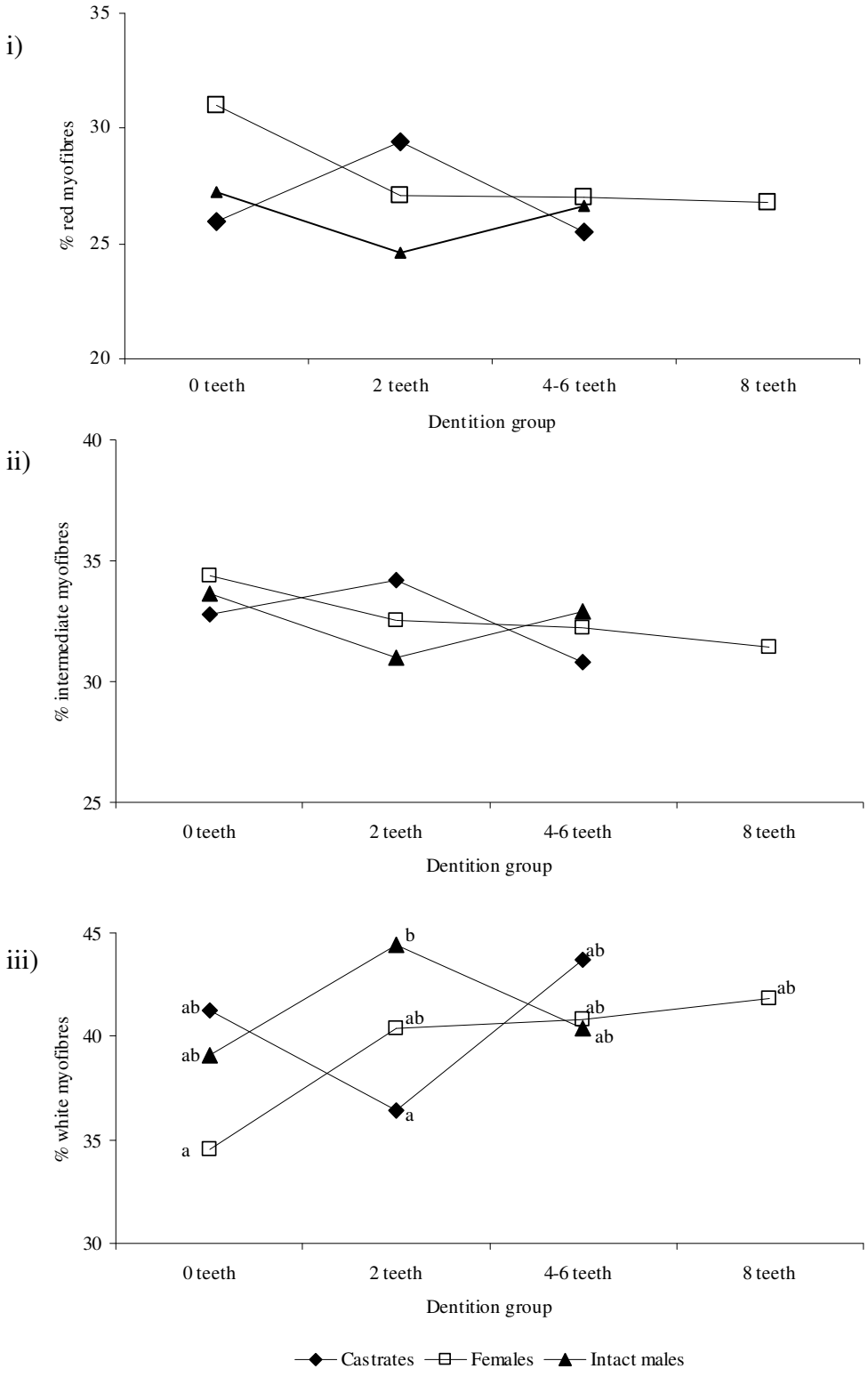
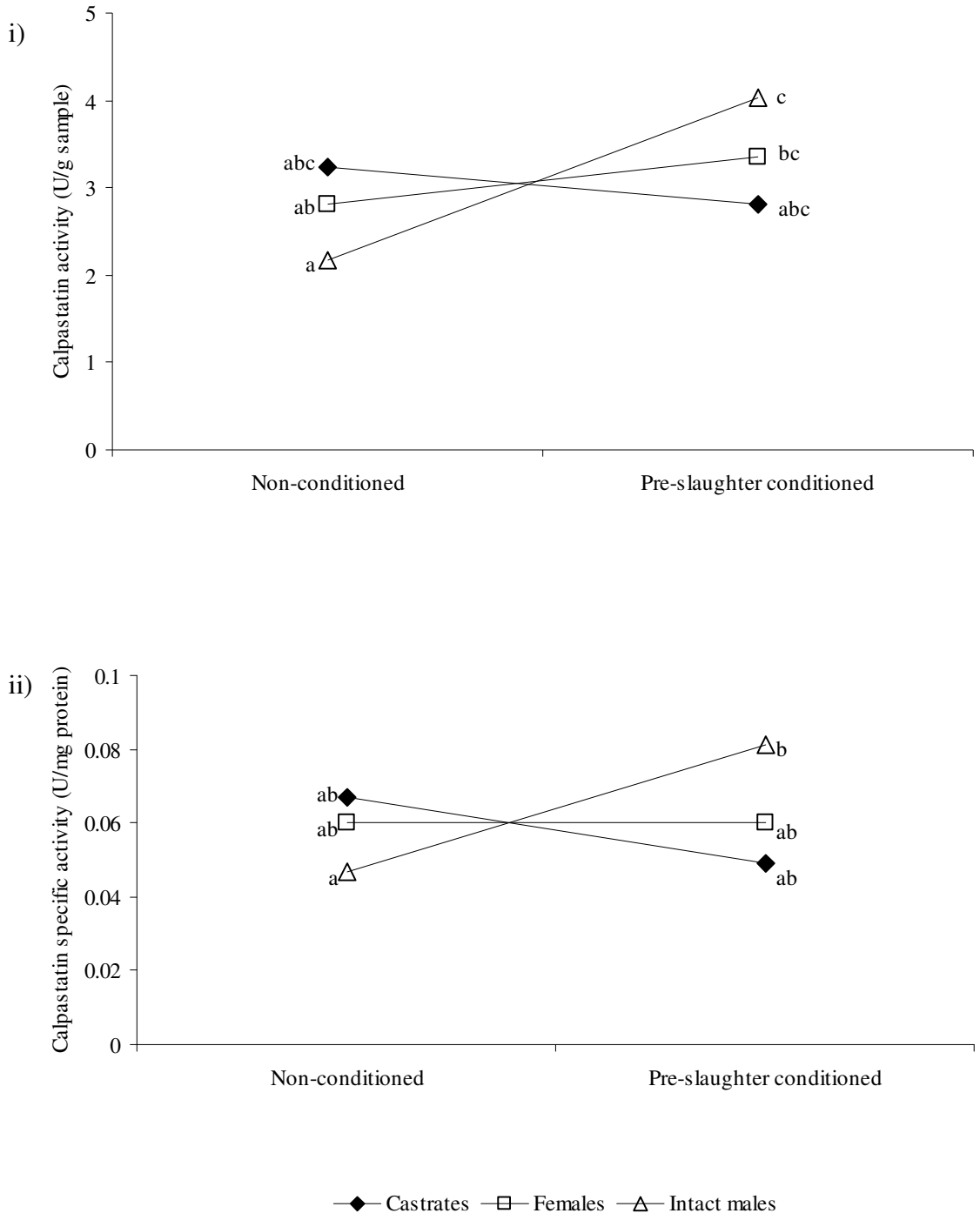


NB: Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$).

Figure 5.5 Age and sex interaction effects on i) red, ii) intermediate and iii) white myofibre proportions (%)



NB: Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$).

Figure 5.6 Sex and pre-slaughter conditioning interaction effects on i) calpastatin activity (U/g sample) and ii) calpastatin specific activity (U/mg extractable protein)

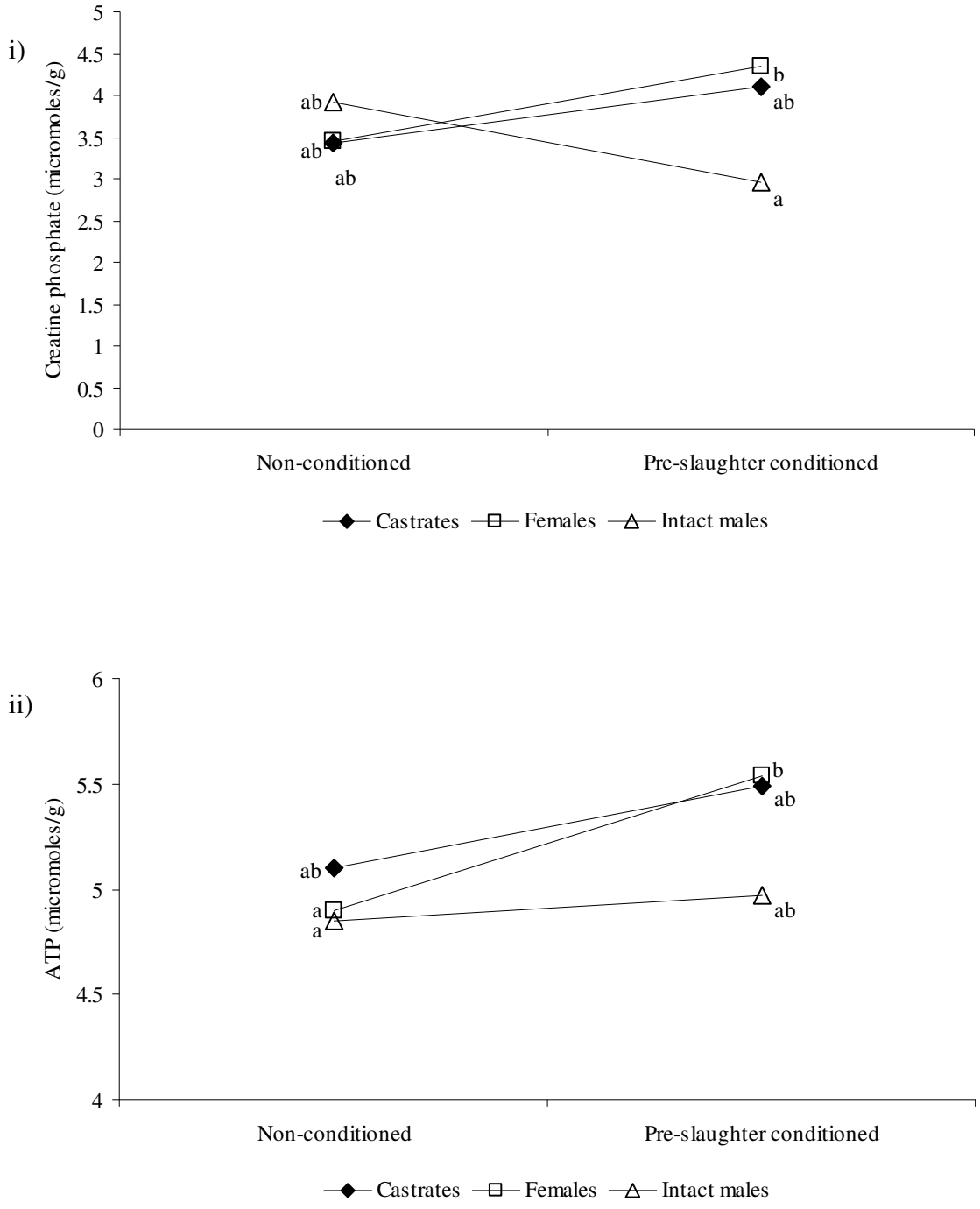
Sex by pre-slaughter conditioning effect on concentration of creatine phosphate was significant (P=0.046) (Figure 5.7i). Within the non-conditioned goats, creatine phosphate concentration was similar amongst the three sexes (P>0.05). The means were 3.41±0.54µmol/g, 3.44±1.08µmol/g and 3.92±1.00µmol/g for castrates, females and intact males, respectively. Pre-slaughter conditioned intact males had the lowest concentration (2.95±0.37µmol/g), which significantly differed from the concentration in the females of the same group (4.34±1.93µmol/g). Creatine phosphate concentration of pre-slaughter conditioned castrates (mean= 4.10±1.12µmol/g) did not differ significantly (P>0.05) from that of the females and intact males. A similar sex by pre-slaughter conditioning effect on ATP concentration was observed (P=0.039).

Non-conditioned goats had similar ATP concentrations with means of 4.85±0.65µmol/g, 4.90±0.58µmol/g and 5.10±0.59µmol/g for intact males, females and castrates, respectively. Within the pre-slaughter conditioned group, intact males tended to have lower ATP concentration (mean = 4.97±0.41µmol/g) though not significantly different (P>0.05) from that of the castrates (mean = 5.49±0.68µmol/g) and females (mean = 5.54±1.06µmol/g). In essence, *M. longissimus thoracis* ATP concentration of female goats significantly increased between non-conditioned and pre-slaughter conditioned groups (P<0.05) while the concentration in castrates and intact males was not affected by pre-slaughter conditioning.

5.2.1.4 Simple correlations between carcass and the meat quality traits of the *M. longissimus lumborum et thoracis*

Simple correlations between myofibre types and carcass and meat quality traits (Table 5.9) as well as between pH and carcass and meat quality traits (Table 5.10) were computed.

The correlations amongst the myofibre type areas were high (r≥0.80; P<0.0001). However, between the myofibre areas and proportions only the white myofibre area significantly correlated with the intermediate myofibre percentage (r=0.27; P<0.05). Between the myofibre proportions, significant correlations were observed between the red and white and intermediate and white (P<0.0001). The proportions of the red and intermediate myofibres were not correlated (P>0.05).



NB: Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$).

Figure 5.7 Sex and pre-slaughter conditioning interaction effects on immediate post-mortem concentrations of i) creatine phosphate (µmol/g) and ii) ATP (µmol/g)

Table 5.9 Simple correlations between myofibre types, carcass and chevon quality attributes that were determined on the *M. longissimus thoracis et lumborum* of South African indigenous goats

	Myofibre area (µm^2)			Myofibre composition (%)		
	Red	Int	White	Red	Int	White
Red (µm^2)						
Intermediate (µm^2)	0.85***					
White (µm^2)	0.80***	0.89***				
% Red	-0.12	0.01	0.02			
% Intermediate	0.19	0.17	0.27*	-0.06		
% White	-0.04	-0.12	-0.20	-0.73***	-0.64***	
Hot carcass weight (kg)	0.32**	0.32**	0.21	-0.20	0.12	0.07
Total carcass fat (g)	0.21	0.27*	0.22	-0.05	0.20	-0.10
pH_0	-0.23	-0.31**	-0.28*	-0.06	-0.12	0.13
pH_3	-0.26*	-0.36**	-0.25*	0.05	-0.15	0.06
pH_6	-0.24*	-0.35**	-0.29*	-0.02	-0.20	0.15
pH_{24}	-0.05	-0.11	-0.08	-0.15	-0.25*	0.28*
SL (µm) 24hr	0.10	0.17	0.15	0.04	0.03	-0.05
SL (µm) 96hr	0.19	0.33**	0.32**	0.26*	0.11	-0.27*
GP (µmol/g)	0.05	0.12	0.08	0.08	0.02	-0.08
Lactate (µmol/g)	0.03	0.13	0.20	-0.14	0.10	0.04
Glycogen (µmol/g)	0.04	0.06	-0.01	0.15	-0.04	-0.09
Lactate %	-0.03	0.01	0.09	-0.21	0.02	0.14
Glycogen %	0.04	0.00	-0.08	0.20	-0.04	-0.13
Glucose (µmol/g)	0.09	0.21	0.25*	-0.09	0.12	-0.02
G-6-P (µmol/g)	-0.13	-0.07	-0.07	-0.02	0.14	-0.08
ATP (µmol/g)	-0.07	-0.06	-0.05	0.14	0.17	-0.22
CP (µmol/g)	-0.14	-0.13	-0.15	0.24*	0.18	-0.31*
Calpastatin (U/g sample)	0.21	0.19	0.25*	0.03	0.27*	-0.21
Calpastatin (U/mg protein)	0.15	0.08	0.18	-0.07	0.24*	-0.11

Level of significance: * (P<0.05); ** (P<0.01); *** (P<0.001)

Int = intermediate; SL= sarcomere length; G-6-P = glucose-6-phosphate; CP = creatine phosphate

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Correlations between myofibre properties and carcass weight and fat content were generally low and mostly not significant (P>0.05). The significant correlations were between red and intermediate myofibre areas and carcass weight (r=0.32; P<0.01) and between intermediate myofibre area and carcass fat (r=0.27; P<0.05).

All myofibre areas significantly and negatively correlated with early post-mortem pH (-0.36 ≤ r ≤ -0.24; P<0.05) but the myofibre proportions were not linearly associated with early post-mortem pH (P>0.05). Myofibre proportions were however correlated to pHu, with significant correlations between intermediate (r=-0.25; P<0.05) and white (r=0.28; P<0.05) myofibre %.

Myofibres properties tended to correlate with 96-hour rather than 24-hour SL. Significant correlations between 96-hour SL and intermediate (r=0.33; P<0.01) and white (r=0.32; P<0.01) myofibre areas; and red (r=0.26; P<0.05) and white (r=-0.27; P<0.05) myofibre percentages were observed.

Very few correlations between myofibre characteristics and the glycolytic metabolites were significant. These were between the white myofibre areas and glucose concentration (r=0.25; P<0.05), and the red and white myofibre percentages and creatine phosphate concentration (r=0.24 and r=-0.31; P<0.05, respectively) (Table 5.9).

Calpastatin activity per sample, but not specific activity, correlated with white myofibre area (r=0.25; P<0.05). However the correlations with intermediate myofibre percentage were positive and significant for both the calpastatin activity per sample (r=0.27; P<0.05) and the specific activity (r=0.24; P<0.05).

Carcass weight and fat significantly and negatively correlated with the early post-mortem pH (P<0.05) but not with pHu of the LT (P>0.05) (Table 5.10). The heavier and fatter the carcasses were associated with longer sarcomeres (r~0.45, P<0.01).

Three-hour temperature was highly correlated with hot carcass weight (r=0.71, P<0.001) and total fat content (r=0.96; P<0.001). Correspondingly, 3-hour temperature had similar though stronger correlations with pH and SLs as the carcass weight and fatness.

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Table 5.10 Simple correlations of pH, carcass and chevon quality attributes determined on the *M. longissimus lumborum et thoracis* of South African indigenous goats

	HCW	Carcass	Temp	pH_0	pH_3	pH_6	pH_{24}	SL 24hr	SL 96hr	MFL	MFL	Calpastatin
pH_0	-0.09	-0.27*	-0.35**									
pH_3	-0.41***	-0.43***	-0.61***	0.37**								
pH_6	-0.38**	-0.55***	-0.69***	0.56***	0.78***							
pH_{24}	-0.15	-0.01	-0.18	0.11	0.23	0.23*						
SL 24hr	0.43***	0.45***	0.52***	-0.17	-0.38***	-0.40***	-0.25*					
SL 96hr	0.43***	0.46***	0.57***	-0.25*	-0.51***	-0.54***	-0.34**	0.66***				
GP	0.18	-0.11	0.01	0.08	-0.03	0.04	-0.38***	0.10	0.16	0.07	0.23*	-0.18
Lactate	0.01	-0.03	0.06	-0.12	-0.36**	-0.31**	-0.09	0.06	0.12	0.14	-0.06	0.01
Glycogen	0.106	-0.09	-0.05	0.15	0.12	0.18	-0.35**	0.08	0.10	0.01	0.26*	-0.20
Lactate %	0.08	0.00	0.06	-0.18	-0.26*	-0.26*	0.25*	-0.05	-0.07	0.07	-0.23*	0.08
Glycogen %	-0.10	0.01	-0.06	0.19	0.24*	0.26*	-0.27*	0.07	0.06	-0.07	0.24*	-0.10
Glucose	-0.09	-0.08	0.10	-0.25*	-0.35**	-0.33**	0.06	-0.13	0.10	0.22	-0.18	0.21
Glucose-6-P	0.02	0.00	0.04	-0.02	0.01	-0.01	-0.05	0.03	0.19	-0.03	0.12	-0.04
ATP	0.10	0.19	0.28*	0.06	0.03	-0.12	-0.24*	0.12	0.16	-0.13	-0.01	0.07
CP	0.07	0.30*	0.15	0.11	0.29*	0.08	-0.02	-0.05	-0.08	-0.12	-0.06	-0.13
Calp spec.	0.08	0.07	-0.05	0.03	-0.10	-0.07	0.16	0.10	0.20	-0.07	-0.24*	0.90***
Calpastatin	0.17	0.22	0.22	-0.02	-0.22	-0.20	0.08	0.26*	0.36**	-0.11	-0.17	

Level of significance: * (P<0.05); ** (P<0.01); *** (P<0.001)

HCW = hot carcass weight (kg); SL = sarcomere length (µm); MFL = Myofibrillar fragment length (µm); GP = Glycolytic potential (µmol/g); Glucose -6-P = glucose-6-phosphate (µmol/g); CP = creatine phosphate (µmol/g); Calp spec. = Calpastatin specific activity (U/mg protein); Calpastatin = Calpastatin activity (U/g sample).

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Sarcomere lengths negatively correlated with early post-mortem pH of the LT (-0.54≤ r ≤ -0.38; *P*<0.001) and pHu (-0.25 and -0.34; *P*<0.05) indicating that the degree of sarcomere shortening was low when the rate of pH decline was slow and the pHu attained was low. Early post-mortem pH correlated positively with the initial glycogen percentage and inversely with lactate concentration, lactate percentage and the glucose concentration (*P*<0.05). However, the correlations with GP, the concentration of glycogen and the energy compounds (ATP and creatine phosphate) were mostly not significant (*P*>0.05). Ultimate pH correlations with initial GP, glycogen and ATP concentrations and glycogen percentage were significant and negative (*P*<0.05). pHu significantly and positively correlated with lactate percentage (*P*<0.05) but not lactate concentration (*P*>0.05). The results conformed to the fact that low initial muscle energy reserves and high lactate concentration limit the extent of post-mortem glycolysis

Sarcomere lengths at both ageing periods positively correlated with calpastatin activity per gram sample (*P*<0.05) but not with the specific activity (*P*>0.05). This suggests that the SL–calpastatin relationship was confounded by the extractable protein content, which tended to increase with carcass weight as did SLs. Only the 96-hour MFL correlated with some of the muscle metabolites. Correlations with GP, glycogen, glycogen percentage and calpastatin specific activity were positive but negative with lactate percentage (*P*<0.05).

5.2.1.5 Effect of early post-mortem and ultimate pH on some carcass and meat quality traits measured on the *M. longissimus lumborum et thoracis*

Carcass and meat quality traits that significantly correlated with LT pH_3 and pHu were further analysed for variation with groups created from these two variables (Tables 5.11 and 5.12). Only 22% of the LT were glycolysing so as to attain a pH_3 of less than 6.1 (Table 5.11). The majority of the carcasses (54%) were glycolysing slow such that their pH_3 was above 6.3. The differences between the mean pH values of the two groups were 0.58 (*P*<0.0001) and 0.39 units (P<0.0001) three and six hours post-mortem, respectively. Carcasses with LT pH_3<6.1 were the heaviest (*P*=0.007) and fattest (*P*=0.001) and chilled at a slow rate (*P*<0.0001; Table 5.11). They weighed 22% more, had 54% more fat and a 3-hour temperature that was 5.17°C higher than carcasses with LT pH_3>6.3. The pH_3<6.3 group also had the thickest red and intermediate myofibres (*P*<0.05).

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Table 5.11 Effect of pH_3 on selected carcass and meat quality traits of the *M. longissimus thoracis et lumborum* (means ± S.D.) of South African indigenous goats

	pH_3< 6.1	pH_3 = 6.1 to 6.3	pH_3 > 6.3	*P*-value
N	16	18	40	
pH_3	5.94 ± 0.17^{a}	6.20 ± 0.07^{b}	6.52 ± 0.15^{c}	<0.0001
pH_6	5.91 ± 0.17^{a}	6.06 ± 0.14^{b}	6.30 ± 0.23^{c}	<0.0001
pH_{24}	5.88 ± 0.08^{a}	5.89 ± 0.17^{ab}	5.96 ± 0.14^{b}	0.0394
3-hour temperature (°C)	16.38 ± 3.48^{b}	15.34 ± 4.19^{b}	11.21 ± 4.00^{a}	<0.0001
Hot carcass weight (kg)	15.61 ± 3.06^{b}	14.34 ± 3.49^{ab}	12.82 ± 2.87^{a}	0.0074
Total carcass fat (g)	1 134 ± 331^{b}	1 056 ± 503^{ab}	744 ± 616^{a}	0.0013
Sarcomere length (µm) 24hr	1.84 ± 0.11^{b}	1.84 ± 0.15^{b}	1.75 ± 0.19^{a}	0.0477
Sarcomere length (µm) 96hr	1.86 ± 0.08^{b}	1.80 ± 0.13^{b}	1.70 ± 0.16^{a}	0.0003
Red myofibre area (µm^2)	1 974 ± 565^{b}	1 669 ± 555^{a}	1 745 ± 617^{ab}	0.0468
Intermediate myofibre area (µm^2)	2 524 ± 580^{b}	2 147 ± 505^{a}	2 252 ± 566^{ab}	0.0352
White myofibre area (µm^2)	3 260 ± 786	2 821 ± 517	3 049 ±746	0.0782
Lactate (µmol/g)	36.71 ±13.48^{b}	28.25 ± 5.34^{ab}	27.81 ± 8.81^{a}	0.0420
Glucose (µmol/g)	1.96 ± 0.59	1.65 ± 0.42	1.59 ± 0.47	0.1083
Lactate %	17.13 ± 5.63	15.54 ± 5.99	14.44 ± 4.94	0.4824
Glycogen %	29.56 ± 6.19	31.47 ± 6.67	32.64 ± 5.65	0.3478
Creatine phosphate (µmol/g)	3.33 ± 0.71	3.44 ± 0.63	4.06 ± 1.62	0.0515
Calpastatin activity (U/g sample)	3.46 ± 0.77	3.00 ± 0.87	3.00 ± 1.02	0.3012

[a, b, c] Means within the same row with different superscripts differ significantly (*P*<0.05)

Carcasses of the faster glycolysing group had a lower pHu (*P*=0.039) than those with pH_3> 6.3. The group also had the highest initial lactate concentration (*P*=0.042) and a tendency for low initial creatine phosphate concentration (*P*=0.052), which suggest a high rate of peri-mortem glycolytic activity. Sarcomeres of the group were long, measuring above 1.8µm at both ageing periods. The pH_3>6.3 group had the shortest SLs (*P*<0.05) by at least 0.9µm.

The intermediate group, with pH_3 between 6.1 and 6.3 had intermediate values for most of the meat quality traits except for myofibre areas. The smallest myofibres were associated with this group and not the low weight, slow glycolysing group.

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Although pH_3 significantly correlated with glucose, lactate percentage, glycogen percentage and calpastatin activity, these did not significantly vary with the pH_3 groups defined in Table 5.11 (P>0.05).

An ultimate LT pH of less than 5.8 was attained by 16% of the carcasses while the vast majority (55%) were between pHu 5.8 and 6.0 (Table 5.12). The means of the three pHu groups differed by up to 0.34 units (P<0.0001). A low pHu was associated with longer sarcomeres, higher peri-mortem GP, glycogen and ATP content as well as an intermediate proportion of intermediate myofibres (P<0.05). Carcasses with a high pHu (pH_{24}>6.0) had on average 0.15µm shorter sarcomeres, 27.73µmol/g lower GP, 11.5µmol/g less glycogen, 0.52µmol/g less ATP and 2.36% units less intermediate fibres than carcasses with an LT pHu of 6.0 or less.

Table 5.12 Effect of pH_{24} on selected meat quality traits of the *M. longissimus thoracis et lumborum* (means ± S.D.) of South African indigenous goats

	pH_{24}< 5.8	pH_{24} =5.8 to 6.0	pH_{24} > 6.0	*P*-value
N	12	41	21	
pH_{24}	5.76 ± 0.02^{a}	5.89 ± 0.06^{b}	6.10 ± 0.10^{c}	<0.0001
Sarcomere length (µm) 24hr	1.89 ± 0.16^{b}	1.79 ± 0.17^{ab}	1.74 ± 0.15^{a}	0.0298
Sarcomere length (µm) 96hr	1.85 ± 0.12^{b}	1.77 ± 0.16^{ab}	1.69 ± 0.14^{a}	0.0086
Intermediate myofibre %	32.31 ± 3.28^{ab}	33.57 ± 3.26^{b}	31.21 ± 2.51^{a}	0.0139
White myofibre %	39.25 ± 4.62	39.65 ± 5.12	41.25 ±3.81	0.3957
Glycolytic potential	114.82 ± 15.89^{b}	105.18 ± 21.61^{ab}	87.09 ± 23.68^{a}	0.0041
Glycogen (µmol/g)	37.83 ± 9.90^{b}	34.60 ± 10.35^{ab}	26.36 ± 11.71^{a}	0.0057
ATP (µmol/g)	5.39 ± 0.81^{b}	5.26 ± 0.74^{ab}	4.87 ± 0.77^{a}	0.0329
Lactate %	14.59 ± 5.97	14.62 ± 4.00	17.27 ± 7.83	0.1822
Glycogen %	32.75 ± 6.40	32.47 ± 4.55	29.23 ± 7.83	0.0988

$^{a, b, c}$ Means within the same row with different superscripts differ significantly (P<0.05)

The proportions of white myofibres, lactate and glycogen did not vary with the pHu groups as delineated herein, despite the fact that they significantly correlated with pH_{24} (Table 5.8 and 5.9).

5.2.2 Post-mortem pH, Temperature, Histological and Physical Properties of Chevon as Determined from the *M. Semimembranosus*

5.2.2.1 Effects of sex, age and pre-slaughter conditioning on pH and temperature

Mean pH and temperatures of the SM of carcasses in different sex, age and pre-slaughter conditioning classes are presented in Tables 5.13 to 5.15 and illustrated in Figures 5.8 to 5.10. As was the case with the LT, sex had no effect on SM pH (P>0.140), which dropped by 0.58 units over 24 hours (Table 5.13, Figure 5.8). However, female carcasses cooled at a slower rate such that at three hours post-mortem their mean temperature was a significant 1.34°C higher than that of the intact males (P=0.036).

There were no significant differences in pH (P>0.05) amongst the four age groups (Table 5.14, Figure 5.9). The trends of the pH profiles were similar to those of the LT (Figure 5.2) in that the 2-teeth group tended to have lower values than those of other three groups and at six hour post-mortem, the difference tended to significance (P=0.056). The 2-teeth group had the highest while the 4-to-6 teeth group had the lowest mean temperatures, which differed significantly at three (P=0.046) and 24 (P=0.032) hours post-mortem. Temperature of the milk- and 8- teeth groups were similar but significantly different from the lower and upper means (P<0.05).

Pre-slaughter conditioning significantly affected pH_3 (P=0.008) and pH_6 (P=0.002) readings (Table 5.15, Figure 5.10). At these times, the pH values for pre-slaughter conditioned goats were 0.27 and 0.29 units lower, respectively. All SM temperature readings of the pre-slaughter conditioned goats were significantly higher than those of the non-conditioned group (P<0.05). The final temperature differed by 5.85°C between the two groups.

5.2.2.2 Effects of sex, age and pre-slaughter conditioning on the histological and physical properties

Means, minimum and maximum values of the histological and physical properties of the SM are presented in Table 5.16. The effects of sex, age and pre-slaughter conditioning are shown in Tables 5.17 to 5.19.

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Table 5.13 Effect of sex on pH and temperature (°C) profiles (means ± S.D.) of the *M. semimembranosus* South African indigenous goats

Parameter	Time post-mortem	Sex			*P*-value
		Castrates	Females	Intact males	
pH	15 minutes	6.53 ± 0.33	6.49 ± 0.32	6.60 ± 0.24	0.1401
	3 hours	6.38 ± 0.21	6.31 ± 0.28	6.24 ± 0.32	0.3383
	6 hours	6.19 ± 0.23	6.10 ± 0.21	6.12 ± 0.25	0.2529
	24 hours	5.88 ± 0.14	5.97 ± 0.17	5.97 ± 0.11	0.6460
Temp (°C)	15 minutes	34.88 ± 1.94	35.74 ± 2.05	35.53 ± 2.95	0.3637
	3 hours	16.36 ± 4.31^{ab}	16.59 ± 3.36^{b}	15.25 ± 3.97^{a}	0.0363
	6 hours	9.58 ± 4.92	10.46 ± 3.61	9.43 ± 3.82	0.6383
	24 hours	4.09 ± 4.00	4.42 ± 3.38	3.10 ± 3.08	0.0554

$^{a, b}$ Means within the same row with different superscripts differ significantly (P<0.05)

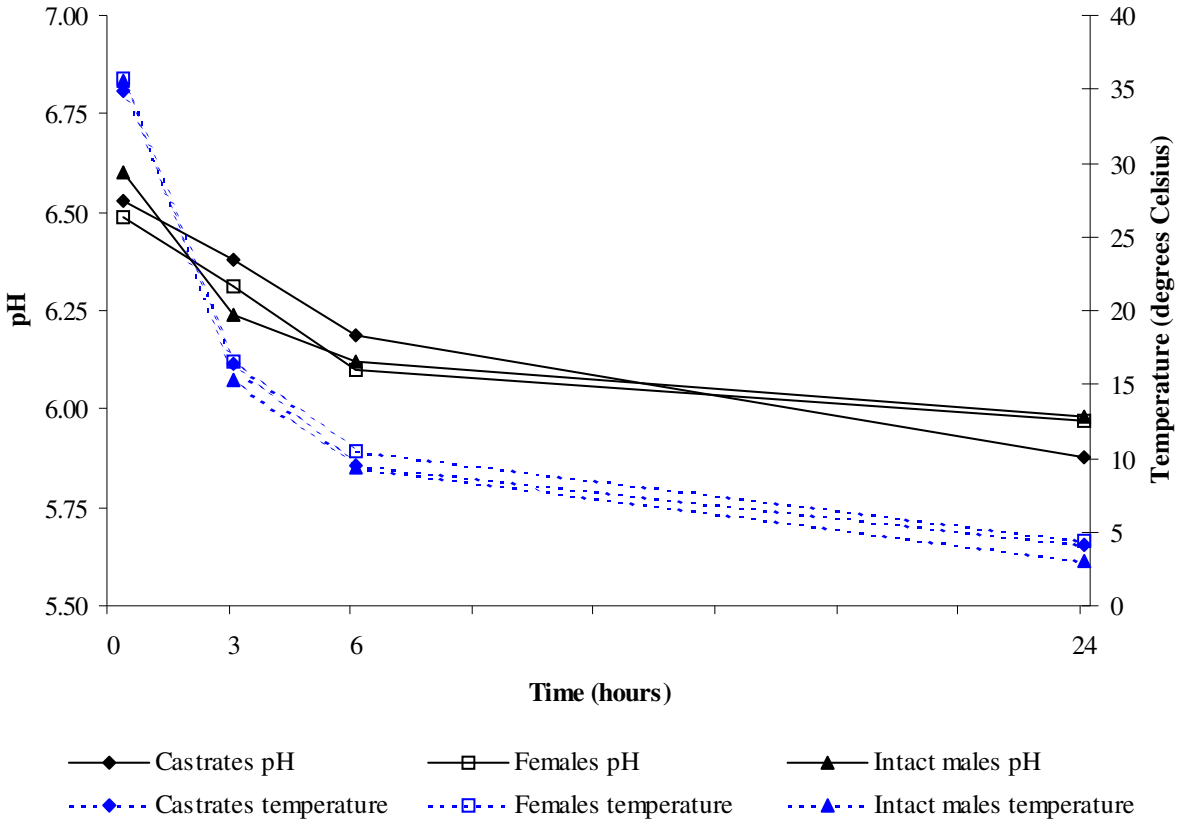

Figure 5.8 Effect of sex on pH and temperature (°C) profiles the *M. semimembranosus* of South African indigenous goats

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Table 5.14 Effect of age on pH and temperature (°C) profiles (means ± S.D.) of the *M. semimembranosus* of South African indigenous goats

Parameter	Time post-mortem	Dentition group				*P*-value
		0 teeth	2 teeth	4-to-6 teeth	8 teeth	
pH	15 min	6.56 ± 0.227	6.41 ±0.32	6.64 ± 0.26	6.65 ± 0.28	0.1120
	3 hours	6.41 ± 0.25	6.23 ± 0.25	6.38 ± 0.24	6.40 ± 0.30	0.1882
	6 hours	6.18 ± 0.18	6.01 ± 0.18	6.31 ± 0.20	6.18 ± 0.24	0.0562
	24 hours	5.96 ± 0.12	5.88 ± 0.15	5.98 ± 0.15	6.01 ± 0.18	0.1423
Temp (°C)	15 min	35.36 ± 3.05	35.94 ± 1.53	35.27 ± 2.23	34.21 ± 2.35	0.1268
	3 hours	14.99 ± 2.81^{b}	18.78 ± 3.42^{c}	13.05 ± 1.85^{a}	15.11 ± 3.53^{b}	0.0464
	6 hours	8.39 ± 2.63^{b}	12.77 ± 3.48^{c}	6.51 ± 2.09^{a}	8.81 ± 4.42^{b}	0.0583
	24 hours	3.74 ± 2.85^{b}	6.34 ± 3.25^{c}	0.55 ± 1.32^{a}	2.58 ± 2.37^{b}	0.0317

$^{a, b, c}$ Means within the same row with different superscripts differ significantly (P<0.05)

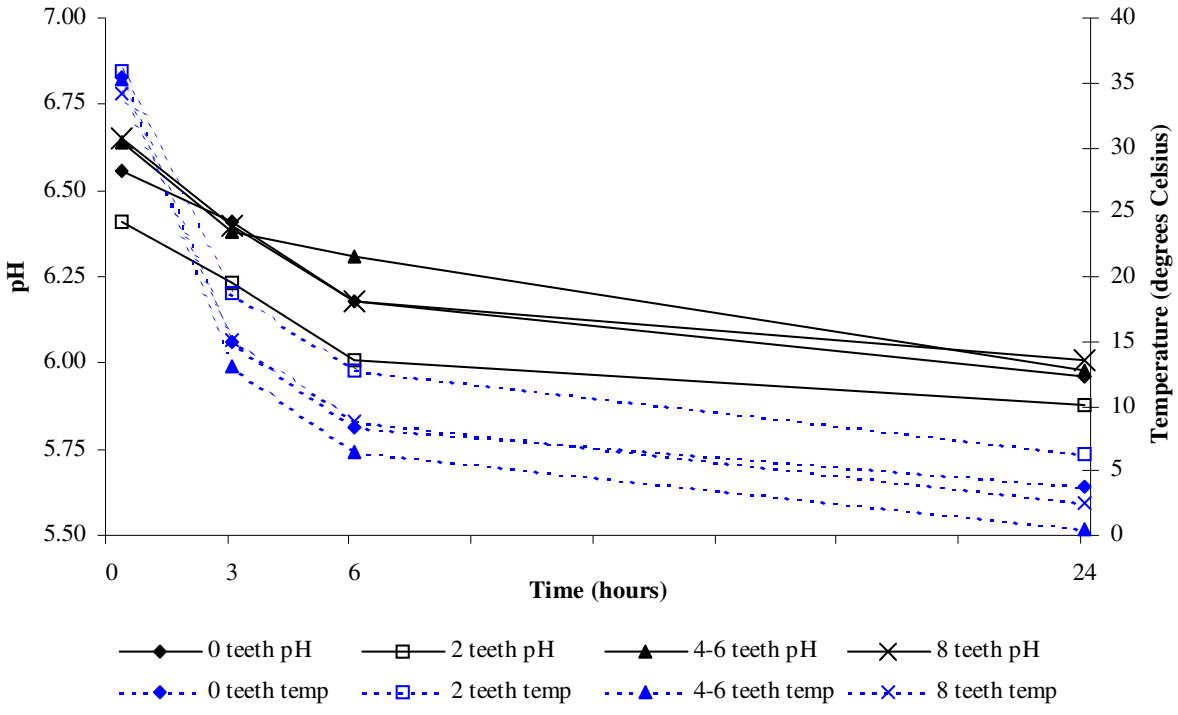

Figure 5.9 Effect of age on pH and temperature (°C) profile of the *M. semimembranosus* of South African indigenous goats

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Table 5.15 Effect of pre-slaughter conditioning on pH and temperature (°C) profiles (means ± S.D.) of the *M. semimembranosus* of South African indigenous goats

Parameter	Time post-mortem	Pre-slaughter conditioning		*P*-value
		Non-conditioned	Pre-slaughter conditioned	
pH	15 minutes	6.61 ± 0.28	6.43 ± 0.31	0.3494
	3 hours	6.44 ± 0.23	6.17 ± 0.24	0.0075
	6 hours	6.27 ± 0.19	5.98 ± 0.15	0.0016
	24 hours	5.93 ± 0.13	5.95 ± 0.18	0.0954
Temperature (°C)	15 min	34.72 ± 2.45	36.24 ± 1.60	0.0492
	3 hours	13.47 ± 2.22	19.53 ± 2.35	<0.0001
	6 hours	6.74 ± 2.13	13.76 ± 2.05	<0.0001
	24 hours	1.36 ± 1.70	7.21 ± 2.23	<0.0001

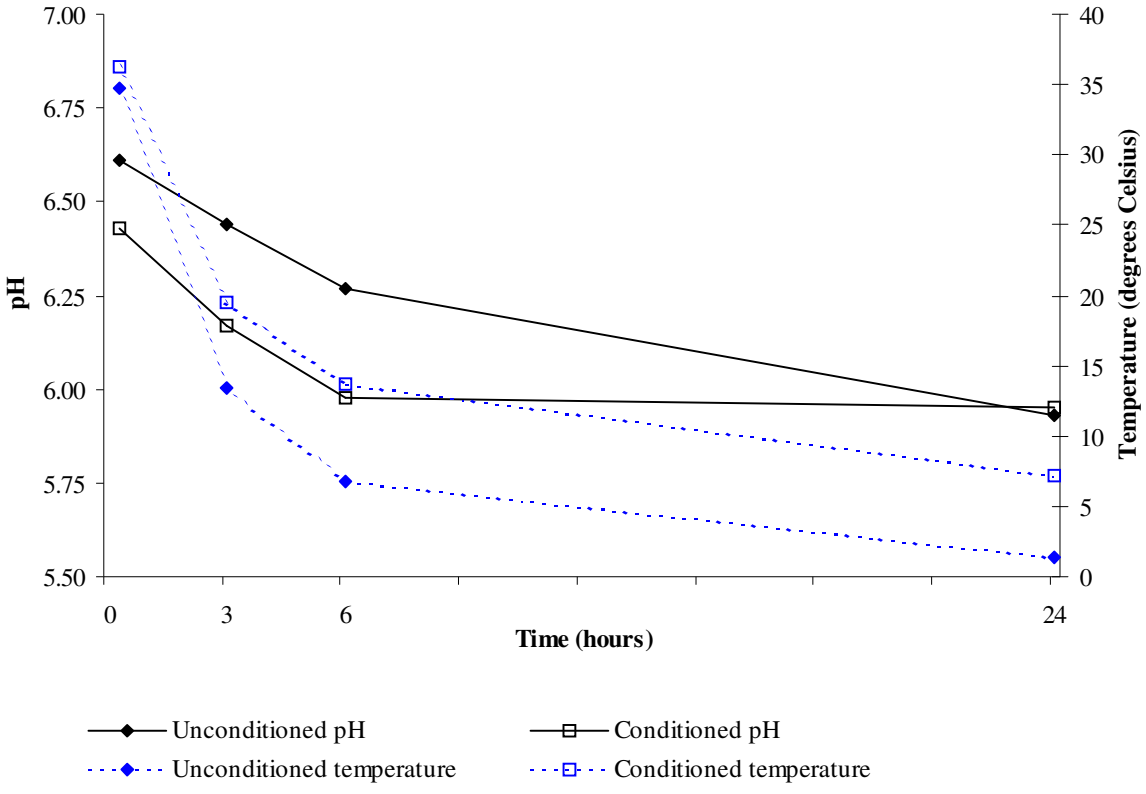

Figure 5.10 Effect of pre-slaughter conditioning on pH and temperature (°C) profile of the *M. semimembranosus* of South African indigenous goats

Table 5.16 Overall means (± S.D.) and range of values of chevon quality attributes that were determined on the *M. semimembranosus* of South African indigenous goats

	Mean ± S.D.	Minimum	Maximum
N	74		
Histological characteristics:			
Sarcomere length (µm) 24hr	1.72 ± 0.16	1.24	2.15
Sarcomere length (µm) 96hr	1.75 ± 0.15	1.25	2.27
Myofibre fragment length (µm) 24hr	17.82 ± 2.26	13.99	23.93
Myofibre fragment length (µm) 96hr	17.06 ± 2.18	12.63	23.64
Physical characteristics:			
% Cooking losses 24hr	32.83 ± 2.19	27.42	38.76
% Cooking losses 96hr	32.29 ± 2.22	26.63	38.59
Shear force (N) 24hr	74.81 ± 17.70	38.37	119.96
Shear force (N) 96hr	66.94 ± 17.21	25.03	113.33
L* 24hr	38.57 ± 2.42	32.71	43.81
a* 24hr	13.78 ± 2.37	4.00	19.32
b* 24hr	9.60 ± 1.52	5.69	12.77
Chroma 24hr	16.88 ± 2.49	10.21	22.54
L* 96hr	38.14 ± 2.29	32.97	43.22
a* 96hr	14.30 ± 2.20	4.99	19.01
b* 96hr	9.72 ± 1.38	5.46	12.00
Chroma 96hr	17.34 ± 2.35	12.08	22.42

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Sarcomere and myofibrillar fragment lengths, cooking losses and shear force values at both ageing periods as well as all the colour co-ordinates at 96 hours post-mortem were similar amongst the three sex groups (Table 5.17). Significant sex effects were in that at 24 hours post-mortem, the intact males had lower a* values (P=0.003) than the castrates and females, and hence a lower chroma (P=0.015) than the castrates only. L* and b* values were not affected (P>0.05). After ageing for 96 hours, the castrates tended to have more tender chevon (P=0.052) than the females and intact males by an average of 3.8N.

As with sex, age effects were mainly on the colour co-ordinates (Table 5.18). The 24-hour a* value for the 2-teeth group was 2.45 to 4.15 units higher than the values of the other three groups (P=0.002). Accordingly, the 2-teeth group had the most vivid colour (chroma =18.49; P=0.003) of the four age groups. Chevon from the milk-teeth group was significantly lighter in colour than that from the 8-teeth group by 2.10 units of L* (P=0.039).

The 2-teeth group tended to have the longest sarcomeres (P=0.092 at 96 hours), with means above 1.8µm, and the lowest 96-hour shear force values by some 10 to 17N (P=0.074). At the other end, the 4-to-6 teeth group had the shortest sarcomeres (1.66 ±0.11µm at 96 hours) while the SM of the 8-teeth group tended to be tough, with a shear force above 75N even after ageing for 96 hours.

Pre-slaughter conditioning had profound effects on the quality traits of the SM (Table 5.19). Even after ageing, the sarcomeres of the carcasses of the non-conditioned goats remained less than 1.7µm and significantly shorter (P<0.0001 at 24 hours) than those of the pre-slaughter conditioned group. Mean SL for the latter group were greater than 1.8µm at both ageing periods. As in all previous cases, the MFL were not significantly affected (P>0.05).

Cooking losses from the SM of the non-conditioned goats were higher than of those from the pre-slaughter conditioned group (Table 5.19). The 2.21% difference at 96 hours post-mortem was significant (P=0.030). The non-conditioned goats had shear force values of 75N or more, even after ageing. These goats were significantly tougher than those of the pre-slaughter conditioned group by about 17N (P<0.0001) at both ageing periods.

Table 5.17 Effects of sex on the chevon quality attributes (means ± S.D.) that were determined the *M. semimembranosus* of South African indigenous goats

	Sex			*P*-value
	Castrates	Females	Intact males	
N	24	35	15	
Histological characteristics:				
Sarcomere length (µm) 24hr	1.68 ± 0.21	1.74 ± 0.19	1.71 ± 0.23	0.8271
Sarcomere length (µm) 96hr	1.72 ± 0.17	1.76 ± 0.18	1.76 ± 0.15	0.4795
MFL (µm) 24hr	17.46 ± 2.22	17.83 ± 2.19	18.84 ± 2.69	0.3596
MFL (µm) 96hr	17.09 ± 2.01	17.30 ± 2.38	16.45 ± 2.66	0.1079
Physical characteristics:				
% Cooking losses 24hr	32.88 ± 2.46	32.65 ± 2.54	33.19 ± 1.18	0.4881
% Cooking losses 96hr	32.60 ± 2.38	31.59 ± 2.59	33.43 ± 1.71	0.0686
Shear force (N) 24hr	73.00 ± 16.58	74.83 ± 19.38	77.62 ± 23.84	0.1261
Shear force (N) 96hr	64.28 ± 17.09	68.24 ± 20.65	67.99 ± 21.59	0.0518
L* 24hr	39.06 ± 1.85	37.79 ± 2.82	39.60 ± 2.28	0.4565
a* 24hr	14.50 ± 2.72^{b}	13.90 ± 3.08^{b}	12.34 ± 3.30^{a}	0.0025
b* 24hr	9.93 ± 1.43	9.40 ± 1.61	9.53 ± 1.39	0.6045
Chroma 24hr	17.60 ± 2.85^{b}	16.87 ± 2.98^{ab}	15.73 ± 2.90^{a}	0.0146
L* 96hr	38.54 ± 1.82	37.59 ± 2.60	38.78 ± 2.61	0.9453
a* 96hr	14.68 ± 2.17	14.29 ± 2.65	13.75 ± 2.68	0.7675
b* 96hr	9.89 ± 1.01	9.48 ± 1.59	10.01 ± 1.00	0.6693
Chroma 96hr	17.72 ± 2.23	17.18 ± 2.91	17.13 ± 1.86	0.6876

$^{a, b}$ Means within the same row with different superscripts differ significantly ($P<0.05$)

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Table 5.18 Effects of age on chevon quality attributes (means ± S.D.) that were determined on the *M. semimembranosus* of South African indigenous goats

	Dentition group				
	0 teeth	2 teeth	4-6 teeth	8 teeth	*P*-value
N	16	32	16	10	
Histological characteristics:					
Sarcomere length (µm) 24hr	1.65 ± 0.25	1.81 ± 0.17	1.59 ± 0.16	1.71 ± 0.16	0.9043
Sarcomere length (µm) 96hr	1.70 ± 0.16	1.82 ± 0.15	1.66 ± 0.11	1.72 ± 0.23	0.0924
Myofibre fragment length (µm) 24hr	17.97 ± 2.73	17.35 ± 2.10	18.82 ± 2.28	17.75 ± 2.00	0.3596
Myofibre fragment length (µm) 96hr	17.00 ± 2.32	17.77 ± 2.53	16.39 ± 1.52	15.83 ± 1.87	0.3426
Physical characteristics:					
% Cooking losses 24hr	33.81 ± 2.39	32.51 ± 1.94	32.24 ± 2.38	33.17 ± 2.74	0.8112
% Cooking losses 96hr	32.97 ± 2.64	31.50 ± 1.77	32.85 ± 2.87	32.85 ± 2.92	0.6228
Shear force (N) 24hr	77.55 ± 24.29	69.27 ± 17.74	79.89 ± 15.89	79.99 ± 18.22	0.6510
Shear force (N) 96hr	70.83 ± 20.12	59.87 ± 20.15	69.75 ± 14.35	77.39 ± 18.54	0.0743
L* 24hr	39.49 ± 2.63	38.23 ± 2.11	39.16 ± 2.76	37.39 ± 2.77	0.4903
a* 24hr	13.11 ± 1.76^{a}	15.56 ± 2.36^{b}	12.42 ± 3.32^{a}	11.41 ± 3.41^{a}	0.0016
b* 24hr	9.45 ± 1.89	9.92 ± 1.48	9.50 ± 1.10	9.00 ± 1.40	0.1215
Chroma 24hr	16.20 ± 2.30^{a}	18.49 ± 2.59^{b}	15.76 ± 2.80^{a}	14.70 ± 2.86^{a}	0.0028
L* 96hr	38.96 ± 2.44^{b}	38.13 ± 2.41^{ab}	38.04 ± 2.43^{ab}	37.07 ± 2.16^{a}	0.0392
a* 96hr	13.65 ± 1.62	13.53 ± 2.15	12.76 ± 2.84	13.78 ± 2.56	0.2535
b* 96hr	9.56 ± 1.30	9.90 ± 1.54	9.75 ± 1.08	9.38 ± 0.97	0.5773
Chroma 96hr	16.69 ± 1.91	18.43 ± 2.53	16.19 ± 2.20	16.70 ± 2.56	0.4334

$^{a, b}$ Means within the same row with different superscripts differ significantly ($P<0.05$).

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Table 5.19 Effects of pre-slaughter conditioning on chevon quality attributes (means ± S.D.) that were determined on the *M. semimembranosus* of South African indigenous goats

	Pre-slaughter conditioning		
	Non-conditioned	Conditioned	*P*-value
N	40	34	
Histological characteristics:			
Sarcomere length (µm) 24hr	1.59 ± 0.17	1.86 ± 0.14	<0.0001
Sarcomere length (µm) 96hr	1.68 ± 0.14	1.82 ± 0.17	0.4918
Myofibre fragment length (µm) 24hr	17.94 ± 2.44	17.70 ± 2.14	0.3553
Myofibre fragment length (µm) 96hr	16.36 ± 1.97	17.85 ± 2.43	0.6435
Physical characteristics:			
% Cooking losses 24hr	33.36 ± 2.60	32.21 ± 1.69	0.0520
% Cooking losses 96hr	33.31 ± 2.33	31.09 ± 2.03	0.0297
Shear force (N) 24hr	82.41 ± 16.06	65.86 ± 19.19	<0.0001
Shear force (N) 96hr	74.95 ± 16.76	57.75 ± 18.78	<0.0001
L* 24hr	39.42 ± 2.35	37.57 ± 2.37	0.0291
a* 24hr	12.62 ± 2.97	15.14 ± 2.63	0.0483
b* 24hr	9.72 ± 1.27	9.46 ± 1.75	0.2963
Chroma 24hr	16.03 ± 2.68	17.87 ± 3.01	0.2616
L* 96hr	38.73 ± 2.26	37.43 ± 2.39	0.0391
a* 96hr	13.18 ± 2.22	15.63 ± 2.15	0.0034
b* 96hr	9.74 ± 1.07	9.69 ± 1.59	0.9901
Chroma 96hr	16.45 ± 2.03	18.40 ± 2.61	0.0340

At 24 hours post-mortem, L* of chevon from non-conditioned goats was greater (P=0.029) and a* smaller (P=0.048) than the corresponding values of the chevon from pre-slaughter conditioned goats. The b* and chroma values did not differ significantly between the two groups (P>0.05). At 96 hours post-mortem, the SM of non-conditioned goats were significantly lighter (P=0.039) by 1.35 units of L* and less red by 1.45 units of a*, and hence had a less vivid colour (P=0.034). The b* values did not differ significantly (P>0.05).

5.2.2.3 Interaction effects of sex, age and pre-slaughter conditioning on histological and physical meat quality properties of the *M. semimembranosus*

A summary of the first order interaction effects that were tested on the histological and physical meat quality properties of the SM is presented in Table 5.20. Significant interaction effects are highlighted.

Age and sex interaction effects on the 96-hour SLs were significant (P=0.011). Milk-teethed castrates had the shortest sarcomeres, while the 2-teeth intact males and females had the longest sarcomeres (Figure 5.11i). The SLs of the 4-to-6 teeth and 8-teeth groups did not significantly from each other or from the lower and upper means (P>0.05). All age groups had similar 96-hour sarcomere lengths within the non-conditioned group (Figure 5.11ii). Pre-slaughter conditioning tended not to have a significant effect on the 96-hour sarcomere length of milk teethed goats but to result in longer sarcomeres of the 2- and 8-teeth groups (P=0.058)

Pre-slaughter conditioning and sex (P=0.021) and pre-slaughter conditioning and age effects (P=0.015) interaction effects on 96-hour shear force values were significant (Figure 5.12). Generally, the shear force values of the pre-slaughter conditioned goats were lower than those of the non-conditioned group but the castrates had significantly the lowest values compared to all other groups (Figure 5.12i). Amongst the different age groups, the 8-teeth group had the highest mean shear force in the earlier slaughtered group but the mean shear force values were similar for all age groups amongst the pre-slaughter conditioned goats (Figure 5.12ii).

Although there were significant pre-slaughter conditioning by age interaction effects on the 24-hour MFL, this is not discussed further because the measurement was highly confounded by the sarcocyst infection of the muscles (§ 5.3.3.1 refers).

Table 5.20 *P*-values of the first order interaction effects on the traits measured on the *M. semimembranosus* of South African indigenous goats

	Interaction effects		
	Age(sex)	Sex*conditioning	Conditioning(age)
pH_0	0.8027	0.1039	0.1513
pH_3	0.7160	0.6322	0.5428
pH_6	0.3121	0.7853	0.7267
pH_{24}	0.8321	0.5561	0.7586
Sarcomere length (µm) 24hr	0.9399	0.9878	0.3926
Sarcomere length (µm) 96hr	0.0108	0.3159	0.0580
MFL (µm) 24hr	0.3189	0.1052	0.0380
MFL (µm) 96hr	0.4722	0.1932	0.1908
% Cooking losses 24hr	0.7357	0.3432	0.8372
% Cooking losses 96hr	0.7785	0.4921	0.9504
Shear force (N) 24hr	0.1696	0.1120	0.1099
Shear force (N) 96hr	0.1051	0.0210	0.0152
L* 24hr	0.8759	0.8890	0.8966
a* 24hr	0.2191	0.2071	0.3414
b* 24hr	0.6172	0.2834	0.6633
Chroma 24hr	0.3279	0.1555	0.4045
L* 96hr	0.3231	0.2095	0.2959
a* 96hr	0.9686	0.7765	0.4820
b* 96hr	0.6790	0.4833	0.5883
Chroma 96hr	0.8253	0.7052	0.5574

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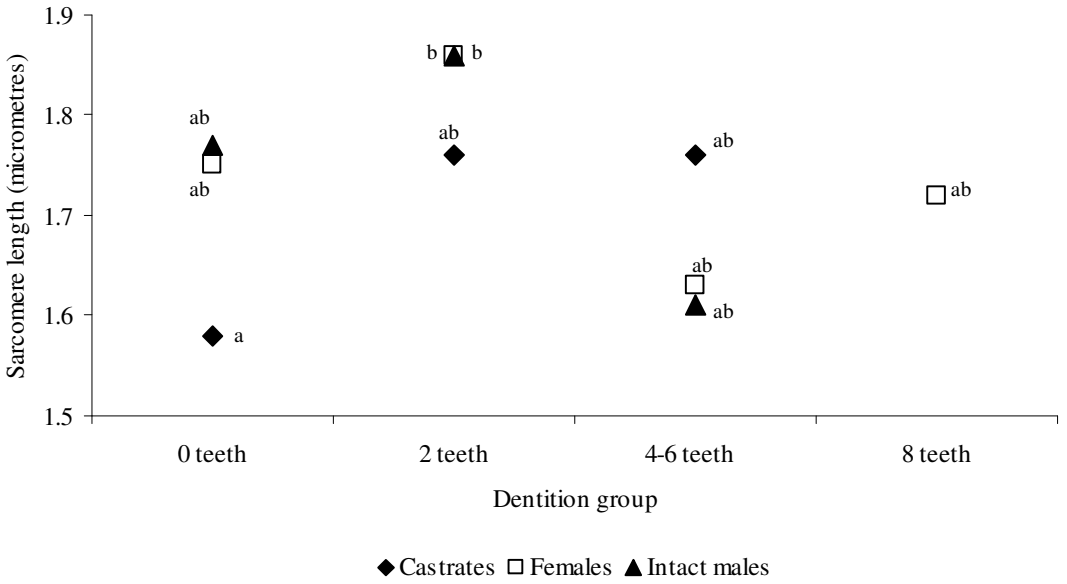
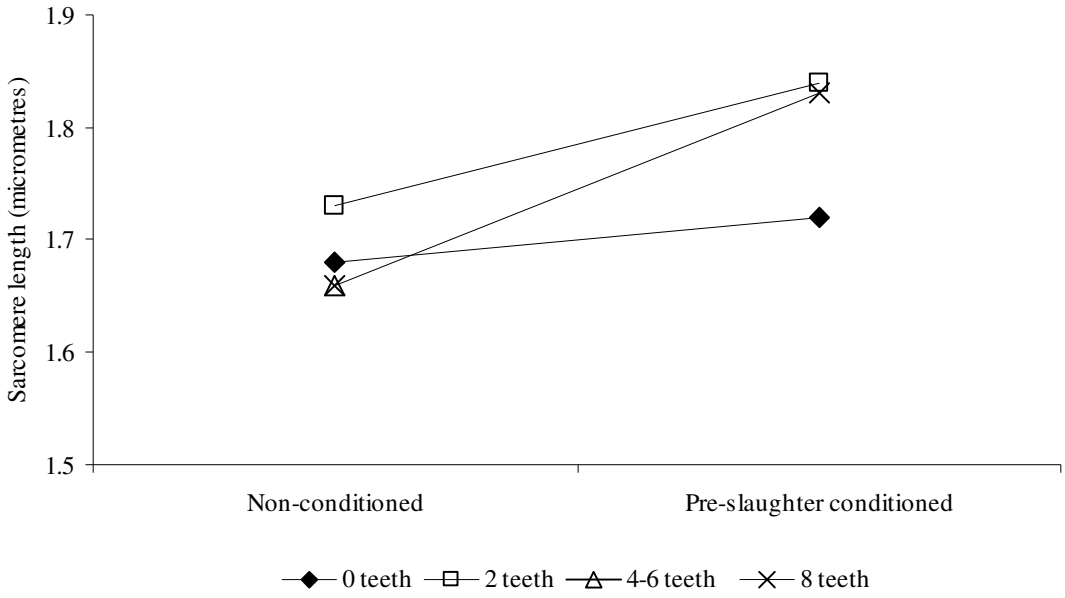
i)

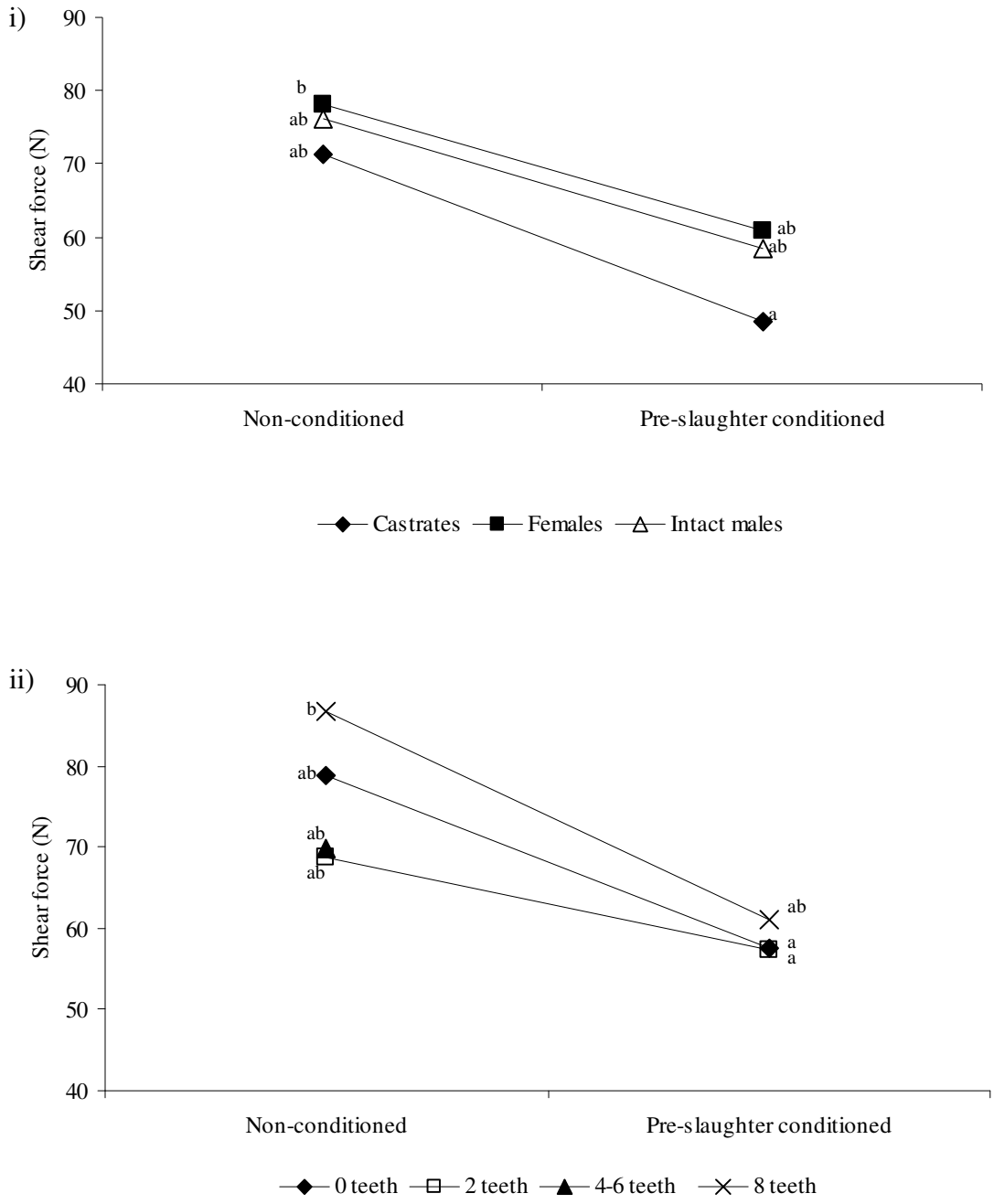


ii)



NB: Points with different letters 'a' or 'b' differ significantly ($P<0.05$)

Figure 5.11 i) Age and sex and ii) pre-slaughter conditioning age interaction effects on the 96-hour sarcomere lengths (µm) of the *M. semimembranosus*



NB: Points within a graph with different letters 'a' or 'b' differ significantly (P<0.05).

Figure 5.12 The i) sex and pre-slaughter conditioning, and ii) age and pre-slaughter conditioning interaction effects on the 96-hour shear force values (N) of the *M. semimembranosus*

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5.2.2.4 Correlations between carcass and meat quality traits of the *M. semimembranosus*

Correlations of myofibre properties with carcass and meat quality traits (Table 5.21) as well as amongst pH, carcass and chevon quality traits (Table 5.22) that were determined on the SM were calculated. Myofibre type correlations were based on only 27 SM samples (§ 3.2 refers).

As was observed with the LTL (Table 5.9), there were high positive correlations between the myofibre areas ($r \geq 0.59$; $P<0.001$) and, the proportion of the white myofibres significantly and negatively correlated with the proportions of the red and intermediate myofibres ($P<0.05$; Table 5.21). Unlike in the LTL, the proportion of the red myofibres negatively correlated with that of the intermediate myofibres ($r=-0.47$; $P<0.05$). Except for the correlation between red myofibre area and white myofibre percentage (r=045; $P<0.05$), correlations between myofibre areas and proportions were not significant ($P>0.05$).

The correlations of the SM myofibre properties with carcass weight and fat content were not in the same order as those observed for the LTL. In the former case, the myofibre areas and not the proportions tended to correlate significantly and positively with the carcass characteristics. For the SM, white myofibre percentage tended to correlate positively with carcass weight ($r=0.40$). There was also a tendency for red myofibre area ($r=0.43$) and proportion ($r= -0.40$) to correlate with carcass fat.

A further contrast was that whereas in the LTL the myofibre areas significantly correlated with early post-mortem pH, in the SM the myofibre proportions only had this relationship ($P<0.05$). The coefficients were negative with the red myofibre, positive with the intermediate myofibre proportions and were of low level of significance ($P<0.1$). There were no significant correlations between pH and white myofibre proportions ($P>0.05$). Correlations of myofibre properties with pHu, sarcomere lengths, cooking losses, shear force values and colour co-ordinates were not significant ($P>0.05$).

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Table 5.21 Simple correlations between myofibre types, carcass and chevon quality attributes that were determined on the *M. semimembranosus* of South African indigenous goats

	Myofibre area			Myofibre %		
	Red	Intermediate	White	Red	Intermediate	White
Red myofibre area (µm^2)						
Intermediate myofibre area (µm^2)	0.79***					
White myofibre area (µm^2)	0.59**	0.70***				
% Red myofibres	-0.32	-0.04	0.17			
% Intermediate myofibres	-0.13	-0.08	-0.27	-0.47*		
% White myofibres	0.45*	0.12	0.06	-0.63**	-0.39†	
Hot carcass weight (kg)	0.29	0.21	0.03	-0.18	-0.22	0.40†
Total carcass fat (g)	0.43†	0.28	0.19	-0.40†	0.08	0.36
pH_0	0.15	0.26	-0.01	-0.35	0.05	0.34
pH_3	0.03	0.01	-0.21	-0.58**	0.38†	0.27
pH_6	-0.06	-0.02	0.18	-0.38†	0.43*	0.01
pH_{24}	-0.09	-0.33	0.01	0.00	-0.17	0.16
Sarcomere length (µm) 24hr	0.10	0.26	0.06	0.01	0.01	-0.02
Sarcomere length (µm) 96hr	-0.05	-0.09	-0.16	-0.06	0.04	0.03
% Cooking losses 24hr	-0.19	-0.01	-0.06	0.31	0.04	-0.37†
% Cooking losses 96hr	-0.33	-0.24	-0.20	0.05	-0.04	-0.02
Shear force (N) 24hr	-0.10	-0.17	0.13	0.17	-0.35	0.12
Shear force (N) 96hr	-0.31	-0.22	-0.03	0.30	-0.25	-0.09
L* 24hr	-0.17	-0.06	-0.24	0.30	-0.17	-0.17
a* 24hr	-0.21	-0.13	-0.27	0.21	0.10	-0.33
b* 24hr	-0.28	-0.10	-0.27	0.18	0.13	-0.32
Chroma 24hr	-0.26	-0.14	-0.29	0.22	0.12	-0.36
L* 96hr	-0.22	-0.11	-0.15	0.16	0.06	-0.23
a* 96hr	0.13	0.33	0.04	-0.06	0.14	-0.07
b* 96hr	0.05	0.26	-0.04	-0.05	0.16	-0.10
Chroma 96hr	-0.06	-0.09	-0.10	-0.17	0.00	-0.18

Level of significance: † (P<0.1); * (P<0.05); ** (P<0.01); *** (P<0.001)

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Carcass weight and fat content negatively correlated with early post-mortem pH (P<0.01) but not with pHu (Table 5.22) of the SM. Correlations between the carcass traits and cooking losses (r=-0.30 to -0.46, P<0.01), shear force values (r=-0.44 to -0.49, P<0.001) and SLs (r=0.34 to 0.53, P<0.01) were comparatively strong. The carcass traits did not significantly correlate with MFL (P>0.05). However they significantly and negatively correlated to L* values (P<0.01), positively to a* and chroma (P<0.05) but were not correlated to b* values (P>0.05).

Early post-mortem pH correlated positively and significantly with 96-hour cooking losses only (P<0.01). Correlations with shear force values were mostly non-significant (P>0.05) except between the 24-hour shear force and pH_3 (r=0.23; P<0.05) and pH_6 (0.29; P<0.05), and between the initial pH and the 96-hour shear force values (r=0.26; P<0.05). Early post mortem pH (pH_3 and pH_6) correlations to SLs were significant (P<0.01), negative and in the relatively intermediate range of -0.30 to -0.38. However, only pH_6 correlated to 96-hour MFL (r=-0.26, P<0.05). Early post-mortem pH correlated positively but weakly to the L* value at 24 hours post-mortem (r=0.30; P<0.01), relatively strongly and negatively to a* values (r=-0.55 to-0.27; P<0.05) and chroma (r= -0.45 to -0.25; P<0.05) but not to b* values (P>0.05).

The correlations between the 3-hour temperature of the SM and hot carcass weight and total carcass fat were 0.64 (P<0.001) and 0.71 (P<0.001), respectively. As such the correlations of temperature to the meat quality traits were similar to the relationships with carcass traits.

Ultimate pH did not correlate significantly with cooking losses or with any of the myofibre linear measurements (P>0.05). The pHu correlated significantly and weakly with the 96-hour shear force value only (r=0.26; P<0.05). Correlations of pHu with colour co-ordinates were all negative and tended to be stronger than those of the early post-mortem pH readings (P<0.01).

Sarcomere lengths did not correlate with the cooking losses and MFL (P>0.05). They negatively correlated with both the 24-hour and 96-hour shear force values (P<0.05). Amongst the colour co-ordinates, SLs positively correlated with the a* (P<0.05) and hence the chroma (P<0.05) values. Only the 96-hour SL and b* values were significantly and positively correlated (r=0.30; P<0.01). There were no significant correlations between SLs and either of the L* values (P>0.05).

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Table 5.22 Simple correlations of pH, carcass and chevon quality attributes that were determined on the *M. semimembranosus* of South African indigenous goats

	Carcass weight (kg)	Carcass fat (g)	Temp (°C) 3hr	pH_0	pH_3	pH_6	pH_{24}	SL 24hr	SL 96hr	Cooking losses 24hr	Cooking losses 96hr	Shear force 24hr	Shear force 96hr
pH_0	0.02	-0.24*	-0.23*										
pH_3	-0.48***	-0.38***	-0.44***	0.31**									
pH_6	-0.46***	-0.60**	-0.67**	0.48***	0.60***								
pH_{24}	-0.13	0.023	-0.21	0.07	0.00	0.08							
SL 24 hr	0.48***	0.54***	0.49***	-0.22	-0.35**	-0.30**	-0.18						
SL 96 hr	0.34**	0.36**	0.42***	-0.19	-0.30**	-0.38***	-0.10	0.35**					
Cooking losses 24h	-0.33**	-0.30**	-0.24	0.02	0.11	0.13	0.09	-0.07	0.17				
Cooking losses 96h	-0.39***	-0.46***	-0.37**	0.19	0.31**	0.34**	0.08	-0.19	0.04	0.52***			
Shear force 24hr	-0.44***	-0.49***	-0.48***	0.23	0.23*	0.29*	0.16	-0.36**	-0.29*	0.21	0.42***		
Shear force 96hr	-0.44***	-0.45***	-0.52***	0.26*	0.16	0.22	0.26*	-0.41***	-0.31**	0.27*	0.42***	0.83***	
MFL 24hr	0.06	0.07	-0.05	0.19	0.00	-0.03	0.16	-0.09	-0.01	0.05	0.20	-0.01	0.10
MFL 96hr	0.05	0.20	0.23	-0.02	-0.04	-0.26*	-0.06	0.06	0.22	0.02	-0.20	-0.15	-0.06
L* 24 hr	-0.38***	-0.45***	-0.34**	0.03	0.21	0.30**	-0.26*	-0.18	-0.02	0.18	0.44***	0.13	0.11
a* 24 hr	0.28*	0.36**	0.62***	-0.38***	-0.44***	-0.55***	-0.40***	0.25*	0.40***	-0.07	-0.29*	-0.41***	-0.41***
b* 24 hr	-0.01	-0.14	0.07	-0.13	-0.03	-0.06	-0.54***	0.00	0.21	0.09	0.09	-0.11	-0.11
Chroma 24 hr	0.23	0.24*	0.52***	-0.34**	-0.35**	-0.45**	-0.49***	0.22	0.39***	-0.02	-0.20	-0.36**	-0.37**
L* 96 hr	-0.34**	-0.35**	-0.16	-0.03	0.09	0.13	-0.30**	-0.15	0.04	0.32**	0.29*	0.03	0.03
a* 96 hr	0.44***	0.53***	0.63***	-0.27*	-0.34**	-0.47***	-0.40***	0.43***	0.52***	-0.09	-0.26*	-0.50***	-0.50***
b* 96 hr	0.11	-0.04	0.17	-0.04	-0.06	0.09	-0.48***	0.14	0.30**	0.16	0.08	-0.22	-0.26*
Chroma 96 hr	0.40***	0.43***	0.56***	-0.19	-0.25*	-0.35**	-0.49***	0.35**	0.48***	-0.01	-0.12	-0.40***	-0.47***

Level of significance: * (P<0.05); ** (P<0.01); *** (P<0.001)

SL = sarcomere length (µm); MFL = myofibrillar fragment length (µm)

Cooking losses positively correlated with shear force values (P<0.001) but did not correlate with MFL (P>0.05). Cooking losses also tended to correlate positively with L*, negatively with a* but not with chroma and b* values.

Shear force values did not significantly correlate with MFL (P>0.05). The values tended to correlate negatively and relatively strongly with a* and chroma values (P<0.01), negatively with the 96-hour b* values (P<0.05) but not to any of the L* values (P>0.05).

Calpastatin activity of the SM was determined for just 27 muscles (§ 3.2.2 refers). The correlations of this calpain inhibitor with shear force values were all non-significant (P>0.05).

5.2.2.5 Effects of early post-mortem and ultimate pH on some carcass, histological and physical meat quality traits measured on the *M. semimembranosus*

Table 5.23 shows the effect of pH_3 groups on the carcass and meat quality traits that significantly correlated with pH_3. As was the case with LTL (Table 5.11), a low proportion (16%) of the SM muscles were glycolysing at a rate fast enough to attain a pH_3 of less than 6.1. A difference of similar magnitude to that obtained for the LTL (0.59 units) occurred between the lower and upper pH_3 group m ns (P<0.0001). At six hours post-mortem, the difference was 0.3 units (P=0.0001).

As was the case with the LTL, low SM pH_3 typically occurred in the heaviest (P=0.003) and fattest (P=0.004) carcasses. The low pH_3 carcasses chilled slowly such that their 3-hour temperature was 5.18°C higher than that of the pH_3>6.3 group. Accordingly they the longest SL 24 hours post-slaughter (P=0.0004), and higher a* values (P=0.006). The lesser values of these traits were associated with the pH_3 > 6.3 group. The latter made up 58% of the SM samples.

Generally carcasses with SM pH_{24} of less than 5.8 had higher colour co-ordinate values, more so the a*, b* and chroma (P<0.01), which denotes a better colour quality (Table 5.24). In addition, they had the lowest 96-hour mean shear force value, which was about 18N (P=0.005) less than the average for the carcasses with a SM pH_{24} of 5.8 or higher. There were however, a few carcasses in this category (20%) compared to the 45% with a pH_{24} between 5.8 and 6.0 and the 35% with a pH_{24} that was greater than 6.0.

Table 5.23 Effect of pH_3 on selected carcass and meat quality traits of the *M. semimembranosus* (means ± S.D.) of South African indigenous goats

	$pH_3 < 6.1$	pH_3=6.1 to 6.3	$pH_3 > 6.3$	*P*-value
N	12	19	43	
pH_3	5.90 ± 0.16[a]	6.20 ± 0.05[b]	6.49 ± 0.17[c]	<0.0001
pH_6	5.92 ± 0.18[a]	6.07 ± 0.20[b]	6.22 ± 0.20[c]	0.0001
Temperature (°C)	20.04 ± 2.43[b]	17.01 ± 4.25[ab]	14.86 ± 306[a]	0.0001
Hot carcass weight (kg)	16.44 ± 3.22[b]	14.81 ± 2.81[b]	12.62 ± 2.78[a]	0.0003
Total carcass fat (g)	1 189 ± 359[b]	1 034 ± 508[ab]	780 ± 603[a]	0.0039
Sarcomere length (µm) 24hr	1.85 ± 0.20[b]	1.78 ± 0.20[b]	1.65 ± 0.19[a]	0.0004
Sarcomere length (µm) 96hr	1.79 ± 0.10[ab]	1.84 ± 0.19[b]	1.69 ± 0.16[a]	0.0023
Shear force (N) 24hr	67.05 ± 18.14	73.41 ± 16.48	77.67 ± 20.55	0.1311
a* 24 hr	15.71 ± 1.99[b]	14.36 ± 2.80[ab]	12.96 ± 3.17[a]	0.0058
Chroma 24hr	18.39 ± 2.19	17.38 ± 2.72	16.25 ± 3.06	0.0691
Cooking losses (%) 96 hr	31.26 ± 1.72	32.37 ± 2.21	32.73 ± 2.61	0.0865
a* 96hr	15.50 ± 2.33	14.73 ± 2.09	13.86 ± 2.55	0.0531
Chroma 96 hr	18.51 ± 2.32	17.34 ± 2.65	16.99 ± 2.44	0.0998

[a, b] Means within the same row with different superscripts differ significantly ($P<0.05$)

5.2.3 Comparison of the *M. Longissimus Thoracis et Lumborum* and the *M. Semimembranosus*

The pH, myofibre properties and calpastatin activity of the LTL and the SM were compared (Table 5.25). No significant differences occurred between the pH values ($P>0.05$) of the two muscles. Both muscles had an initial pH of just over 6.5, which declined by 0.6 units in 24 hours. Although its initial temperature was lower ($P<0.0001$), subsequent readings for the SM were significantly higher than those of the LTL throughout the chilling period ($P\leq0.007$). The LTL had red myofibres that were about 328µm^2 smaller than those of the SM were ($P=0.014$) but the intermediate and white myofibre sizes were similar in size ($P>0.05$, Table 5.26). The proportions of the myofibres in the two muscles were markedly different. The LTL had less of the red and intermediate but more of the white myofibres than the SM ($P\leq0.006$). The average ratios of red: intermediate: white were 26:33:41 in the LTL versus 29:37:34 in the SM.

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Table 5.24 Effect of pH_{24} on selected carcass and meat quality traits of the *M. semimembranosus* (means ± S.D.) of South African indigenous goats

	pH_{24} < 5.8	pH_{24} = 5.8 to 6.0	pH_{24} > 6.0	*P*-value
N	15	33	26	
pH_{24}	5.74 ± 0.03[a]	5.90 ± 0.06[b]	6.10 ± 0.08[c]	<0.0001
Shear force (N) 96hrs	52.57 ± 14.87[a]	70.71 ± 18.91[b]	69.88 ± 20.03[b]	0.0048
L* 24hr	39.33 ± 1.67	38.78 ± 2.22	37.93 ± 3.10	0.2115
a* 24hr	15.83 ± 2.83[b]	13.51 ± 2.99[a]	12.98 ± 2.85[a]	0.0071
b* 24hr	10.46 ± 0.90[b]	9.90 ± 1.15[b]	8.75 ± 1.70[a]	0.0013
Chroma 24hr	19.01 ± 2.66[b]	16.84 ± 2.71[a]	15.75 ±2.79[a]	0.0026
L* 96hr	38.57 ± 2.05	38.58 ± 2.24	37.48 ± 2.61	0.2098
a* 96hr	16.46 ± 1.69[b]	14.12 ± 2.24[a]	13.46 ± 2.52[a]	0.0004
b* 96hr	10.48 ± 0.96[b]	9.91 ± 1.04[ab]	9.19 ± 1.36[a]	0.0094
Chroma 96hr	19.52 ± 1.88[b]	17.23 ± 2.29[a]	16.23 ± 2.33[a]	0.0004

[a, b, c] Means within the same row with different superscripts differ significantly ($P<0.05$)

Table 5.25 Comparison of pH and temperature values (means ± S.D.) of the *M. longissimus thoracis* (LT) and the *M. semimembranosus* (SM) of South African indigenous goats

	Time post-mortem	LT	SM	*P*-value
N		74	74	
pH	Initial	6.54 ± 0.29	6.53 ± 0.31	0.5291
	3 hours	6.31 ± 0.28	6.32 ± 0.27	0.4274
	6 hours	6.16 ± 0.26	6.13 ± 0.22	0.4619
	24 hours	5.93 ± 0.14	5.94 ± 0.15	0.5660
Temperature	Initial	36.19 ± 1.85	35.43 ± 2.14	<0.0001
(°C)	3 hours	13.32 ± 4.44	16.42 ± 3.72	0.0001
	6 hours	8.35 ± 4.18	10.00 ± 3.98	0.0001
	24 hours	3.74 ± 3.89	3.89 ± 3.34	0.0065

Table 5.26 Comparison of myofibre properties and calpastatin activities (means ± S.D.)of the *M. longissimus thoracis et lumborum* (LTL) and the *M. semimembranosus* (SM) of South African indigenous goats

	LTL	SM	*P*-value
N	27	27	
Red myofibre area (µm^2)	2 001 ± 546	2 329 ± 582	0.0411
Intermediate myofibre area (µm^2)	2 651 ± 604	2 826 ± 727	0.5902
White myofibre area (µm^2)	3 392 ± 758	3 730 ± 722	0.2088
% Red myofibre	26.09 ± 3.39	29.07 ± 3.71	0.0062
% Intermediate myofibre	33.41 ± 3.17	37.30 ± 3.21	<0.0001
% White myofibre	40.50 ± 4.25	33.64 ± 4.00	<0.0001
Sarcomere length (µm) 24 hr	1.80 ± 0.16	1.76 ± 0.22	0.0745
Sarcomere length (µm) 96hr	1.76 ± 0.15	1.75 ± 0.17	0.6222
Myofibrillar fragment length (µm) 24 hr	18.16 ± 2.24	17.91 ± 2.35	0.6287
Myofibrillar fragment length (µm) 96 hr	16.86 ± 2.17	16.85 ± 2.31	0.8780
Calpastatin activity (U/g sample)	3.49 ± 0.96	3.83 ± 0.54	0.0523
Extractable protein (mg/g sample)	53.73 ± 9.49	53.58 ± 4.64	0.8339
Calpastatin specific activity (U/mg protein)	0.067 ± 0.022	0.072 ± 0.096	0.3379

Calpastatin activity tended to be higher (P=0.052) in the SM than the LTL, with a difference of 0.36U/g sample between the means of the two muscles (Table 5.26). However, the extractable protein and specific activity of calpastatin were similar between the two muscles (P>0.05).

5.2.4 Effects of Post-mortem Ageing on Chevon Quality

It is evident from the preceding sections that ageing chevon had some effect on the meat quality parameters. Table 5.27 shows that a further 72-hour ageing decreased both the sarcomere and myofibrillar fragment lengths of the LTL (P≤0.021) but only the MFL of the SM (P≤0.001). Cooking losses decreased by only 0.6% but significantly (P=0.026). Shear force values improved by 8.18N (P<0.0001) but the variation remained high (S.D. ~20N) even after the further 72 hours of ageing. The L* values were unaffected but a* (P=0.036) and b* (P=0.062) both improved with ageing resulting in a more vivid colour at 96 hours post-mortem (P=0.031).

Table 5.27 Effects of post-mortem ageing on sarcomere and myofibrillar fragment lengths (µm), cooking losses (%), shear force (N) and colour co-ordinates of South African indigenous goats

Muscle	Trait	Post-mortem ageing		*P*-value
		24 hours	96 hours	
	N	74	74	
M. *longissimus*	SL[†] (µm)	1.79 ± 0.16	1.75 ± 0.15	0.0208
lumborum	MFL[‡] (µm)	18.22 ± 2.20	16.77 ± 2.15	<0.0001
M. *semimembranosus*	SL[†] (µm)	1.75 ± 0.22	1.75 ± 0.17	0.8462
	MFL[‡] (µm)	17.90 ± 2.34	16.75 ± 2.32	0.0011
	Cooking losses %	32.65 ± 2.48	32.06 ± 2.67	0.0257
	Shear force (N)	71.54 ± 20.22	63.36 ± 20.37	<0.0001
	L*	38.24 ± 2.59	38.09 ± 2.33	0.3446
	a*	13.88 ± 2.92	14.44 ± 2.38	0.0358
	b*	9.49 ± 1.53	9.70 ± 1.27	0.0619
	Chroma	16.90 ± 2.86	17.44 ± 2.40	0.0306

[†] SL = sarcomere length

[‡]MFL = myofibrillar fragment length

5.3 DISCUSSION

5.3.1 Post-mortem Metabolic State and pH Profile

The initial pH values in this study were low compared to values that have been reported for lamb (Rashid, Henrickson, Asghar and Claypool, 1983; Solomon, Lynch and Berry, 1986; McGeehin, Sheridan and Butler, 2001), beef (Farouk and Lovatt, 2000; Rhee and Kim, 2001), pork (Offer, 1991; Klont and Lambooy, 1995; Henckel, Karlsson, Oksbjerg and Petersen, 2000) and chevon (Kannan et al., 2003), which usually range between 6.7 and 7.0 within 30 minutes after slaughter. In keeping with the low initial pH, initial glycogen content was low, even for goats with a lower pHu (Table 5.12), and considerably below the optimal minimum of 50µmol/g that is required for sufficient lactic acid production in order to attain a satisfactory pHu (Monin, 1981; Purchas and Keohane, 1997). Kannan et al. (2003) have also published initial glycogen content and pHu values for caprine *M. longissimus*. In that study, only the non-stressed two-year-old

castrates had an initial (15minutes) glycogen content of just over 50µmol/g. The stressed goats had about 50µmol/g muscle glycogen while the values for stressed and non-stressed castrated kids were about 20µmol/g and 40µmol/g, respectively. Contrary to the findings of this study however, the initial pH readings in Kannan et al. (2003) were high and ranged between 6.7 and 6.9 even for the stressed animals with low muscle glycogen. The low immediate post-slaughter glycogen levels observed for the goat carcasses in this study are similar to the levels that have been reported for stressed cattle, which are typically associated with high pHu values (Table 5.28).

Table 5.28 Initial glycogen content (µmol/g sample) and ultimate pH values of the *M. longissimus thoracis* of the goats in the present study compared to some published values for stressed cattle

Species	Glycogen (µmol/g)	Time of sampling	pHu	Source
Goats	32.82	15 minutes	5.93	Current study
Heifers in oestrus	33.7	40 minutes	5.92	Kenny and Tarrant (1988)
Mixed Brown Swiss bulls	14.82	20 minutes	≥6	Sanz et al. (1996)
Mixed Pirenaico bulls	20.78	20 minutes	≥6	Sanz et al. (1996)
Mixed bulls	33.3	Ante-mortem	6.70	Lahucky et al. (1998)
Mixed bulls	22.5	1 hour	6.70	Lahucky et al. (1998)

The pH of living muscle at rest is 7.2 to 7.4 (Puolanne, Reeta Pösö, Ruusunen, Sepponen and Kylä-Puhju, 2002) and it takes glycogenolysis of 26µmol/g of glycogen to produce enough lactic acid to drop the pH of meat by one unit (Kivikari, 1996 as cited by Immonen et al., 2000a; Immonen, Schaefer, Puolanne, Kauffman and Nordheim, 2000b). Premise on these facts and in simplified terms, the drop from pH 7.4 to the mean initial pH of 6.54 would have utilised some 22.36umol/g glycogen. Therefore, goats in this study would have had a mean pre-slaughter glycogen concentration of about 55µmol/g. Such a concentration is much lower than the *in vivo* values that have been reported for bovine, ovine and porcine *M. longissimus*.

The normal resting concentration of glycogen in the LTL of cattle is about 80 to 100µmol/g (McVeigh and Tarrant, 1982; Sanz et al., 1996; Immonen, Kauffman, Schaefer and Puolanne,

2000c). In GP terms, the reported values for *in vivo* bovine LTL range from 137µmol/g to 220µmol/g (Immonen et al., 2000b; Immonen, et al., 2000c). In Immonen et al. (2000b) the pHu values were in the acceptable range of 5.45 to 5.56.

In vivo GP values in higher ranges such as 214 and 276µmol/g (Fernandez, Mågård and Tornberg, 1992) and 150 to 320µm/g, with an average of about 202µmol/g (Miller, Ellis, Bidner, and McKeith 2000) have been reported for porcine *M. longissimus*. In Fernandez et al. (1992) the GP of the pigs dropped by some 20 to 37µmol/g just before slaughter due to the stress associated with lairage, but still remained high enough to lead to pHu values of about 5.4.

Przybylski et al. (1994) reported post-slaughter plateau values, above which any further increase in GP does not improve the pHu, in the range of 87 to 168µmol/g for various porcine, bovine and ovine muscles (including the *M. longissimus*). These GP values were of samples taken 10 minutes after exsanguination. The estimated pHu ranged from 5.47 to 5.87 and the variation in these values seemed to depend more on the muscle/species than the GP content.

In beef cattle, Immonen et al. (2000c) reported GP values in the range of 130µmol/g to 146µmol/g for LTL samples taken within 15 minutes after exsanguination. Yambayamba et al. (1996) obtained 142µmol/g from LL samples taken from heifers off restricted feeding within five minutes after slaughter compared to 171µmol/g from heifers off ad libitum feeding. The pHu values in Yambayamba et al. (1996) were 5.45 and 5.56, respectively indicating that the GP levels were adequately high to sustain a substantial pH decline.

In this study the GP, which averaged 101.74µmol/g, was in the lower end of the ranges reported for beef, pork and lamb that have been discussed thus far. Moreover, it was insufficient for the muscles to develop the acceptable post-mortem acidity of pH 5.4 to 5.7. Rather the low GP resulted in a high mean pHu of about 5.9, which is associated with the dark cutting condition. Even the group of goats with a mean LT pHu below 5.8 (mean GP = 115µmol/g) did not have GP levels that were comparable to normal beef and pork nor a mean pHu value below 5.7.

The initial lactate content in goat LTL (30.19µmol/g) was almost double the 17.6µmol/g obtained by Immonen et al. (2000b) from LTL of heifers, taken within 15 minutes after

exsanguination, and the 15.66µmol/g obtained by Yambayamba et al. (1996) from the LL of heifers sampled within five minutes after exsanguination. The latter workers obtained a similar lactate concentration for the nutritionally stressed heifers (30.18µmol/g) to that reported in the present study. However, due to the higher initial glycogen levels, the glycogen: lactate ratio was 4.63 and much higher than the average 1.09 obtained in this study. For the ad libitum fed heifers in Yambayamba et al. (1996) and the heifers in Immonen et al. (2000c), the glycogen: lactate ratios were 11.47 and 3.46, respectively. In these studies, the balance between the glycogen and lactic acid concentration was evidently sufficient for extensive glycolysis to occur, unlike in the present study.

Vetharaniam and Daly (2000) showed that when glycogen is not limiting, the initial lactate concentration may limit the extent of pH decline by limiting the total change in lactate concentration that can take place before glycolysis is inhibited. The authors showed that a 700% increase in the initial lactate concentration from a basal level of 2.8µmoles can result in a 0.43 units increase in pHu, to 5.96. In the present study, the relationship between lactate concentration and pHu was not as strong as that between the pHu and GP and glycogen. However, there was a tendency for the carcasses with a lower percentage of initial lactate and a higher percentage of initial glycogen to have a lower pHu, and vice versa, suggesting that a high initial lactate concentration impaired the extent of pH decline.

In living cells, the concentration of ATP is about 8–10µmol/g and that of creatine phosphate is 20–25µmol/g (Puolanne et al., 2002). During early post-mortem glycolysis, concentrations of these energy metabolites decline with time while those of glucose and glucose-6-phosphate increase from glycogenolytic activity. Thus, the levels of these metabolites in muscle are an indication of the extent glycolysis at the time of sampling early post-mortem. Consequently the glucose concentration tended to be higher and creatine phosphate lower in muscles that were at an advanced stage of glycolysis peri-mortem than in the slower ones (Table 5.11). Kim, Kim, Lee and Baik (2000) collected muscle samples some 40 minutes post slaughter and recorded concentrations of about 4µmol/g, 1.7µmol/g and 3µmol/g for ATP, creatine phosphate and glucose-6-phosphate, respectively.

From the foregoing, it may be inferred that the limitation to pH decline in this study may have been twofold; due to the low initial GP and to the high initial lactate concentrations. The former is associated with chronic pre-slaughter stress, which occurs earlier in handling, such as transportation, deprivation of food and lairage (Fernandez and Tornberg, 1991; Yambayamba et al., 1996). It has bee been shown that goats are highly susceptible to these stressors (Kannan, Terill, Kouakou, Gelaye and Amoah 2002b). High lactate concentration immediately after slaughter is associated with acute pre-slaughter stress, occurring during the handling between the lairage and the stunning area (Fernandez and Tornberg, 1991; Yambayamba et al., 1996). It thus appears that the goats in this study suffered both chronic and acute stress.

Oddly, the initial glycogen and GP values were similar between the non-conditioned and pre-slaughter conditioned groups suggesting that, if better nutrition improved the glycogen reserves in goat muscles, it did not boost their tolerance to stress. This is in contrast to findings such as by Warner et al. (1998), Pethick et al. (2000) and Immonen et al. (2000a) in which improved nutrition not only increased muscle glycogen store but protected the animals against pre-slaughter stressors so that the animals off the better diets had higher initial glycogen levels post-slaughter and lower pHu. Fernandez and Tornberg (1991) suggest that highly stressful conditions prior to slaughter may nullify any differences in stored glycogen. They reached this conclusion after reviewing the results of Beecher, Cassens, Hoekstra and Briskey (1965, as cited by Fernandez and Tornberg, 1991), in which, contrary to expectation, seven porcine muscles of different metabolic types were found to have similar glycogen content. All these muscles had a low initial pH of less than 6.4, which was indicative of substantial glycolysis prior to sampling. Similarly, after finding that short term feed depravation had no effect on the plasma concentration of cortisol but isolation without visual contact did, Kannan et al. (2002b) suggested that unfamiliar environment might have been a more potent stressor to goats than feed depravation.

Although Kannan et al. (2002b) showed the effect of new environment and feed depravation on plasma concentrations of cortsiol and other blood metabolites, the study did not include the impact of these stressors on the muscle glycogen metabolism. It therefore remains to be proved whether low GP is intrinsic to caprine *M. longissimus* and/or is a consequence of an acute response to pre-slaughter stress. The former possibility is intimated by the lack of effect of pre-

slaughter conditioning on the GP of the goats in present study as well as the results of Kannan et al. (2003), in which the non-stressed goats had low glycogen content compared to the values that are considered ideal for a satisfactory pHu.

High pHu values for goat muscles are prevalent in literature (Table 2.6). In view of the fact that such a high incidence of high pH meat often occurs amongst temperamental animals such as young bulls and heifers on heat (Tables 2.10 and 5.28) and boars (Fernandez and Tornberg, 1991), the chevon pHu values suggest that goats are generally highly prone to stress. The peri-mortem biochemical changes occurring in muscles as reported herein and by Kannan et al. (2003) and in the blood (Kannan et al., 2002b) verify this suggestion. Additionally, the fact that there are reports of chevon with normal or close to normal pH values, such as the feral goats of Hogg et al. (1989), the Boer x Angora of Dhanda et al. (1999) and the older goats of Kannan et al. (2003) precludes the notion that high pHu is an intrinsic characteristic of the species. This is further attested to by the fact that goat carcasses with lower pHu have better values of tenderness indices such as SL and shear force (Table 5.12 and 5.23) and a better colour (Table 5.23) than those with high pHu. However, it is not clear why goats are so susceptible to pre-slaughter stress. A possibility is what Hopkins and Fogarty (1998) refer to as a 'genotype effect on animal behaviour', which implies that the excitable nature of goats predisposes them to yielding high pH meat.

The concentrations of the glycolytic metabolites observed in this study show that the high chevon pHu is a consequence of both the limited GP at slaughter and high glycolytic activity peri-mortem. This outcome did not seem to be dependent on the sex, age or pre-slaughter conditioning of the goats. However, mature does (the 8-teeth group) had a high pHu and tendency for a lower GP than the younger goats, suggesting that the older goats are more prone to pre-slaughter stress than the younger animals. From the results of Brown et al. (1990) in which cows had the second highest incidence of dark cutting beef to bulls; Warner, Truscott, Eldridge and Franz (1988) in which the older cattle had a higher pHu than the younger animals, and the survey conducted by Tarrant (1981), it seems that it is not uncommon for mature females to yield high pH meat.

The foregoing shows that the biochemical pathways that lead to the high pHu of chevon merit further research. Such research would be useful not only for chevon production but also for other meats, such as lamb/mutton (Hopkins, Fogarty and Menzies, 1996; Gardner et al.; 1999), for which breed differences in pHu have been observed.

5.3.2 Myofibre Types of Chevon

5.3.2.1 Myofibre profiles of the *M. longissimus thoracis et lumborum* and the *M. semimembranosus*

The myofibre profiles of caprine LTL and SM differ from those of the conventional meats, lamb and beef. Using the SDH method, Pinkas, Marinova, Tomov and Monin (1982) obtained a *longissimus* profile of 40%, 34% and 28% red, intermediate and white myofibres for 30 weeks old lambs. For the same muscle, Ceña et al. (1992) obtained a profile of 66% oxidative (red and intermediate) and 34% non-oxidative (white) myofibres for three months old lambs, using the NADH tetrazolium method. For the SM muscle, and using the ATPase and NADH dehydrogenase staining techniques, Aalhus and Price (1991) reported a profile of 39%, 45% and 21% for lambs that were between 27 and 36kg. Older/heavier lambs seem to have predominantly more intermediate fibres. For example, Hawkins, Moody and Kemp (1985) used the ATPase method and reported red, intermediate and white myofibre percentages of 5-10, 52-65 and 25-35 in the *M. longissimus* and 10-20, 47-60 and 26-40 in the SM for lambs between 32 and 50kg.

Reported bovine profiles are dominated by the white myofibres as shown by the following examples. Hunt and Hedrick (1977) reported red, intermediate and white myofibre percentages of 29, 25 and 46 for *M. longissimus*, 16, 33 and 51 for outer SM, and 12, 28 and 61 for inner SM of steers. The myofibre typing was based on ATPase staining. Employing the same method, Johnston et al. (1981) obtained a similar *M. longissimus* profile to Hunt and Hedrick (1997) for steers and heifers (29%, 22% and 49%, red, intermediate and white myofibres, respectively). In that study, the *semimembranosus* profile averaged 20%, 31% and 49%. Seideman et al. (1986) used SDH dehydrogenase to typecast *M. longissimus* myofibres of bulls and steers. The resultant average profile for the 16 month old cattle was 25%, 23% and 52% red, intermediate and white myofibres. More recently, Ozowa, Mitsuhashi, Mitsumoto, Matsumoto, Itoh, Itagaki, Kohno and Dohgo (2000), obtained an average profile of 27% red, 18% intermediate and 55% white myofibres for Japanese Black steers *M. longissimus*.

The cited results underscore the diversity of myofibre proportions between and within muscles; amongst different species, age and sex as well as with the method of myofibre typecasting that was used. They show that goats are indeed a unique species and hence there should be a move from the common view of chevon as an alternative to lamb and mutton. They also serve to show that the *M. longissimus* and the SM differ histochemically. Therefore, any inferences based on one of the muscles should be extended to the other with caution, if at all.

5.3.2.2 Sex, age, pre-slaughter conditioning and interaction effects on myofibre properties

The changes in the myofibre profile of intact male goats were in accordance with the changes reported for bulls (Jurie et al., 1995; Brandstetter et al., 1998a); that early growth is characterised by an increase in glycolytic activity and ageing by a decline in glycolytic and increase in oxidative activities. Histologically, this is manifest by an increase in white myofibres accompanied by a decrease in the red and/or intermediate myofibres in young animals and the reverse situation in older animals (Ashmore et al., 1972; Brandstetter et al., 1998a). The surge of androgens at puberty stimulates the ageing effect of a decline in glycolytic activity and an increase in oxidative activity (Young and Bass, 1984; Jurie et al., 1995; Brandstetter et al., 1998a). In the present study, indications are that the reconversion to oxidative metabolism may have occurred between the first pair of permanent incisors and the 4-to-6 teeth stages. Reconversion reportedly occurs earlier in intact males than in females and castrates. In fact, the reconversion did not occur at all in the female goats herein. Instead, after the initial proliferation between the milk and 2-teeth stages, the white myofibre count remained more or less fixed to the full mouth stage. Such persistence of the juvenile-like pattern of myofibre proliferation is in concordance with the fact that the females are later maturing compared to intact males (Jurie et al., 1995).

The changes in the myofibre population of the castrated males have been reported previously. Pinkas et al. (1982) also reported a decrease in the white myofibre percentage associated with an increase in the red myofibre percentage in male lambs between 22kg and 30kg. That study did not however include the changes that occur thereafter. The decline in the white myofibre proportion with increase in age/weight is contrary to the results of Moody, Kemp, Mahyuddin, Johnston and Ely (1980) and to some of the sheep breeds and sex groups studied by Hawkins et al. (1985). The white myofibre percentage in the SM of the Suffolk x Rambouillet crossbreeds in

Hawkins et al. (1985) continually decreased in white myofibre percentage between 32 and 50kg, but unlike the castrated goats of the present study, there was no reversion to a higher glycolytic state. According to Hawkins et al. (1985) and Jurie et al. (1995) the early decline in glycolytic myofibres and increase in oxidative activity are associated with delayed physiological maturation in animals. Therefore, one may infer that castration delayed the physiological maturation of the goats to a rate that is lower than that of the female goats during the first year of growth (up to the 2-teeth stage).

Whereas in earlier studies with cattle and sheep, improved nutrition was associated with changes in myofibre proportions, particularly an increase in the white and a decrease in the red myofibre percentages (Moody et al., 1980; Johnston, et al., 1981; Brandstetter et al., 1998b), in the present study improved nutrition resulted in an overall slight increase in the proportion of the intermediate myofibres only. There were no sex by pre-slaughter conditioning interaction effects of the myofibre proportions. However, the myofibres of the intact males all enlarged remarkably between the non-conditioned and pre-slaughter conditioned goats. The increase was consistent with the perception that androgens not only affect myofibre proportions within the muscle but also have an anabolic effect on all myofibre types (Seideman et al., 1986; Harrison, Rowlerson and Dauncey, 1996; Brandstetter et al., 1998b). In contrast, there were virtually no changes in myofibre area of the female and castrated goats with pre-slaughter conditioning.

Contrary to Seideman and Crouse (1986) who reported that a low energy diet resulted in a higher percentage of red myofibres and larger white myofibres, the greatest increase as a result of pre-slaughter conditioning was in the red and the least in the white myofibre areas of the intact males. Therefore androgens not only decreased the proportion of the white myofibres with the age of the intact males but, with improved nutrition, also enhanced the enlargement of all and more so the red myofibres.

Generally, the myofibres of the intact males appear more sensitive to nutrition than those of castrates are (Brandstetter et al., 1998b). This is probably because the former have a higher propensity to deposit lean than the castrates and females (§ 4.2.2 refers). On an improved plane of nutrition, castrates' propensity for growth changes from muscle to fat sooner than in intact males (Hawkins et al., 1985).

5.3.2.3 Relationships between myofibre types, carcass characteristics and meat traits

As in Seideman and Crouse (1986) and Seideman et al. (1986), all myofibre areas positively correlated to hot carcass weight. However whereas in Seideman et al. (1986) stronger correlations were between the white and intermediate myofibre areas and carcass weight, in this case the red and intermediate myofibres had stronger correlations with carcass weight than the white. Correspondingly myofibre areas (more so the intermediate) negatively correlated to early post-mortem pH, implying that the carcasses with the thicker LTL myofibres were the heavier ones which had a faster rate of post-mortem glycolysis and were therefore not subject to cold shortening and hence had longer sarcomeres. Another point of diversion from the results of Seideman et al. (1986) is that in the present study, the area of the intermediate rather than the percentage of the white myofibres positively correlated to the carcass fat content.

The respectively positive and negative correlations of the white and intermediate myofibre percentages with the pHu of the LTL were peculiar. A negative correlation between intermediate myofibres and pHu was also obtained for bovine LT by Ozawa et al. (2000). These observations are contrary to the fact that a high proportion of intermediate myofibres is associated with high pHu, and hence the dark cutting condition in cattle (Hunt and Hedrick, 1977; Young and Foote 1984). Generally, in beef, a higher proportion of oxidative rather than the glycolytic (white) myofibres is associated with susceptibility to the dark cutting condition (Seideman et al., 1986; Zerouala and Stickland, 1991). In this study however, the dark cutting condition would be associated with a high proportion of white myofibres and a low proportion of the intermediate myofibres for the LTL.

Further analysis showed that LTL with a pHu between 5.8 and 6.0 had the highest proportion of intermediate myofibres while those with less than 5.8 had an intermediate percentage and those with a pHu greater than 6 the least. The variation of the white myofibre percentage with the pHu groups was not significant but there was a trend of increase in the white myofibre percentage increase in pHu. Other positive relationships between myofibres and meat quality were between white myofibre area with calpastatin activity and intermediate myofibre percentage with calpastatin activity (both positive). No explanation can be forwarded for these trends.

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Attempts have been made to predict carcass and meat quality traits of lamb from the histological and histochemical properties (Valin, Touraille, Vigneron and Ashmore, 1982; Vigneron, Nougues, Bacou, Valin and Ashmore, 1984) but the results were not promising. In general, relationships were established between myofibre type and sensory measure of juiciness and flavour but not tenderness (Calkins, Dutson, Smith, Carpenter and Davis, 1981). There has been reports of a significant influence of myofibre types on the shear force values of aged beef (Geesink, Koolmees, van Laack and Smulders, 1995) but these have not always been repeatable (Wegner, Albrecht, Fielder, Teuscher, Papstein and Ender, 2000; Ozawa et al., 2000). Thus, it seems that myofibre types are not ideal for predicting meat quality. Taylor (2001) suggests that myofibre bundle size would be more effective in differentiating meat of different tenderness than myofibre types as such.

5.3.3 Tenderness, Cooking Losses and Colour

5.3.3.1 Myofibrillar fragment lengths and calpastatin activity

Myofibrillar fragment lengths of both the LTL and the SM were much shorter than the 23.2 to 26.7µm obtained for bovine *M. longissimus* by Scheepers (1999) after ageing for up to three days and the 32 to 34µm obtained for bovine *M. longissimus* aged for a day (Dalle Zotte et al., 2000). The goat MFL were however comparable to those of bovine *M. longissimus* that was aged for 7 to 14 days (Scheepers, 1999).

Although MFL is a measure of the degree of proteolysis, the short fragments herein were not consistent with the high shear force values. In fact, the MFL did not correlate significantly with the shear force values or with the calpastatin activity, implying that they were not an indication of the degree of post-mortem proteolysis in this case. The short myofibrillar fragments were likely caused by the high degree of sarcocyst infection of the muscles. At least 44 LTL and 55 SM of the 74 goats were mildly to heavily infected with sarcocysts. The sarcocysts caused myofibres to clump together (Figure 5.13) and in the worse cases, only a few fragments, which could not have been truly reflective of the extent of proteolysis, were free for measurement. Despite the confounding effects of the infection, MFL of both muscles were shorter after ageing.

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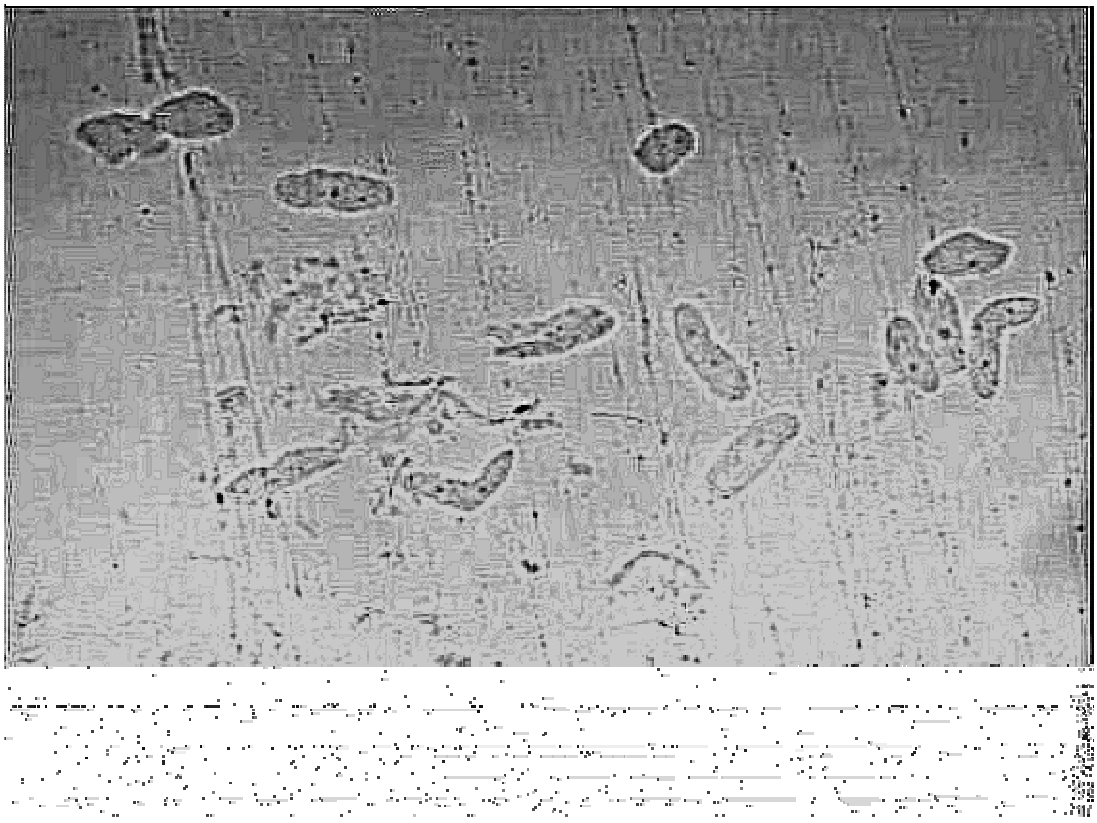

Figure 5.13 Sarcocyst infection in muscle prepared for myofibrillar length determination and viewed under a visual image analyser (40x magnification)

Ruminants are intermediate hosts of sarcocysts and are infected by ingesting the sporocysts while grazing (Levine, 1985). In the intermediate host, the cysts develop through stages in the endothelial cells of the small blood vessels to a final generation, the sarcocysts, in the striated muscles (Levine, 1985). Most sarcocysts are not pathogenic to the intermediate hosts or to their predators (Levine, 1985). Therefore, there are no recognisable symptoms of infection, except detection of the sarcocysts through histological examinations.

Tentatively, goats the calpastatin activity of the LTL of goats is comparable to that reported for beef and lamb. For instance, in a multi-species trial, Koohmaraie et al. (1991a) reported immediate post-mortem activities of 2.45U/g sample for lamb and 4.15U/g sample for beef within 30 minutes of slaughter. In later studies lower within-30-minutes of slaughter activities, such as 3.28 U/g sample for bulls and 2.24U/g for steers (Morgan et al., 1993a) and 2.8U/g sample for steers (Ilian et al., 2001) were reported for *M. longissimus*. Values for lamb tend to be

around 2.8 to 2.9U/g sample for *M. longissimus* samples taken within 30 minutes of slaughter (Ilian et al., 2001; Delgado, Geesink, Marchello, Goll and Koohmaraie, 2001). A value similar to the LTL mean in the present study (3.18±0.81U/g sample) was obtained by Koohmaraie, Shackelford, Wheeler, Lonergan and Doumit (1995b; 3.2U/g sample) within 30 minutes of slaughter. Higher 24-hour activities of 4.3 to 4.5 U/g sample were reported for Coopworth lambs (Geesink, et al., 2001).

Undoubtedly, the large variation amongst the different works is due to the methods and conditions of experimentation and the species and breed effects. However, the various activities cited suffice to show that at slaughter, chevon has a proteolytic capacity within the range of the normal conventional meats, as opposed to the limited potential such as that of callipyge sheep. In the latter case, reported calpastatin activity ranges between 5U/g and 6U/g sample in *M. longissimus* (Koohmaraie et al., 1995b; Delgado et al., 2001). In a study involving several breeds of cattle and using much a similar method of calpastatin determination as was used in the present study, Shackelford et al. (1994a) obtained mean 24-hour calpastatin activities in the range of 2.49 to 3.15U/g sample. The range of values in that study was 1.2 to 5.4U/g sample and compares very well to the range of initial calpastatin activity of the goats in this study (Table 5.4). It is worth noting that calpastatin samples were taken when the LT muscle pH was about 6.5; before calpastatin degradation commenced (Dransfield, 1993). Therefore, the values obtained should be close to the in vivo concentrations of the enzyme inhibitor. Thus, at most, goats have similar but most likely lower calpastatin content than cattle. The level of activity observed herein suggests that any toughness in goat meat is not due to excessive calpastatin content as is the case with callipyge sheep (Koohmaraie et al., 1995b) or animals administered β-adrenergic antagonists (Koohmaraie et al., 1991b). Rather, chevon toughness is possibly due to factors such as the conditions under which the post-mortem proteolysis takes place, the extent of myofibre contraction and the connective tissue contribution.

Calpastatin activity did not vary with age or sex of the goats. Ou, Meyer and Forsberg (1991) also found no sex or age effects on initial calpastatin activity. The higher calpastatin activity in pre-slaughter conditioned goats was likely a result of a general increase in the extractable proteins with pre-slaughter conditioning rather than an increase in the concentration of calpastatin as such. This is evident from that the extractable protein was higher in pre-slaughter

conditioned goats but the specific calpastatin activity (Units per mg of extractable protein) was not affected. Similarly, the relationship between calpastatin activity and early post-mortem pH as well as SL (Table 5.10) is likely to be due to the differences in the extractable protein content between the heavy and light carcasses rather than a specific association of these traits with proteolytic activity.

Despite that some workers have found that initial calpastatin activity is an indication of the proteolytic potential of the meat (e.g. Goll et al., 1998; Sensky et al., 2001), in this study the calpastatin activity was not related to shear force values at either ageing period. The lack of correlation between calpastatin and glycolytic metabolites suggest that there were no stress-induced changes in calpastatin activity, such as was reported by Sensky et al. (1996) and Parr et al. (2000). A better understanding of the contribution of calpastatin to meat tenderness might be obtained by measurement of temporal changes of the activity of this enzyme and the calpains (Delgado et al., 2001). However, the cost of such experimentation was beyond the financial scope of this study.

5.3.3.2 Sarcomere lengths and effects of early post-mortem glycolysis

The overall mean SLs of both the LL and SM of the goats in this study fell in the range that is associated with intermediate tenderness (1.7 to 2.0µm) as delineated by Marsh and Leet (1966). However, when grouped according to early post-mortem pH, the carcasses that had a pH_3 of less than 6.1 (at which cold shortening was unlikely to occur) had the longest sarcomeres and tended to have a lower shear force at 24 hours post-mortem. The differences in tenderness amongst the pH_3 groups were probably resolved by proteolysis during further ageing (Geesink et al., 1995; O'Halloran et al., 1997b) and hence there was no correlation between the 96-hour shear force and early post-mortem pH of the SM. The increase gains in tenderness fromm producing beef with a pH_3 of about six , along with the detrimental effects of pH_3 values above 6.3 have been reported (Martin et al., 1983; Marsh et al., 1987; Smulders et al., 1990; Pike et al., 1993; O'Halloran et al., 1997b).

A fast rate of post-mortem glycolysis has often been associated with elongated sarcomeres (Smulders et al., 1990; O'Halloran et al., 1997b). The exact nature of the relationship between SL and tenderness in these instances has not been elucidated. Although the correlations between

the two parameters were highly significant, in the current study (Table 5.22), the degree of the relationship differed amongst the pH_3 groups (Figure 5.14). For carcasses with pH_3<6.1, there was virtually no relationship (Figure 5.14i and ii) between 24-hour SL and 24- and 96-hour shear force values. However, contrary to Smulders et al. (1990) there was a strong negative linear relationship between SL and shear force for carcasses with pH_3 6.1 to 6.3 (Figure 5.14iii), which was even stronger for muscles aged for 96 hours post-mortem (Figure 5.14iv). Whereas this relationship was very strong (r=0.84) for carcasses with a pH_3>6.3 in Smulders et al. (1990), it was very weak for the goat carcasses in the same category and unaffected by ageing (Figure 5.14v and vi).

While in Smulders et al. (1990) and O'Halloran et al. (1997b) there were no significant differences in the temperature of the beef carcasses, and hence the differences in tenderness were explained in terms of the effect of pH on the endogenous proteolytic enzymes, in this case temperature played a considerable role in tenderness differences. Carcass weight and fatness heavily influenced the rate of temperature and, hence pH decline and the extent of sarcomere contraction. The lightweight and leaner carcasses which were slow glycolysing (pH_3>6.3), evidently underwent cold shortening (mean 24-hour SL = 1.65µm) and hence the toughness. According to Swartz, Greaser and Marsh (1993), at 1.7µm or less, sarcomeres are short enough that the A band touches the Z line and hence the meat is tough due to the lack of an I band region which is normally where the myofibres break when the meat tenderises.

It is noteworthy that the temperature effect would have explained some 27% of the variation in the tenderness (shear force) amongst the SM. Therefore, the larger part of the differences may have been due to the other tenderness determinants such as the extent of proteolysis as well as the state of the connective tissue.

Amongst the main factors investigated in the current study, pre-slaughter conditioning effectively resulted in a fast glycolytic rate, slow chilling and hence an ideally low pH_3 and sufficiently long sarcomeres. The majority of the carcasses had shorter sarcomeres and higher *M. semimembranosus* shear force values. This therefore implies that aside from the pre-slaughter conditioned goats, the majority of the carcasses suffered some degree of cold shortening because of fast chilling and the concomitantly retarded rate of glycolysis.

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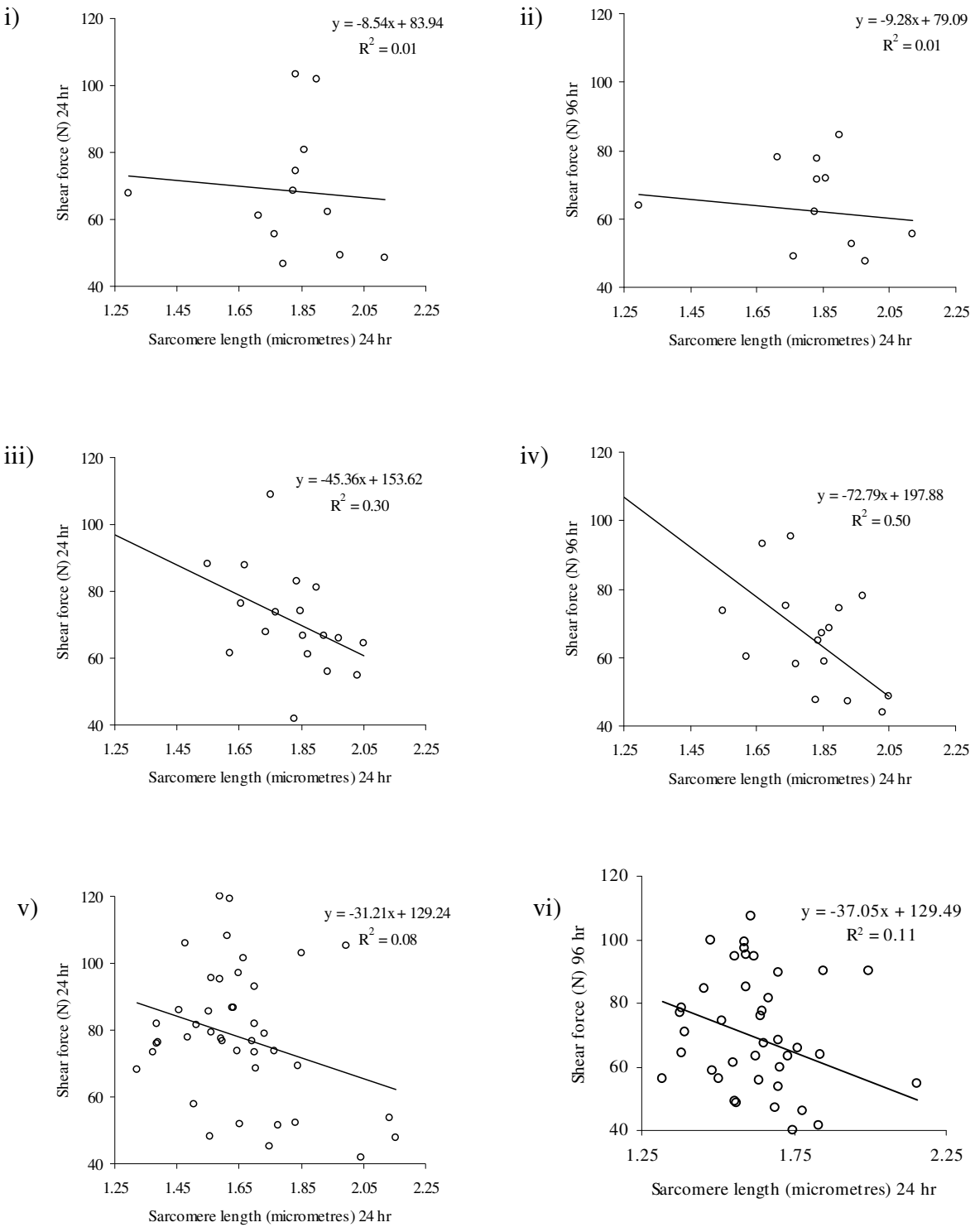


Figure 5.14 Relationship between shear force (N) and 24-hour sarcomere length (µm) of goat *M. semimembranosus* with pH_3 <6.1 (i, ii); 6.1 to 6.3 (iii, iv) and >6.3 (v, vi)

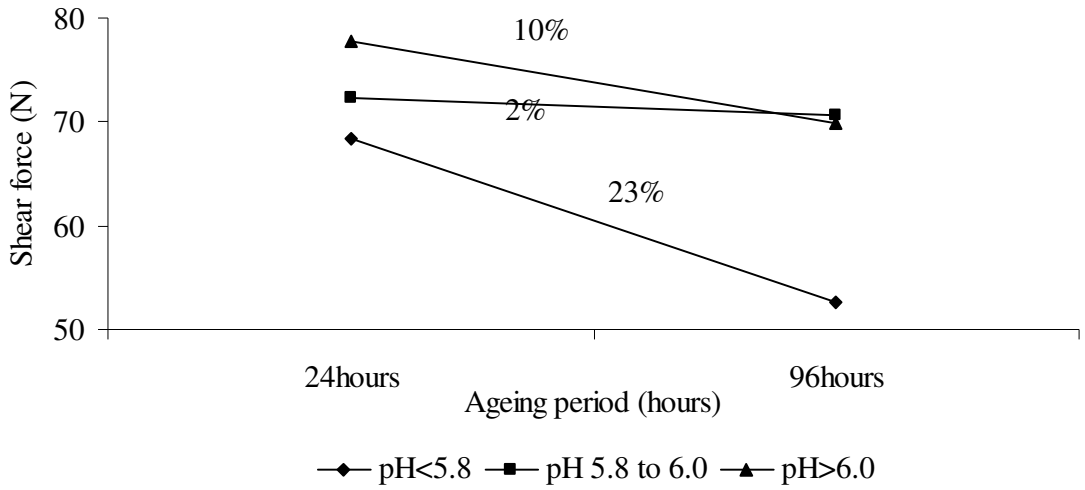
5.3.3.3 Shear force values and the effect of pHu on tenderness

The shear force values obtained herein are higher than some of the values reported for chevon (Table 2.9) such as Nuñez Gonzalez et al. (1983); Babiker and Bello (1986); Babiker et al. (1990); Schönfeldt et al. (1993a) and Dhanda et al. (1999) but compare favourably to others (e.g. Smith et al., 1978; Hogg et al., 1992; Swan et al., 1998; Sheridan et al., 2003). Noteworthy is that the shear force values of the more tender caprine SM in the current study (i.e. those of the castrates, 2-teeth group, the pre-slaughter conditioned group or the pH_{24}<5.8 group) were similar to the values reported by Schönfeldt et al. (1993a). This was despite the fact that in the latter study the Boer and Angora goats were electrically stimulated and aged for seven days. The tender groups also fell in the same range of tenderness as reported by Babiker and Bello (1986) for high temperature conditioned goats and Nuñez Gonzalez et al. (1983) whose post-slaughter conditions were not specified.

The tougher SM in the present study had shear force values close to the average 7.55kg of the SM of lamb with thin subcutaneous fat cover (<3.0cm) aged for 72 hours at 1°C (Smith et al., 1976). The more tender groups, such as the pre-slaughter conditioned goats, had similar shear force values to the fatter lambs with 7.1cm subcutaneous fat cover. Even lower shear force values, of 1.6kg to 2.16kg, have been reported for South African Merino lambs (Bosman, Webb, Cilliers and Steyn, 2000). Such low values were not attained by any of the caprine SM muscles within the ageing times employed herein.

Amongst the Australian and New Zealand consumers, acceptable lamb tenderness is associated with shear force values below 5kgF (Shorthose, Powell and Harris, 1986; Bickerstaffe, 1996), which is about 3kg Warner Bratzler shear force (Watanabe et al., 1996). Beyond 11kgF (~6.6kg WBS) lamb is considered unacceptably tough (Bickerstaffe, 1996). The published limits for beef are less than 7kgF (~4.2kg WBS) for acceptable tenderness, 8 to 10kgF (~4.8 to 6kg WBS for moderately acceptable) and greater than 10kgF for unacceptably tough beef (Daly, 2000). These values compare well with the acceptability levels recommended for the beef industry of the United States of America. The research teams working on beef tenderness recommend that the industry targets shear force values that are less than 4.5kg in order to obtain a high rate of consumer acceptability (Huffman, Miller, Hoover, Wu, Brittin, and Ramsey, 1996; Boleman et al., 1997; Miller et al., 2001). Beef loin steaks with shear force values above 4.9kg are said to be

unacceptable to consumers. None of the main factors under investigated in the present study resulted in such a low average tenderness (≤45N). The closest were the carcases with pH_{24}<5.8, whose mean tenderness after 96 hours of ageing was 52.57N. Even then there was a high variation of 14.87 standard deviations around that mean, which shows that although some of the SM samples were acceptably tender, a number of them were also quite tough. Overall, only 9% of the samples attained shear force values equal to or below 45N. Judging from the tenderisation rate of the SM with pH_{24}<5.8 (Figure 5.15), lower shear force values may have been attained with extended ageing. However, for the majority of the samples, which had a high pHu, there would have been little gain in tenderness but a higher risk of spoilage.



NB values next to each line indicate percentage change in tenderness per pH_{24} group

Figure 5.15 Effect of ultimate pH and ageing on the shear force (N) of the *M. semimembranosus* of goats

It is proven that as pHu decreases between 7 and 5.5, meat tenderness declines to a point of inflection at about pH 6 and then increases thereafter (Purchas, 1990; Purchas and Aungsupakorn, 1993; Watanabe et al., 1996; Figure 2.5). The pHu values of the goats in this study clustered around the region of minimum tenderness. Nonetheless even within the narrow band of pHu values, the carcasses with lower pHu were notably more tender than those with high pHu but only after ageing to 96 hours post-mortem. This indicates that pHu affected chevon tenderness by modifying the proteolytic activity post-mortem and not initial tenderness (Figure 5.15), which was mainly affected by the rate of cooling and/or pH decline.

CHAPTER 5

The differences in tenderness amongst the pHu groups have been ascribed to the response of proteolytic enzyme systems to pH changes (Yu and Lee, 1986). According to Yu and Lee (1986), the intermediate pH range is (pHu 5.8 to 6.3) is outside the optima of proteolytic enzyme systems and hence the slow rate of tenderisation of meat with pHu values in this range (Figure 5.15). At low pHu, the acidic proteases are active while at the higher end, the neutral calpains are active. Notably, there was limited tenderisation of meat in the higher pHu range compared to the lower one, which would imply limited activity of the calpains.

The pHu-related differences in tenderness apparently disappear eventually following a sufficiently long ageing period, which was up to 5 days for the lamb LTL of Watanabe et al. (1996) and 30 days for beef strip loins (LL) of Simmons, Auld, Thomson, Cairney and Daly (2000). Judging from the differences in the rate of ageing amongst the caprine SM in the different pHu groups of the present study, it would taken far more than five days for all the chevon samples to reach similar levels of tenderness.

In some studies, SLs of meat with pHu in the intermediate range have been found to be shorter compared to the low pHu groups (Yu and Lee, 1986; Purchas, 1990; Purchas and Aungsupakorn, 1993), as was the case with the LL sarcomeres in this study. Yet, as was the case with the SM herein, others have observed no relationship between SLs and pHu (Purchas, Yan, and Hartley, 1999). Unfortunately, the shear force values of the LTL could not be determined in this study because the muscles were too flat to be cored successfully for the Warner-Bratzler shear force device. Therefore, the relationship between SL and tenderness of the LL cannot be established for the different pHu groups. Nonetheless, more recent studies indicate that these relationships are weak and account for a small proportion of the variation in tenderness (Watanabe et al., 1996; Purchas et al., 1999; Simmons et al., 2000) except in cases of severe sarcomere contraction (Simmons et al, 2000).

From the foregoing, it is apparent that the tenderness of chevon was affected by cooling rate and both the rate and extent of glycolysis. Chevon can attain low shear force values if the carcasses are heavy, have more fat content and are chilled slowly, or they attain a pHu below 5.8. The meat however does not seem to attain the same degree of tenderness as is reportedly achieved by lamb and beef (Pike et al., 1973a; Schönfeldt et al., 1993a).

5.3.3.4 Cooking losses and colour

5.3.3.4.1 The cooking losses

Juiciness of meat is directly related to the intramuscular lipids and moisture content of the meat (Cross, Durland and Seidman, 1986) but the water remaining in the cooked product is the major contributor to the sensation of juiciness during eating (Forrest et al., 1975). The mean cooking losses of the present study (32–33%) were at least 30% higher than those reported by Schönfeldt et al. (1993b) for SM of lamb and Angora and Boer goats, and by Smith et al. (1976) for lamb carcasses of varying fatness. The values were in a similar range to the 34% to 39% reported by Dhanda et al. (1999) for capretto (about 15kg live weight) but in a narrower band than the 32% to 51% obtained for chevon in that study. Babiker et al. (1990) and Johnson, Eastridge, Neubauer and McGowan (1995) reported values of about 30% to 36%.

The variation in cooking losses from the various works can be attributed to the different durations and temperature of cooking, pHu and the muscle used. Boiling samples in polythene bags in a water bath (Babiker et al, 1990, Dhanda et al., 1999, current study) generally yields higher losses than oven cooking (Smith et al., 1976, Schönfeldt et al., 1993b). The high losses obtained by Johnson et al. (1995) for oven broiled samples may have been due to the fact that they used comminuted meat.

Whereas in Schönfeldt et al. (1993b) and Smith et al. (1976), cooking losses tended to be higher for the older and/or fatter animals, the losses in this study were higher for the leaner goats (Tables 5.14, 5.16). This was in line with the viewpoint that during cooking, melted fat lodges along the band of the perimysial connective tissue where it acts as a barrier to moisture loss, leading to less shrinkage and moisture loss, and hence a juicy product (Forrest et al., 1975).

5.3.3.4.2 The colorimetric co-ordinates

The L* co-ordinate in this study was similar to values reported by Dhanda et al. (1999), higher than those reported for Sudanese desert goats but lower than those reported for Spanish does and capretto of Boer crosses (Table 2.4). The a* co-ordinate was also similar to the values reported by Dhanda et al. (1999) and Husain et al. (2000) but lower than those for the Spanish does of Kannan et al. (2001) and the Sudanese desert goats of Babiker and co-workers (1986, 1990). The b* co-ordinate was at least six units higher than the values reported by Dhanda et al. (1999) and

Husain et al. (2000) but were similar to those of Babiker and Bello (1986), Babiker et al. (1990) and Kannan et al. (2001).

The colorimetric co-ordinates L* and b* compare favourably to values reported for lamb, but a* tends to be lower. For example, Gardner et al. (1999) reported L* of 35 to 36, a* of 17.4 to 19.7 and of b* 7.58 to 10.1 for the *M. longissimus* of Merino/Merino cross lambs. Hopkins, Beattie and Pirlot (1998) reported L* of 36.8 to 39.5, a* of 14.6 to 15.0 and b* of 7.9 to 8.2 for SM of lambs. Higher colorimetric values (L* of 47 to 50, a* of about 23 and b*of about 9) have been reported for lamb (Vergara, Molina and Gallego, 1999). However, most 24-hour colour co-ordinate values that have been published for the conventional red meats (beef and lamb) range between 35 and the lower 40s; 12 and 30, and 7 and 15 for L*, a* and b*, respectively. Lower (particularly L*) values have been published for game, such as (L*, a*, b*, respectively) 29.4, 5.5 and 3.5 for 14 month old ostrich (Hoffman and Fisher, 2001) and 29.2, 11.3 and 7.4 for impala (Hoffman, 2000).

The a* co-ordinate is commonly high in bovine compared to that of chevon. The value is often in the mid twenties (e.g. Jones, Schaefer, Robertson and Vincent, 1990; Jeremiah, Aalhus, Robertson and Gibson, 1997; Wulf et al., 1997; Abril et al., 2001, Kim, Yoon, Song and Lee, 2003). Very low values of all the co-ordinates are associated with the dark cutting condition (Purchas et al., 1999; Abril et al., 2001, Page et al., 2001).

5.3.3.4.3 Variation of colour co-ordinates with carcass and meat traits

The a* co-ordinate was the most variable of the colour co-ordinates for the 24-hour samples and chroma tended to be affected in a similar pattern. According to Gardner et al. (1999), a* is an indication of total myoglobin content. In that study a* was greater for crossbred than for the purebred Merino lambs that were commercially slaughtered. However, under minimal stress environment, the two breed types had similar a* values, which were higher than those of lambs slaughtered under commercial conditions. This suggests that the a* co-ordinate is not just an indication of myoglobin content per se, but is affected by other extenuating factors, particularly the pHu. Vergara et al. (1999) suggest that the variation in the co-ordinate is allied to the oxidation state of myoglobin, which varies with pHu such that a* is high in red, normal pHu,

normal colour meat when oxymyoglobin is prevalent and low in high pHu, dark meat when the darker metmyoglobin is prevalent.

The pHu of the caprine SM had a significant impact on the meat colour. As is expected the carcasses with a lower pHu (<5.8) had the better colour attributes, more so the a*, b* and chroma, than those with a higher pHu (Young et al., 1999). The pHu>6 group had an a* value approaching 12, which is indicative of the DFD condition and hence a short shelf life (Wiklund, Stevenson-Barry, Duncan and Littlejohn, 2001a). In addition, its chroma values were 3.3 units below those of the pHu<5.8 group, indicating that, compared to the latter high pHu chevon had a duller and less pure colour (Onyango, Izumimoto and Kutima, 1998). Low shelf-life and poor colour quality are typical of such high pH meat.

The colour co-ordinates were affected by the rate of pH decline to a lesser extent than pHu. Only the a* co-ordinate, and chroma values were affected. According to Yang, Lanari, Brewster and Tume (2002) the effect could have been due to differences in carcass weight, fatness and hence the chilling rate.

Differences in the rate of pH decline and pHu probably best explains the superior a* values of the 2-teeth group and the pre-slaughter conditioned group. Both these groups chilled slower than their contemporary groups (Tables 5.14 and 5.15) and carcasses of the pre-slaughter conditioned goats were heavy with high fat content (Table 4.3). The mature does (8 teeth group) had a notably different mean SM pHu (6.01) from the 2- teeth group (5.88). Consequently the older goats had a much lower 24-hour a* value (and chroma) that was in the range associated with the DFD condition (Wiklund, Barnier, Smulders, Lundström and Malmfors, 1997).

The castrates had superior a* values that were in line with the low pHu of the group. Although the intact males had a similar pH profile to the females, they had lower a* and chroma values. Such sex differences have been observed amongst beef (Page et al., 2001; Kim et al., 2003) and lamb carcasses (Vergara et al., 1999). Page et al. (2001) suggest that the sex differences may be due to underlying mechanisms different from the insulation effect of fat, since they observed sex effects on beef colour despite the fact that the sex groups in their study had similar fat thickness

and pHu values. Lawrie (1998) proposes that the tendency of males to have high levels of haeme pigments may induce the darker meat colour (lower a*).

The colour differences observed with the 24-hour samples did not persist to the 96-hour samples. They may have been annulled by the general improvement in the colour of chevon between the two periods (Ledward, Dickinson, Powell and Shorthose, 1986). An increase in the colour co-ordinate values is a common phenomenon (Orcutt et al., 1984; Yang et al., 2002) caused by the increased light scattering and deeper penetration of oxygen in aged meat (MacDougall, 1982; Ledward, 1992). The downside of extended ageing is that the improved meat colour is not stable but deteriorates rapidly during post-mortem display (MacDougall, 1982; Yang et al., 2002). Maximum deterioration of the surface colour of chevon has been reported to occur within 4 to 8 days of display (Kannan et al., 2001). It is perhaps noteworthy that the caprine SM muscles in Kannan and co-workers' study had a high mean pHu of 6.07 but an a* value of 17.8.

5.4 SUMMARY

The low GP and high initial lactate concentration, low initial pH and high pHu values all point to the fact that peri-mortem handling of goats under commercial slaughter conditions is a potent stressor. High pHu is not an intrinsic characteristic of chevon but is a consequence of low peri-mortem GP. It is however not clear whether the low GP is characteristic of caprine LTL or a result of an acute response to stress. There were indications that mature does are more susceptible to peri-mortem stress than the younger animals. Pre-slaughter conditioning did not improve the response to peri-mortem handling for any of the age and sex groups.

Myofibre types indicate that meat from caprine species is different from the conventional red meats, and hence supports the view that chevon should not be regarded as an alternative to lamb/ mutton. Within the species, the LTL and SM have different myofibre properties. Myofibre types were not useful indices of meat quality in this study.

The level of immediate post-slaughter calpastatin activity suggests that the proteolytic potential of chevon is not essentially different from that of other meat types. Therefore, any perceived

toughness would largely be due to other putative tenderness determinants (particularly, a high pHu) rather than an inherent failure to tenderise.

The pHu and rates of post-mortem glycolysis and carcass chilling were the important determinants of chevon tenderness. The latter affected immediate post-mortem tenderness but its impact was resolved by ageing. The pHu affected the extent of tenderisation during post-mortem ageing, and hence the 96-hour shear force values. The effects of these parameters were reflected in the variation in shear force values amongst the main factors investigated in this study. As such castrates and the 2-teeth group, which tended to have numerically lower pHu values than their contemporary groups also tended to have lower 96-hour shear force values. In turn, the mature does' tendency to high pHu was reflected in a high mean 96-hour shear force value. Pre-slaughter conditioning affected the rate of pH and temperature decline but not pHu. Even then, the goats that were pre-slaughter conditioned yielded chevon of superior tenderness at both ageing periods.

Amongst their respective contemporary groups, better colour (redness) was observed for the castrates and the fast glycolysing groups (the 2-teeth, the pH_3<6.1 and the pre-slaughter conditioned goats). At the other extreme, the mature does had a mean a* value associated with the DFD condition. The pHu had an impact on all colour co-ordinates. Generally, chevon with a low pHu had a better colour quality while that with a pHu>6 tended to DFD characteristics.

Cooking losses decreased with carcass weight and fatness. Ageing the meat for up to 96 hours improved the tenderness of both muscles as suggested by the decrease in the MFL and confirmed by the decrease in shear force values of the SM. Ageing also improved colour quality such that differences that occurred at 24 hours post-mortem had disappeared by 96 hours post-mortem.

CHAPTER 6

6 THE EFFECT OF ELECTRICAL STIMULATION ON CHEVON QUALITY

6.1 INTRODUCTION

The preceding chapter showed that under normal commercial slaughter conditions, goat carcasses are subject high rate of chilling and slow glycolysis early post-mortem. In addition, goats are highly susceptible to the stress associated with peri-mortem handling, which resulted in a low GP and high pHu for a large proportion of the goats. These conditions have an adverse effect on the quality of chevon.

Electrical stimulation was primarily developed to accelerate post-mortem glycolysis so that muscles are prevented from excessive shortening when they enter rigor (Swatland, 1981). The technique has proved to be useful beyond just the prevention of cold-induced sarcomere shortening and the resultant toughness, but it also improves tenderness through the physical disruption of muscle fibres and acceleration of proteolysis (Hwang, Devine and Hopkins, 2003). In addition ES has been shown to reduce the activity of calpastatin, improve meat colour, flavour and shelf life (§2.6.3.2 refers). It has been suggested that ES is only effective on carcasses with high glycogen reserves at slaughter and a high initial pH of about 6.7 to 7.1 (Khan and Lentz, 1973; Dutson et al., 1981). However, ES not only affects biochemical, and thus pH dependent changes but also affects the physical structure of myofibres (e.g. the stretching and tearing of myofibres). In light of this fact, this study aims to investigate the effect of ES on the quality of chevon from indigenous goats slaughtered under commercial conditions. It was shown in Chapter 5, that the indigenous goat carcasses do not always meet the criteria of a high initial pH and high muscle glycogen reserves.

The effects of electrical stimulation were tested on the 4-to-6 teeth castrates, which are perceived as ideal for the chevon market and on the old females, which dominate the goat markets. The objectives of the investigation were to determine the effects of ES on histological, histochemical, metabolic and physical properties of chevon. The results presented herein are the carcass characteristics of the goats in the different electrical stimulation and sex groups followed by the effect of ES on various meat quality traits of the LTL and SM muscles.

CHAPTER 6

6.2 RESULTS

6.2.1 Animal and Carcass Characteristics of Experimental Animals

The live animal and carcass characteristics of the goats that were used in the electrical stimulation trial are presented in Tables 6.1 and 6.2. Females tended to be heavier than the castrates (P=0.055), had significantly longer carcasses (P<0.01) and more internal and intermuscular fat (P<0.01). Consequently the proportion of carcass fat was 7% units higher (P=0.015), and the lean 6% units lower (P=0.005) in females than in castrates. The two sex groups did not differ significantly in any other trait (P>0.05).

Carcasses of the ES group incidentally had thicker LT (P=0.012) than those of the NES group (Table 6.2). Otherwise all other traits were similar between the two groups (P>0.05).

6.2.2 Effect of Electrical Stimulation on Chevon Quality

The effects of electrical stimulation were tested within the two sex classes, between the sex classes as well as the combined classes for each muscle. Within the electrical stimulation treatments (ES or NES) there were practically no differences between the castrates and the females in the quality traits of the LTL (Table 6.3) and SM (Tables 6.4). In light of this and the fact that the two sexes had fairly similar carcass characteristics (Table 6.1), the overall effects of ES for each muscle are presented in this chapter.

6.2.2.1 Effect of electrical stimulation on post-mortem temperature, pH, histological, histochemical, glycolytic and proteolytic properties determined from the *M. longissimus thoracis et lumborum*

Electrical stimulation resulted in a significant 0.61 unit difference in the initial pH (P<0.0001) between the stimulation groups (Table 6.5, Figure 6.1). The differences between the ES and NES groups persisted during the first six hours post slaughter (P<0.0001). In spite of this, the pHu values of the two groups were similar (P=0.382). The early post-mortem muscle temperature was similar between the LTL of the ES and NES carcasses (P>0.05) but at 24 hours post-mortem, the temperature of ES carcasses was 2.6°C warmer than that of the NES group (P=0.005).

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Table 6.1 Live animal and carcass characteristics (means ± S.D.) of 4-to-6 teeth castrate and 8-teeth female South African indigenous goats

Characteristic	Castrates	Females	*P*-value
N	9	20	
Slaughter weight (kg)	34.46 ± 7.58	38.87 ± 3.92	0.1148
Hot carcass weight (kg)	14.11 ± 3.73	15.61 ± 2.84	0.3374
Cold carcass weight (kg)	13.74 ± 3.67	15.24 ± 2.88	0.3374
Dressing out %	39.54 ± 2.25	38.96 ± 4.34	0.7679
Chilling losses (%)	2.70 ± 1.16	2.52 ± 1.23	0.3627
Chest girth (cm)	78.11 ± 8.31	81.24 ± 2.39	0.1383
Carcass length (cm)	69.10 ± 3.69	72.41 ± 3.22	0.0062
Side length (cm)	63.00 ± 4.51	67.66 ± 2.43	0.0057
Chest depth (cm)	29.22 ± 1.89	30.00 ± 0.99	0.3724
M. longissimus thoracis area (cm^2)	10.62 ± 2.25	9.12 ± 3.07	0.2364
Omental fat (g)	370 ± 306	1 238 ± 716	0.0083
Kidney knob and channel fat (g)	282 ± 192	679 ± 444	0.0182
Lean (g)	4 237 ± 1 144	4 202 ± 807	0.9216
Bone (g)	1 368 ± 255	1 410 ± 124	0.5715
Intermuscular fat (g)	472 ± 297	967 ± 567	0.0437
Subcutaneous fat (g)	260 ± 168	366 ± 201	0.1467
Total carcass fat (g)	752 ± 420	1 333 ± 752	0.0550
Lean %	66.19 ± 2.59	60.51 ± 5.81	0.0105
Bone %	21.81 ± 2.45	20.90 ± 4.32	0.4030
Intermuscular fat %	7.27 ± 2.97	12.85 ± 6.43	0.0344
Subcutaneous fat %	3.96 ± 2.15	4.89 ± 2.12	0.1400
Total carcass fat %	11.22 ± 4.36	17.74 ± 8.25	0.0550

Table 6.2 Comparison of the live animal and carcass characteristics (means (±S.D.) of the non-electrically stimulated and the electrically stimulated South African indigenous goats

Characteristic	Non-stimulated	Stimulated	*P*-value
N	15	14	
Slaughter weight (kg)	37.27 ± 5.07	37.65 ± 6.41	0.6779
Hot carcass weight (kg)	14.66 ± 3.00	15.68 ± 3.39	0.3333
Cold carcass weight (kg)	14.31 ± 3.03	15.27 ± 3.36	0.3333
Dressing out %	38.14 ± 3.95	40.30 ± 3.29	0.2310
Chilling losses (%)	2.51 ± 1.35	2.66 ± 1.03	0.5492
Chest girth (cm)	81.30 ± 5.16	79.00 ± 5.05	0.1873
Carcass length (cm)	69.97 ± 2.20	72.92 ± 4.42	0.0836
Side length (cm)	64.87 ± 3.45	66.50 ± 4.39	0.5023
Chest depth (cm)	30.00 ± 1.22	29.46 ± 1.49	0.2188
M. longissimus thoracis area (cm^2)	8.41 ± 2.17	11.79 ± 2.27	0.0118
Omental fat (g)	854 ± 736	1 065 ± 752	0.3684
Kidney knob and channel fat (g)	488 ± 458	625 ± 381	0.2310
Lean (g)	4 049 ± 723	4 402 ± 1 081	0.4611
Bone (g)	1 387 ± 131	1 407 ± 217	0.8901
Intermuscular fat (g)	671 ± 605	980 ± 416	0.0972
Subcutaneous fat (g)	297 ± 226	372 ± 148	0.1970
Total carcass fat (g)	968 ± 799	1 352 ± 555	0.0883
Lean %	63.43 ± 5.48	61.08 ± 5.77	0.3569
Bone %	22.29 ± 4.38	19.93 ± 2.62	0.1405
Intermuscular fat %	9.18 ± 6.74	13.23 ± 4.62	0.0589
Subcutaneous fat %	4.20 ± 2.58	5.04 ± 1.43	0.1971
Total carcass fat %	13.37 ± 8.68	18.27 ± 5.88	0.0530

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Table 6.3 Comparison of histological, histochemical, metabolic and proteolytic characteristics of the *M. longissimus thoracis et lumborum* of electrically stimulated and non-stimulated carcasses of South Africa indigenous 4-to-6 teeth castrates and 8-teeth female goats (*P*-values)

Quality characteristic	*P*-values for the effect of sex	
	Electrically stimulated	Non-electrically stimulated
pH_0	0.1403	0.2149
pH_3	0.8937	0.8447
pH_6	0.3464	0.8960
pH_{24}	0.3168	0.8959
Sarcomere length (µm) 24hr	1.0000	0.9480
Sarcomere length (µm) 96hr	0.4237	0.4727
Myofibre fragment length (µm) 24hr	0.234	0.1791
Myofibre fragment length (µm) 96hr	0.3506	0.2888
Red myofibre area (μm^2)	0.2301	0.2671
Intermediate myofibre area (μm^2)	0.4237	0.3961
White myofibre area (μm^2)	0.3506	0.1704
% Red myofibres	0.1824	0.4727
% Intermediate myofibres	0.7897	0.3275
% White myofibres	0.1425	0.6477
Glycolytic potential (µmol/g)	0.5050	0.1704
Lactate (µmol/g)	0.5050	0.4727
Glycogen (µmol/g)	0.5050	0.5569
Lactate %	0.8939	0.9480
Glycogen %	0.6892	1.0000
Glucose (µmol/g)	0.1425	0.9480
Glucose-6-phosphate (µmol/g)	0.2301	0.6477
ATP (µmol/g)	0.1824	0.9480
Creatine phosphate (µmol/g)	0.8939	0.1332
Calpastatin activity (U/g sample)	0.1425	0.1027
Calpastatin specific activity (U/mg protein)	0.0619	0.1332

Table 6.4 Comparison of pH, histological, tenderness and colour of the *M. semimembranosus* of electrically stimulated and non-electrically stimulated carcasses of South Africa indigenous 4-to-6 teeth castrates and 8-teeth female goats (*P*-values)

	P-values for the effect of sex	
Quality characteristic	Electrically stimulated	Non-electrically stimulated
pH_0	0.7986	0.7437
pH_3	0.2019	0.8960
pH_6	0.6711	0.0777
pH_{24}	0.0216	0.5120
Sarcomere length (µm) 24hr	0.5522	0.1704
Sarcomere length (µm) 96hr	1.000	0.3961
Myofibre fragment length (µm) 24hr	0.1564	0.1332
Myofibre fragment length (µm) 96hr	0.4447	0.1376
% Cooking losses 24hr	0.3502	0.3275
% Cooking losses 96hr	0.2027	0.9480
Shear force 24hrs (N) 24hr	0.6711	0.4727
Shear force (N) 96hr	0.2696	0.3275
L* 24hr	0.2696	0.3275
a* 24hr	0.0085	0.3961
b* 24hr	0.3502	0.3957
Chroma 24hr	0.0745	0.4727
L* 96hr	0.0745	0.2671
a* 96hr	1.0000	1.0000
b* 96hr	1.0000	0.4727
Chroma 96hr	0.7989	0.7441

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Table 6.5 The effect of electrical stimulation on pH and temperature (°C) profiles (means ± S.D.) of the *M. longissimus thoracis et lumborum* (means ± S.D.) of South African indigenous goats

Parameter	Time post-mortem	NES	ES	*P*-value
N		15	14	
pH	15 min	6.66 ± 0.30	6.05 ± 0.0.25	<0.0001
	3 hours	6.37 ± 0.25	5.90 ± 0.14	<0.0001
	6 hours	6.29 ± 0.26	5.90 ± 0.14	<0.0001
	24 hours	6.03 ± 0.18	5.97 ± 0.12	0.3824
Temperature (°C)	15 min	35.52 ± 1.99	36.28 ± 1.22	0.2560
	3 hours	11.53 ± 3.85	13.37 ± 4.05	0.2135
	6 hours	6.43 ± 3.77	7.64 ± 3.70	0.4068
	24 hours	1.53 ± 2.29	4.10 ± 1.10	0.0048

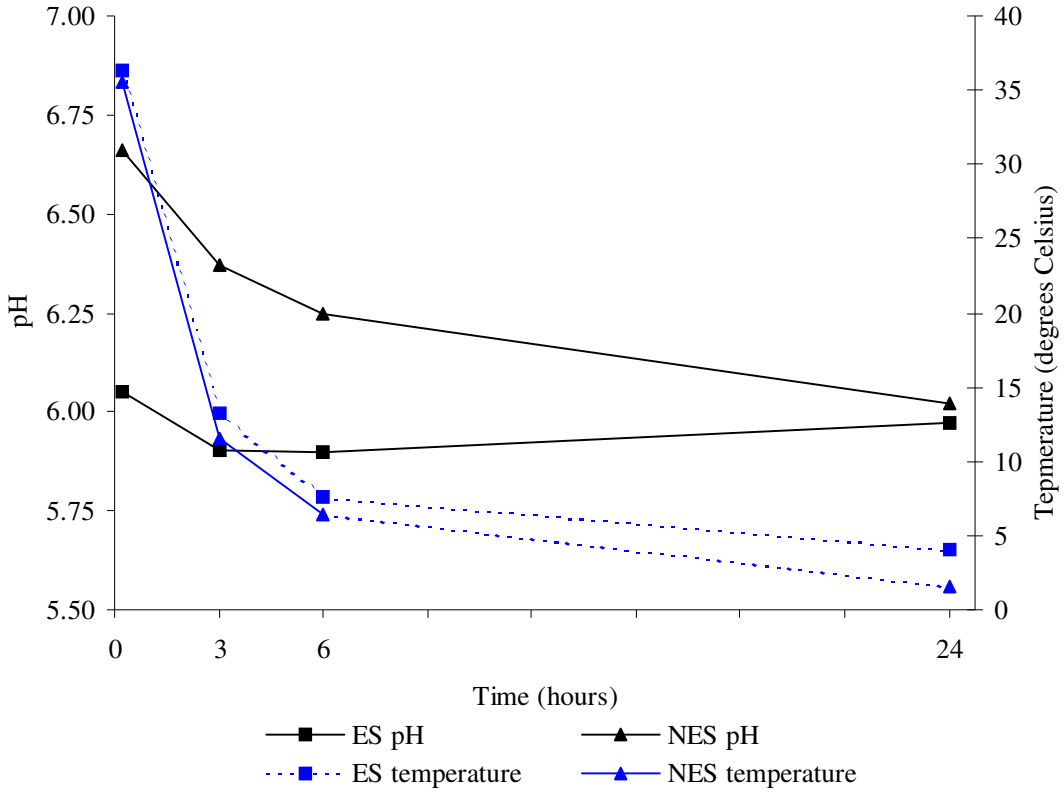

Figure 6.1 The effect of electrical stimulation on pH and temperature (°C) profiles of the *M. longissimus thoracis et lumborum* of South African indigenous goats

Sarcomere and myofibrillar fragment lengths were not significantly affected (P>0.05) by electrical stimulation (Table 6.6). Neither were the myofibre areas and proportions (P>0.05).

The ES and NES groups had similar glycolytic potential (P>0.05), which means that they started off with similar muscle energy levels. As expected, glycogen concentration of the LTL of ES goats was lower and the lactate concentration higher than that of the NES group (P<0.0001). The differences between the concentrations of each of these metabolites were about 50%. Glucose concentration was some 40% (P=0.0003) lower in ES than in NES carcasses. Glucose-6-phosphate was unaffected by ES (P<0.05). The overall mean was 0.99±0.62µmol/g. Electrical stimulation also resulted in a 40% lower ATP concentration (P<0.0001) and a tendency for lower (18%) creatine phosphate concentration (P=0.052).

Calpastatin activity was unaffected by electrical stimulation (P>0.05). Overall means were 3.26±1.09U/g sample and 0.066±0.025U/mg protein.

The correlations between carcass traits and various meat quality attributes that were determined on the LTL muscle are presented in Table 6.7. Carcass fat content, temperature and HCW to a lesser extent, all correlated negatively with early post-mortem pH (P<0.05) but these carcass traits did not significantly correlate with pHu or any of the glycolytic metabolites (P>0.05). They significantly and negatively correlated with calpastatin specific activity (P<0.05) but not with the activity per gram of sample (P<0.05).

Correlations of MFL and SL with early post-mortem pH and pHu were generally non-significant (P>0.05). Exceptions were the coefficient between 24-hour SL and pH_6 (r=-0.63; P<0.05) and between the 24-hour MFL and pHu (r=0.61, P<0.05). The only other significant correlations between these myofibre properties and muscle biochemical traits were between the 24-hour MFL and glucose (r=-0.68; P<0.01) and glucose-6-phosphate (r=-0.54; P<0.05) concentrations. Other significant correlations with pHu were with glycogen, glucose and glucose-6-phosphate concentrations (r=-0.71, -0.70 and -0.76, respectively, P<0.01) and with the lactate percentage (r=0.56; P<0.05).

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Table 6.6 Effect of electrical stimulation on histological, histochemical, metabolic and proteolytic characteristics of the *M. longissimus thoracis et lumborum* of South African indigenous goats (means ± S.D.)

Quality characteristics	Non-stimulated	Stimulated	*P*-value
N	15	14	
Histological and histochemical:			
Sarcomere length (µm) 24hr	1.77 ± 0.15	1.78 ± 0.13	0.8786
Sarcomere length (µm) 96hr	1.67 ± 0.17	1.71 ± 0.15	0.7107
Myofibre fragment length (µm) 24hr	17.61 ± 2.08	17.81 ± 2.23	0.6295
Myofibre fragment length (µm) 96hr	16.67 ± 1.51	15.98 ± 2.03	0.1478
Red myofibre area (μm^2)	1 768 ± 536	1 852 ± 558	0.7434
Intermediate myofibre area (μm^2)	2 227 ± 572	2 645 ± 590	0.0701
White myofibre area (μm^2)	2 943 ± 664	3 542 ± 743	0.0174
% Red myofibres	26.41 ± 3.30	25.24 ± 3.43	0.6784
% Intermediate myofibres	31.26 ± 2.86	33.43 ± 3.81	0.1112
% White myofibres	42.33 ± 4.57	41.33 ± 4.81	0.6784
Metabolic and proteolytic:			
Glycolytic potential (µmol/g)	94.94 ± 23.95	91.10 ± 30.95	0.3947
Lactate (µmol/g)	27.77 ± 7.01	57.75 ± 23.68	<0.0001
Glycogen (µmol/g)	31.13 ± 10.62	13.33 ± 7.15	0.0002
Lactate %	15.19 ± 4.28	31.74 ± 6.21	<0.0001
Glycogen %	32.11 ± 4.89	14.46 ± 6.08	<0.0001
Glucose (µmol/g)	1.58 ± 0.32	2.21 ± 0.39	0.0003
Glucose-6-phosphate (µmol/g)	0.87 ± 0.38	1.12 ± 0.81	0.5268
ATP (µmol/g)	4.85 ± 0.86	3.03 ± 0.68	<0.0001
Creatine phosphate (µmol/g)	3.69 ± 0.90	3.02 ± 0.42	0.0521
Calpastatin activity (U/g sample)	3.14 ± 1.13	3.38 ± 1.07	0.7107
Calpastatin specific activity (U/mg protein)	0.070 ± 0.031	0.062 ± 0.018	0.7767

Table 6.7 Simple correlations between carcass characteristics, histological and biochemical characteristics of the *M. longissimus thoracis et lumborum* of electrically stimulated carcasses of South African indigenous goats

	HCW	Carcass fat (g)	Temp (°C) 3hr	MFL 24hr	MFL 96hr	pH_0	pH_3	pH_6	pH_{24}	SL 24hr	Calpastatin specific
pH_0	0.46	0.55*	0.46	0.30	-0.34						
pH_3	-0.60*	-0.56*	-0.62*	-0.17	0.51	-0.11					
pH_6	-0.41	-0.62*	-0.69**	-0.48	0.23	-0.39	0.73**				
pH_{24}	0.07	0.47	0.44	0.61*	-0.16	0.21	-0.14	-0.28			
SL 24hr	0.12	0.25	0.39	0.14	0.28	0.50	-0.27	-0.63*	0.05		
GP	0.46	0.00	-0.13	-0.35	-0.13	0.20	-0.19	-0.12	-0.47	-0.05	0.05
Lactate	0.40	0.07	-0.08	-0.20	-0.18	0.35	-0.19	-0.23	-0.11	-0.03	-0.08
Glycogen	0.34	-0.04	-0.07	-0.34	-0.01	-0.13	-0.13	0.08	-0.71**	-0.03	0.18
Lactate %	-0.01	0.11	0.03	0.23	-0.11	0.37	0.13	-0.10	0.56*	-0.08	-0.21
Glycogen %	0.11	-0.04	0.04	-0.18	0.07	-0.33	-0.20	0.04	-0.52	-0.09	0.18
Glucose	0.04	-0.33	-0.48	-0.68**	-0.17	-0.21	0.11	0.46	-0.70**	-0.42	0.27
Glucose-6-P	-0.14	-0.03	-0.44	-0.54*	0.35	-0.06	0.33	0.14	-0.76**	0.12	0.27
ATP	0.46	0.42	0.36	0.10	-0.40	0.09	-0.12	-0.07	-0.15	-0.04	-0.36
CP	0.51	0.34	0.25	-0.03	-0.16	0.32	0.06	-0.15	0.12	-0.04	-0.47
Calpastatin	-0.16	-0.40	-0.37	-0.39	0.31	0.24	0.34	0.32	-0.45	0.24	
Calp. specific	-0.48	-0.68**	-0.64*	-0.49	0.38	-0.11	0.36	0.47	-0.45	0.05	

Level of significance: * (P<0.05); ** (P<0.01); *** (P<0.001).

HCW = hot carcass weight (kg); SL = sarcomere length (µm); MFL = myofibrillar fragment length (µm); GP = glycolytic potential (µmol/g); Glucose-6-P = glucose-6-phosphate (µmol/g); CP = creatine phosphate (µmol/g); Calp. specific = Calpastatin specific activity (U/mg protein); Calpastatin = Calpastatin activity (U/g sample).

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6.2.2.2 Effect of electrical stimulation on the meat quality traits of the *M. semimembranosus*

Electrical stimulation resulted in an initial SM pH that was significantly lower than that of the NES group ($P<0.0001$) by 0.71 unit (Table 6.8, Figure 6.2). As in the LTL, these differences were observed during the first six hours of monitoring ($P<0.001$) but did not persist to the ultimate pH ($P>0.05$). It is noted that the pHu values differed significantly ($P=0.0216$) between the castrates (pHu = 5.86±0.04) and females (pHu =6.02±0.14) of the ES treatment (Table 6.4).

The ES group tended to have higher temperature readings (Table 6.8). At three hours post-mortem, the difference was significant ($P=0.011$) and equalled 3.35 °C. By 24 hours post-mortem, the differences in temperature tended to be less significant ($P=0.059$).

At 24 hours post-mortem, sarcomeres of SM of the ES treatment were significantly longer ($P=0.0003$) than those of the NES group by 0.28µm (Table 6.9). This difference did not persist to 96 hours post-mortem ($P>0.05$). Myofibrillar fragment lengths were not affected by ES ($P>0.05$). The overall means were 18.43±2.27µm and 15.70±1.77µm at 24 and 96 hours post-mortem, respectively.

Cooking losses were similar ($P>0.05$) between the ES and NES groups and averaged 32% across both stimulation groups and ageing periods. However, shear force values of the ES group were significantly lower than those for NES carcasses ($P<0.001$) by 27.6N and 33.6N, at 24 and 96 hours post-mortem, respectively.

The colour parameters that were affected by ES were the a* value at both ageing periods ($P<0.05$) and chroma at 96 hours post-mortem only ($P=0.038$). The a* values were 2.7 and 1.8 units higher at 24 and 96 hours, respectively, while chroma at 96 hours was 1.6 units higher for the ES compared to the NES group. In line with the high pHu, ES females had significantly lower ($P=0.009$, Table 6.4) 24-hour a* values (mean = 13.62±1.67) than ES castrates (mean = 16.45±0.96). The females therefore tended ($P=0.075$) to have lower 24-hour chroma (means = 16.00±2.36 vs. 19.18±1.06). However, the differences in the colour of the two groups did not persist with post-mortem ageing ($P>0.05$).

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Table 6.8 The effect of electrical stimulation on pH and temperature profiles (means ± S.D) of the *M. semimembranosus* of South African indigenous goats

Parameter	Time post-mortem	NES	ES	*P*-value
N		15	13	
pH	15 min	6.67 ± 0.27	5.96 ± 0.22	<0.0001
	3 hours	6.38 ±0.26	5.90 ±0.21	0.0003
	6 hours	6.25 ± 0.25	5.87 ±0.13	0.0002
	24 hours	6.02 ± 0.17	5.96 ±0.14	0.2509
Temperature (°C)	15 min	34.30 ± 2.06	35.45 ± 1.72	0.1568
	3 hours	14.63 ± 3.17	17.98 ± 2.79	0.0111
	6 hours	8.09 ± 4.17	10.74 ± 3.41	0.0971
	24 hours	1.87 ± 2.36	3.29 ± 2.07	0.0587

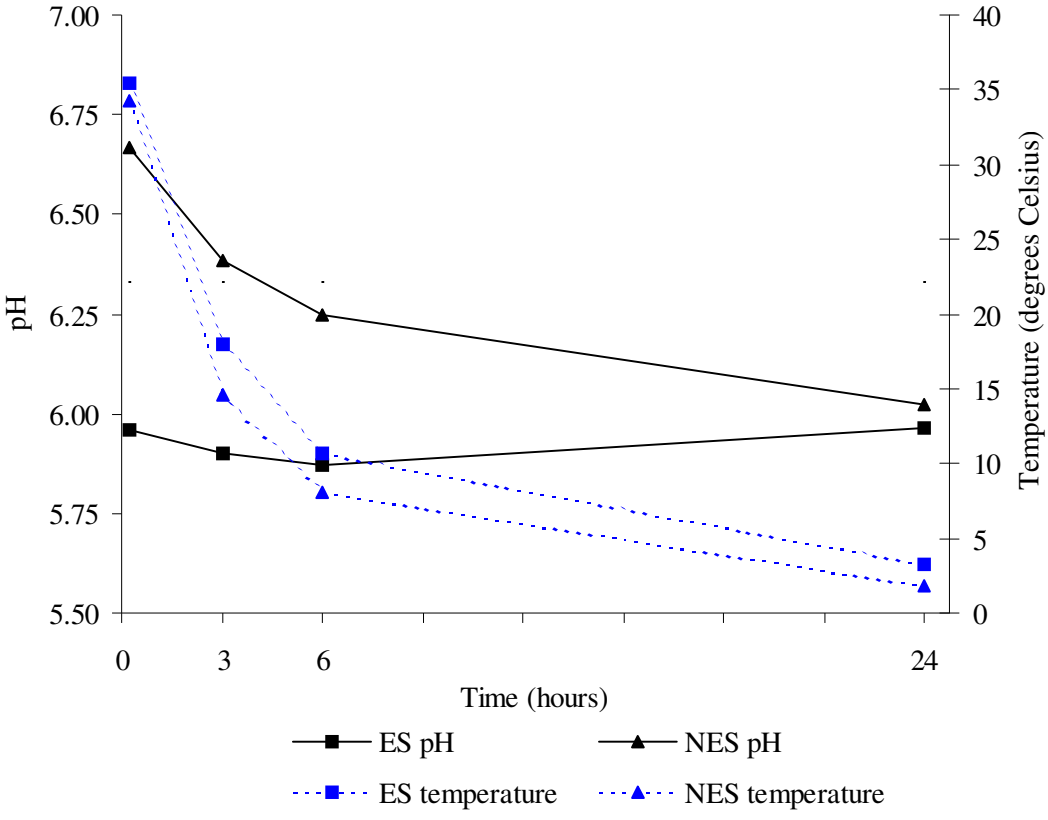

Figure 6.2 The effect of electrical stimulation on pH and temperature profiles of the *M. semimembranosus* of South African indigenous goats

Table 6.9 Effect of electrical stimulation on the chevon quality properties (means ± S.D.) that were determined on the *M. semimembranosus* muscle of South African indigenous goats

	Non-stimulated	Stimulated	*P*-value
N	15	13	
Histological characteristics:			
Sarcomere length (µm) 24hr	1.68 ± 0.17	1.96 ± 0.14	0.0003
Sarcomere length (µm) 96hr	1.73 ± 0.20	1.77 ± 0.17	0.5419
Myofibre fragment length (µm) 24hr	18.20 ± 2.11	18.74 ± 2.55	0.3502
Myofibre fragment length (µm) 96hr	16.19 ± 1.77	15.16 ± 1.70	0.1052
Physical characteristics:			
% Cooking losses 24hr	32.79 ± 2.64	31.69 ± 3.42	0.3932
% Cooking losses 96hr	32.96 ± 3.01	30.69 ± 3.65	0.1643
Shear force (N) 24hr	77.97 ± 17.26	50.39 ± 10.17	0.0003
Shear force (N) 96hr	74.47 ± 16.96	40.86 ± 8.92	<0.0001
L* 24hr	37.85 ± 2.50	36.13 ± 2.30	0.1128
a* 24hr	11.86 ± 3.31	14.56 ± 1.99	0.0338
b* 24hr	9.18 ± 1.15	8.86 ± 1.71	0.8644
Chroma 24hr	15.13 ± 2.96	17.06 ± 2.96	0.1500
L* 96hr	37.38 ± 2.13	37.61 ± 1.96	0.6430
a* 96hr	13.67 ± 2.23	15.46 ± 1.38	0.0205
b* 96hr	9.50 ± 0.96	9.77 ± 1.02	0.5101
Chroma 96hr	16.67 ± 2.24	18.30 ± 1.60	0.0381

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Simple correlations between the carcass traits and various meat quality attributes that were determined on the SM muscle are presented in Table 6.10. As was observed with the LTL muscle, there were stronger negative correlations between early post-mortem pH and the temperature three hours post-mortem (P<0.01) than with HCW and carcass fat content. Carcass fat and temperature also correlated negatively with the 24-hour cooking losses (P<0.05) but not with the 96-hour values (P>0.05). All three carcass traits correlated to the 96-hour shear force but not with the 24-hour shear force nor with any of the MFL values (P>0.05)

Lightness values tended to decrease with an increase in carcass weight and fat content (P<0.05) but were not significantly correlated with the temperature readings (P>0.05). Only the 96-hour a* value significantly correlated with the 3-hour temperature values (r=0.57; P<0.05).

In addition to the carcass traits, early post-mortem pH values also significantly correlated with the 24-hour MFL values (r=-0.57 with pH_6; P<0.05), 96-hour MFL values (r=0.54 with pH_0; P<0.05) and the 96-hour a* and b* values (P<0.05). The pHu values significantly and negatively correlated to cooking losses (P<0.05), all 24-hour colorimetric parameters and the 96-hour L* and b* values (P<0.01). Cooking losses had similarly high and positive correlations with the 24-hour co-ordinates and only the L* and chroma of the 96-hour co-ordinates. There were no significant correlations between the colour of chevon and the shear force values (P>0.05).

6.2.2.3 Effects of electrical stimulation and ageing on chevon quality

The effects of electrical stimulation and post-mortem ageing are shown in Table 6.11. Post-mortem ageing LL samples of the NES carcasses for 96 hours resulted in SL that were 0.1µm shorter (P=0.041) than those of samples aged for 24 hours (mean SL = 1.77±0.15µm). Ageing did not significantly affect *longissimus* sarcomere lengths of the ES carcasses (P>0.05) or *longissimus* MFL of either the ES or NES groups (P>0.05).

Amongst SM samples of NES carcasses, ageing significantly affected myofibrillar fragments lengths (P=0.002), a* (P=0.026) and chroma (P=0.048). Myofibrillar lengths of the samples aged for 96 hours (mean = 16.13±1.82µm) were 2.07µm shorter than those of samples that were aged for 24 hours. Despite the shorter MFL, which suggest that some proteolysis had taken place, the shear force values were not significantly affected by ageing (P>0.05).

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Table 6.10 Simple correlations between carcass characteristics, histological characteristics, shear force and the colorimetric co-ordinates of the *M. semimembranosus* of electrically stimulated carcasses of indigenous South African goats

	Carcass weight (kg)	Carcass fat (g)	Temp (°C) 3hr	pH_0	pH_3	pH_6	pH_{24}	SL 24hr	Cooking losses 24hr	Cooking losses 96hr	Shear force 24hr	Shear force 96hr
pH_0	-0.51	-0.30	-0.11									
pH_3	-0.44	-0.37	-0.77**	0.39								
pH_6	-0.72**	-0.61*	-0.78**	0.47	0.77**							
pH_{24}	-0.04	0.36	0.09	0.36	0.32	0.35						
SL 24 hr	-0.12	0.02	-0.18	-0.05	-0.04	0.09	-0.04					
Cooking losses 24h	-0.37	-0.63*	-0.55*	-0.13	-0.05	0.11	-0.61**	-0.51				
Cooking losses 96h	-0.27	-0.53	-0.29	-0.38	-0.30	-0.15	-0.74**	-0.38	0.79***			
Shear force 24hr	-0.17	-0.31	-0.21	0.42	0.45	0.05	-0.17	-0.40	0.03	-0.01		
Shear force 96hr	-0.65*	-0.62*	-0.57*	0.21	0.22	0.37	0.01	0.17	0.22	0.39	0.32	
MFL 24hr	0.35	0.43	0.43	-0.28	-0.39	-0.57*	0.15	-0.23	-0.07	-0.17	-0.11	-0.32
MFL 96hr	-0.48	-0.34	-0.16	0.54*	0.01	0.30	0.02	-0.07	0.15	0.08	0.10	0.32
L^* 24 hr	-0.57*	-0.72**	-0.48	-0.13	-0.07	0.13	-0.67**	0.11	0.70**	0.74**	0.12	0.42
a^* 24 hr	0.15	-0.27	-0.24	-0.42	-0.35	-0.21	-0.74**	0.21	0.69**	0.67**	-0.16	-0.08
b^* 24 hr	-0.06	-0.32	-0.18	-0.40	-0.33	-0.23	-0.79**	0.23	0.63*	0.69**	-0.06	0.02
Chroma 24 hr	0.07	-0.30	-0.23	-0.43	-0.35	-0.22	-0.78**	0.22	0.69**	0.69**	-0.12	-0.05
L^* 96 hr	-0.24	-0.60*	-0.43	-0.45	-0.03	0.03	-0.75**	0.05	0.64*	0.73**	0.04	0.18
a^* 96 hr	0.51	0.47	0.57*	-0.30	-0.68**	-0.74**	-0.42	0.25	0.03	0.24	-0.25	-0.48
b^* 96 hr	0.33	0.15	0.34	-0.49	-0.56*	-0.62*	-0.72**	0.16	0.34	0.53	-0.19	-0.43
Chroma 96 hr	0.00	0.03	0.20	-0.18	-0.49	-0.48	-0.43	0.72**	0.28	0.55*	-0.14	0.30

Level of significance: * (P<0.05); ** (P<0.01); *** (P<0.001).

SL = sarcomere length (µm); MFL = myofibrillar fragment length (µm)

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Table 6.11 Effects of ageing on sarcomere and myofibrillar fragment lengths (µm), cooking losses (%), shear force (N) and colour of chevon from electrically stimulated and non-stimulated carcasses of South African indigenous goat (*P*-values)

Muscle	Trait	*P*-values	
		NES	ES
M. longissimus lumborum	Sarcomere length (µm)	0.0409	0.1094
	Myofibrillar fragment length (µm)	0.2455	0.0736
M. semimembranosus	Sarcomere length (µm)	0.3305	0.0030
	Myofibrillar fragment length (µm)	0.0015	0.0186
	Cooking losses %	0.9250	0.1961
	Shear force (N)	0.2455	0.0107
	L*	0.1094	0.0131
	a*	0.0258	0.1159
	b*	0.5936	0.0330
	Chroma	0.0480	0.0640

Post-mortem ageing improved the a* value of NES samples from a mean of 11.77±3.41 to 13.41±2.07 and chroma from 15.11±3.07 to 16.42±2.09. This trend was similar to that reported in Chapter 5 (Table 5.27).

Amongst the ES carcasses, *semimembranosus* sarcomere (P=0.003) and myofibrillar lengths (P=0.019) were significantly decreased from means of 1.96±0.17µm and 18.35±2.64µm 24 hours post-mortem to 1.75±0.16µm and 15.13±1.70µm 96 hours post-mortem, respectively. Fittingly, shear force values also decreased with post-mortem ageing, from 54.26±16.07N to 44.68 ± 13.02N (P=0.011). Post-mortem ageing also improved the colour of SM of electrically stimulated carcasses. The L* and b* values were respectively 1.48 and 0.91 units higher after ageing (P<0.05) but a* and chroma values were not affected (P>0.05).

The changes in *semimembranosus* shear force and colour with ageing for the ES and NES carcasses are illustrated in Figure 6.3.

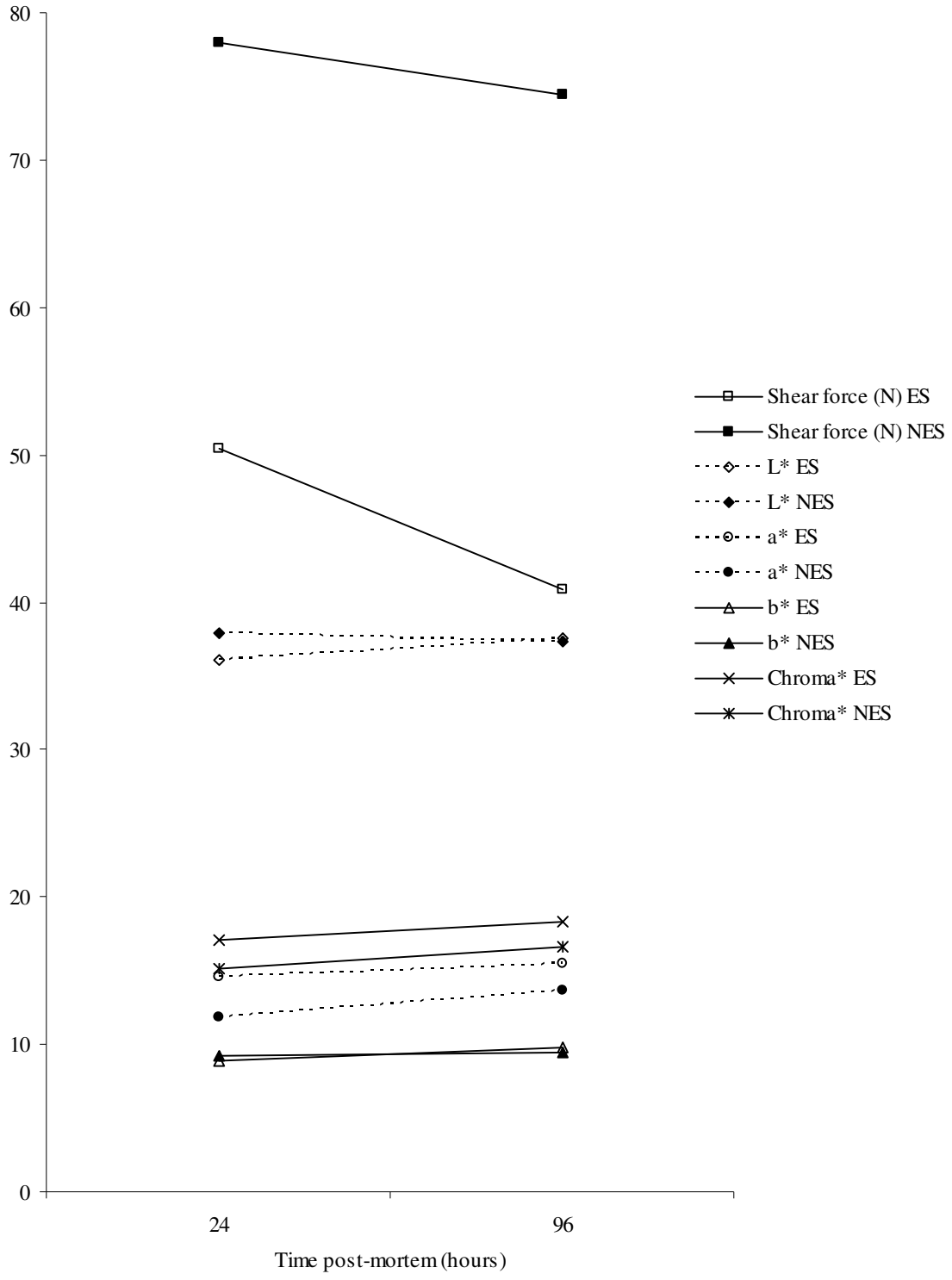

Figure 6.3 Effect of ageing and electrical stimulation on shear force (N) and colour co-ordinate values of the *M. semimembranosus* of South African indigenous goats

CHAPTER 6

6.3 DISCUSSION

The live animal and carcass characteristics of the goats have been discussed in detail in Chapter 4. In this chapter it suffices to say that because of the similarities in carcass traits between the two sexes only the overall effects of ES are presented.

6.3.1 Effect of Electrical Stimulation on Post-Mortem Metabolic State, pH Profile and Tenderness

The subset of goats that was used for this study had low initial GP levels, much like the goats in the previous experiment (Table 5.4). Thus the two sets of animals suffered similar levels of pre-slaughter stress. This led to a very small pH differential during post-mortem glycolysis, and hence high pHu values for both the ES and NES groups. According to Pearson and Young (1989) glycolysis ceases when glycogen concentration is about 10µmol/g and lactate between 80 and 100µmol/g. These concentrations would have been attained much sooner in the ES than the NES carcasses (Table 6.7). In effect both the LTL and SM muscles of the ES carcasses attained their lowest pH values within the first three to six hours post-slaughter and thereafter the pH tended to increase (Figures 6.1 and 6.2).

The changes in glycolytic metabolite concentration and pH show that ES was effective in accelerating glycolysis and thus creating conditions that were unfavourable for cold shortening but favourable for proteolytic activity. According to Bendall et al. (1960, as cited by Kondos and Taylor 1987), no sarcomere shortening occurs below 2µmol/g of ATP. In order to achieve this concentration of ATP, Kondos and Taylor (1987) estimate that NES beef carcasses would have to be held at 15°C for some 24 hours but, this ATP concentration was reached within two hours in electrically stimulated muscles stored at 15°C and 25°C. The present results are in accord with the fact that ES expedites ATP reduction so that low concentrations are attained much sooner.

Although ES produced conditions that were not conducive to cold shortening it had no effect on *longissimus* sarcomere length. Such a lack of effect has been reported in studies where low voltage electrical stimulation was employed (den Hertog-Meishcke, Smulders, van Logtestijn and van Knapen, 1997; Wiklund et al., 2001a) or in cases where post-slaughter holding temperatures posed no risk of cold shortening occurring (Savell et al., 1977). It has also been observed that within a carcass, ES does not have the same effect on the myofibre properties of

different muscles (Olsson, Hertzman and Tornberg, 1994; Eilers, Tatum, Morgan and Smith, 1996; den Hertog-Meishcke, et al., 1997). The lack of effect on *longissimus* SL implies that the LTL muscle was not at risk of cold or heat shortening (den Hertog-Meishcke, et al., 1994).

Electrical stimulation averted cold shortening of the SM muscle. The *semimembranosus* SL of the stimulated carcasses were near the upper limit of the range associated with intermediate tenderness (1.7 to 2.0µm; Marsh and Leet, 1966). By contrast, the corresponding SL of the NES carcasses were shorter and in the range associated with cold shortened and tough meat (Swartz et al., 1993). The shear force values of the SM muscles corroborated these differences in the SL of the two stimulation groups (Figure 6.4). It appears that stimulation not only resulted in SL that were favourable to tenderness but also reduced the variation in shear force.

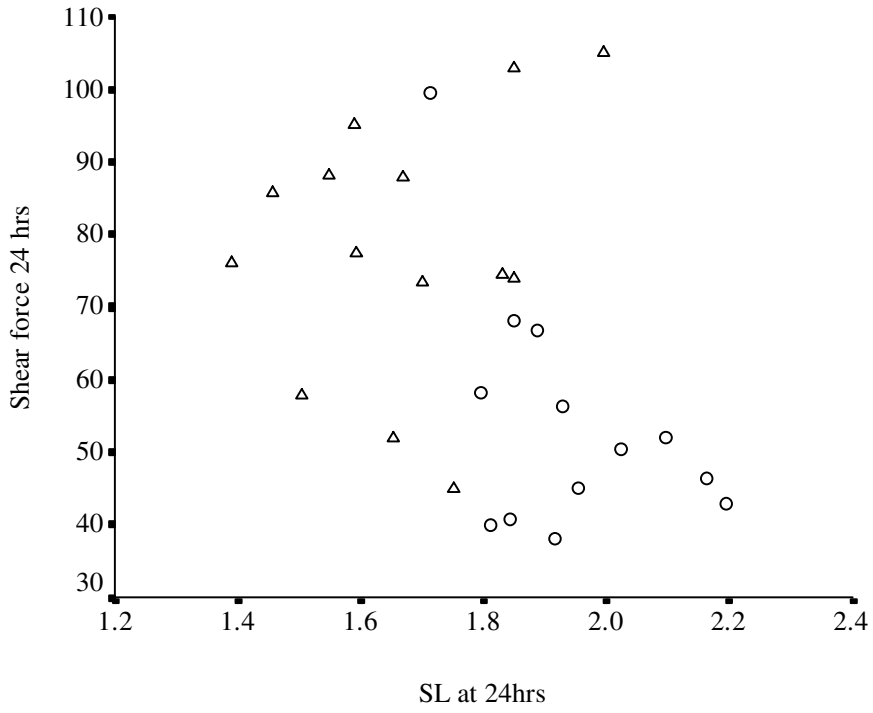

Figure 6.4 Relationship between 24-hour shear force (N) and sarcomere length (µm) of *M semimembranosus* of electrically stimulated (○) and non-stimulated (△) carcasses of South African indigenous goats

Electrical stimulation resulted early post-mortem pH values that were well below the critical points for averting cold shortening muscles (pH<6.2 when temperature <15°C) for both the LTL

and SM muscles, while the muscles of the NES carcasses were in the high risk zone (Honikel et al., 1983; Tornberg, 1996). In fact, when the pH_3 demarcations that were described in Chapter 5 (Tables 5.11 and 5.23) are employed, 86% of the ES carcasses had a *longissimus* pH_3<6.1 and only 14% had a pH_3 that was between 6.1 and 6.3. Similar distributions for the SM of ES goats were 77%, 15% and 8% for pH_3<6.1, between 6.1 and 6.3 and >6.3. In contrast the rate of post-mortem glycolysis was slow in the majority of NES carcasses, such that some 80% of each the LTL and SM had pH3>6.3. Only one SM and three LTL muscles had a pH_3 <6.1.

Muscles with such a slow rate of glycolysis as observed amongst the NES carcasses are susceptible to cold shortening and may yield tough meat. Toughness results not only from cold shortening but also from delayed attainment of a pH that is conducive for proteolysis by the calpain enzymes (Dransfield, 1994b; Hwang and Thompson, 2001a, b; Figure 6.5). Conversely, ES creates a suitable environment for proteolysis by reducing the pH to levels which promote a high rate of proteolytic and autolytic activity of the calpains (Marsh et al., 1987; Devine et al., 1996; Devine et al., 2002). High voltage electrical stimulation may however result in very low pH while carcass temperature is high. Such conditions lead to a rapid loss of μ-calpain activity and hence a reduced tenderisation potential (Hwang and Thompson, 2001a).

An intermediate rate of pH decline, such that muscle pH is 5.9 to 6.2 at 1.5 hours post-mortem (Hwang and Thompson, 2001b) seems to be the most ideal for beef tenderness. In view of these limits, the Meat Standards of Australia (MSA) have defined a pH/temperature window for beef tenderness in which proteolytic enzyme activity is said to be optimal (Thompson, 2002). The limits set for this window are a pH of greater than 6 when the muscle temperature is above 35°C and a pH of less than 6 when muscle temperature is less than 12°C. Electrical stimulation of goat carcasses resulted in temperature and pH values readings of the LT and SM within the MSA boundaries and hence more tender meat with a greater tenderisation potential than chevon from NES carcasses (Figure 6.3 and Figure 6.5). Thus, SM muscles of the ES carcasses were 35% more tender than those of the NES carcasses 24 hours post-mortem and 45% more tender by 96 hours post-mortem (Figure 6.3).

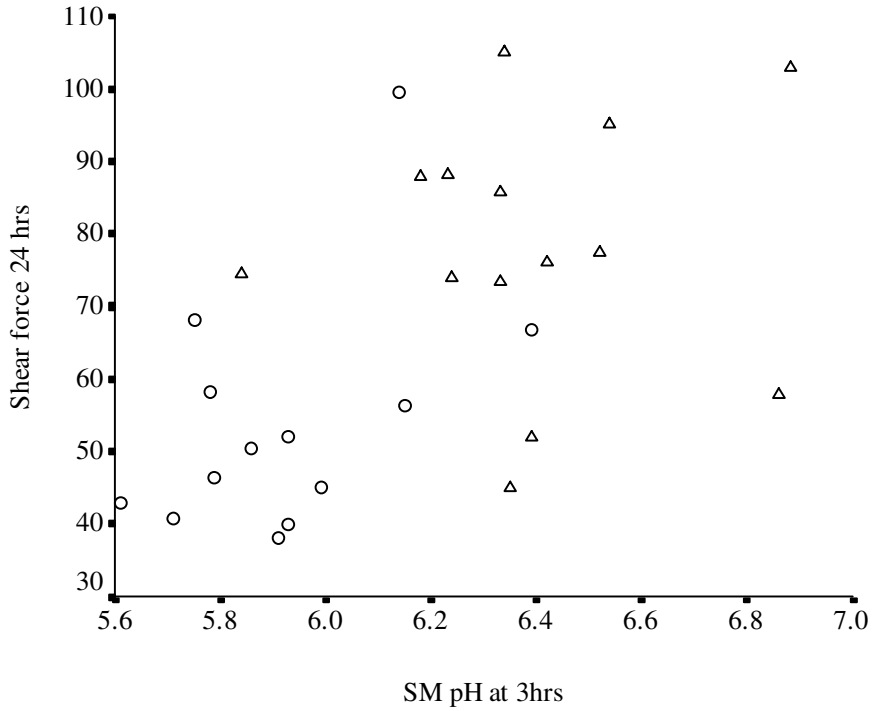

Figure 6.5 Relationship between 24-hour shear force (N) and 3-hour pH of *M. semimembranosus* of electrically stimulated (○) and non-stimulated (△) carcasses of South African indigenous goats

There have been conflicting reports on the efficacy of early post-mortem pH as an index of meat tenderness. Smulders et al. (1990), Pike et al. (1993) and Jones and Tatum (1994) all reported a positive relationship between pH_3 and meat tenderness while Shackelford et al. (1994a) found none at all. Eilers et al. (1996) did not find a significant relationship between pH_3 and tenderness but rather that in the region of pH_3 5.5 to 6.0, there was greater consistency in meat tenderness. Similarly, in this study, lower pH_3 values caused by ES resulted in lower 24-hour shear force values with less variation compared to those of the NES carcasses (Figure 6.5).

While the controversy on the usefulness of early post-mortem pH as an indicator of post-mortem tenderness is yet to be resolved, the present results suggest that there is merit in using ES to attain low pH_3 values. Although the toughness associated with high pH_3 values seems to be eventually resolved by ageing, it would be more advantageous to have lower shear force values

soon after slaughter in order to reduce the time required for ageing. This would also be more beneficial and economic for the fresh meat industry.

The difference in the 24-hour tenderness between NES and ES was evidently due to the prevention of cold shortening by ES (Figure 6.4) and possibly the stretching and tearing of the myofibres during stimulation. The fact that SM samples of ES carcasses continued to tenderise faster than the NES beyond 24 hours post-mortem shows that proteolytic activity was involved. Therefore, contrary to the perception that meat from animals with low pre-slaughter glycogen content and high pHu is not improved by ES, in this case the chevon tenderness was improved.

One study that propounded the view that ES has no effect on high pH meat was that by Dutson et al. (1981) who studied the effect of ES on stressed heifers. However a closer examination of Dutson et al.'s (1981) results shows that compared to the values obtain for the chevon of this study, the heifers had an exceedingly high pHu (6.65 for ES and 6.56 for NES carcasses). At such high pHu values, the dark cutting meat tends to be tender (Yu and Lee, 1986; Geesink, Ouali, Smulders, Talmant, Tassy, Guignot, and van Laack, 1992; Beltrán, Jaime, Santolaria, Sañudo, Albertí and Roncalés, 1997). This was in fact confirmed by the shear force values and the sensory ratings obtained for the beef in the study of Dutson et al. (1981). The shear force values of 4.4 and 4.3kg/1.3cm diameter core for ES and NES respectively, were in the range that is associated with acceptable tenderness by the USA standards (Huffman et al., 1996; Boleman et al., 1997; Miller et al., 2001). Likewise, the sensory panel tenderness ratings of 6.10 and 6.35 on a 1 to 8 scale were also within the acceptable range. Thus, due to the high pHu, the beef was already tender and ES did not have any additional effects. Such a lack of response also occurs with meat that normal pHu and has already attained baseline levels of tenderness (Hwang and Thompson, 2001b).

In contrast to the results of Dutson et al. (1981) the chevon of this study had pHu values that were similar to those of very tough beef (Lee and Yu, 1986; Smulders et al., 1990; Geesink et al, 1992; Beltrán et al., 1997) and lamb (Watanabe, et al., 1996; Simmons et al., 2000). It has been shown that such meat may improve in tenderness with ageing, albeit at a very slow rate (Watanabe et al., 1996). Thus, ES not only improved the initial tenderness of the chevon but also accelerated the rate of tenderisation during ageing despite the unfavourable pHu conditions

(Figure 6.3). Consequently chevon from ES had shear force values that were within the range for acceptable tenderness (Bickerstaffe, 1996; Huffman et al., 1996; Boleman et al., 1997; Daly, 2000; Miller et al., 2001) after ageing for four days.

Meat with a pHu within the intermediate range of 5.8 to 6.2 is not expected to tenderise much with ageing (Dransfield, 1994a) because this range of pH is outside the ranges for the neutral (>6.3) and acidic (<5.8) proteases (Yu and Lee, 1986). Based on this principle, the consistently high shear force values for the NES carcasses in the present study were expected. However, conflicting results have been reported on the ageing potential of intermediate pHu meat. Beef (Silva, Patarata and Martins, 1999) and venison from young reindeer bulls (Wiklund et al., 1997) were reported to age normally and reach acceptable levels of tenderness. Other studies have reported that intermediate pHu meat is tough initially but ages with storage either at a normal or slow rate (Watanabe et al., 1996; Purchas et al., 1999; Simmons et al., 2000; Geesink et al., 2001) while the results of Yu and Lee (1986) suggest that the meat does not tenderise at all with ageing. Results from the present study further illustrate the complexity of meat with intermediate pHu. The results clearly show that ES not only prevented cold –shortening (Figure 6.4) but also enhanced proteolytic activity, and hence tenderisation of chevon during post-mortem ageing (Rhee and Kim, 2002; Hwang and Thompson, 2001a and b). Since the initial toughness of intermediate pHu meat has been attributed to minimal activity of proteolytic enzymes, it is not clear how ES enhanced the rate of tenderisation of chevon within this pHu range.

The effect of proteolytic activity in this study should have been evident from the changes in the MFL. However, as discussed previously (§ 5.3.3.1 refers) myofibre fragmentation was confounded by sarcocyst infection of the muscles such that its representation of the degree of post-mortem proteolysis is uncertain, more so that there were no significant correlations between MFL and shear force values.

Despite the indications that electrical stimulated chevon tenderised more than the NES, the initial calpastatin activity was not affected by ES. Such results were also obtained by Uytterhaegen, Claeys, and Demeyer, (1992) and Geesink et al. (1994) for short duration ES (8 seconds). Other findings, such as Geesink et al. (1994) when using long duration stimulation (90 seconds), and Ferguson et al. (2001) reported a distinct decline in both calpastatin and μ-calpain with electrical

stimulation early post-mortem. A possible explanation for the lack of effect observed in this study is that since the response of calpastatin to ES is not as fast as that of the calpains (Ducastaing et al., 1985, Hwang and Thompson, 2001a) and the samples were collected shortly after stimulation, there were yet no differences between the ES and NES groups in the amount of deactivated calpastatin at the time of sampling. In studies where the temporal changes in the calpains and their inhibitor were monitored, differences in the concentration of these enzymes where observed later during the cause of chilling, even when there were no differences in the initial values (Uytterhaegen et al., 1992; Geesink et al., 1994).

The present study proves than even though chevon tends to have pHu values that are associated with tough meat, electrical stimulation of the carcasses enhances tenderness. It is difficult to fully explain the mechanism of how tenderisation of intermediate pHu chevon is achieved based on the present results. This can only be elucidated from a detailed analysis of the activities of the proteolytic enzymes and changes in their substrates and products in caprine muscles during post-mortem storage. An evaluation of these changes would further facilitate the development of appropriate post-mortem handling procedures for the meat chevon.

6.3.2 Effect of Electrical Stimulation on Cooking Losses and Colour

Cooking losses were not affected by ES or ageing and were about 32%. Reportedly, low voltage ES does not affect the water holding properties of meat but high voltage stimulation may (Eikelenboom, Smulders and Rudérus, 1985; Hanrahan, Ferrier, Shaw and Brook, 1998). However, the differences in water loss between ES and NES carcasses have been said to be too small to be of any economic importance in the production of fresh meat (Cross and Seideman, 1985; Wiklund et al., 2001a).

Electrical stimulation improved the redness and vividness of colour as has been previously reported for beef (Martin et al., 1983; Smith, 1985; Eikelenboom et al., 1985) and game (Wiklund et al., 2001a). This effect is attributed to the damage of oxidative enzymes, which would otherwise compete with myoglobin for oxygen (Ledward, 1992). With reduced competition for oxygen consumption, the concentration of oxymyoglobin formed on the meat surface is higher and hence the redder colour (Ledward, 1992).

As with tenderness, the enhancement of colour quality occurred in spite of the pHu which has been previously observed to hinder the development of normal colour even in electrically stimulated beef (Ledward, Dickson, Powell, and Shorthose, 1986). According to Smith (1985) there are indications that slight cases of dark cutting beef can be ameliorated by ES, whereas severe cases such as in the study of Dutson et al. (1981) study did not respond to ES. The pHu values for chevon in this study could well be in the border region of dark cutting and hence the meat responded positively to electrical stimulation.

Increase in the L* and b* values with ageing imply that the light scattering properties of the meat increased and there was less deoxygenated myoglobin on the surface of the meat (Gardner et al., 1999). These changes are in line with the fact that ageing has similar effects on muscle properties and hence colour quality as ES; the oxygen consuming enzymes in meat are denatured (Ledward et al., 1986) and the lattice structure shrinks (Offer and Trinick, 1983). Similar effects on beef (Martin et al., 1983; Ledward et al., 1986) and game (Wiklund et al., 2001a) have been reported. Even though ES and ageing improve meat colour quality, the resultant colour has been noted to be unstable during display (Ledward, 1992; Wiklund et al, 2001a) especially so for low pH rather than high pH meat (Ledward et al., 1986).

From the foregoing, it is inferred that despite the high pHu, the quality attributes considered important for the initial (colour) and continued acceptance (tenderness) of meat are improved by ES of goat carcasses to levels that are within generally acceptable ranges. Furthermore the advantages of ES on chevon tenderness seem to last beyond the four days considered herein and have been observed to last longer for at least up to seven days in earlier studies (McKeith, Savell, Smith, Dutson and Shelton, 1979). Since high pHu is a common phenomenon of chevon, incorporation of ES in the slaughter procedure would be advisable in order to improve the meat's quality.

6.4 SUMMARY

Electrical stimulation of chevon improved the rate of pH decline to levels outside the risk of cold shortening. In the SM muscle, ES averted cold shortening and resulted in more tender meat 24 hours post-mortem. The tenderness was likely due to the prevention of cold shortening,

enhancement of proteolysis and possibly the disruption of the myofibre structure. Electrical stimulation also improved the ageing potential of the SM muscle, showing that there was some proteolytic activity beyond the initial 24 hours post-mortem. In fact ES resulted in tenderness levels that were within the acceptable limits as defined for lamb and beef within four days of ageing.

Electrical stimulation did not affect cooking losses but it improved the colour of chevon even after ageing for 96 hours. Therefore electrical stimulation is beneficial for improving the quality of chevon even if the pHu is high.

CHAPTER 7

7 THE FATTY ACID AND AMINO ACID COMPOSITION OF CHEVON

7.1 INTRODUCTION

Several studies have indicated that chevon has a salubrious fatty acid profile and therefore suggested that the meat is ideal for the health conscious consumers (Hogg et al., 1992; Mahgoub, Khan, Al-Maqbaly, Al-Sabahi, Annamalai and Al-Sakry, 2002). In addition to their salient role in nutrition, fatty acids also influence flavour and keeping quality of meat. For example, it has been shown that high concentrations of α-linolenic acid (C18:3) such as occurs in meat from ruminants raised on forages (Enser et al., 1998) confer a grassy flavour that is not acceptable in some consumer circles but may be the main attraction in others (Sanudo, Enser, Campo, Nute, Maria, Sierra and Wood, 2000). High linoleic acid (C18:2) concentration is associated with grain-based diets and less intense meat flavour (Enser et al., 1998). Unsaturated fatty acids (UFA) are key to the keeping quality of meat. The higher the proportion of UFA, the more prone the meat is to oxidation and spoilage. The basic fatty acid profile of chevon is therefore an indication of not only the potential nutritive value of the meat but also its organoleptic and storage-related properties. According to Banskalieva, Sahlu and Goetsch (2000), data on the fatty acid composition of chevon is still scanty, fragmentary and based on different muscles and fat depots, making it difficult to compare results from various studies. This chapter will therefore add to the pool of information on chevon fat quality. The findings are based on the *M. longissimus*, which is generally accepted as the standard muscle for meat quality analysis.

Few studies are concerned with the biological value of meat possibly because of the fact that the composition of muscle protein is genetically determined and therefore would not be expected to be readily subject to the conditions during growth of the animal. On the other hand, the influence of growth, diet and sex on the proportions of muscles may well be translated into differences in protein, and hence amino acid composition of the muscle (Gilka, Jelínek, Janková, Knesel, Krejčí, Mašek and Dočekalová, 1989).

In many instances, reports on the nutritive quality of chevon are presented as stand alone studies without the complementary meat quality evaluation or vice versa. This is often the case because

comprehensive studies are expensive and time consuming. This chapter serves to give some indication of the fatty acid composition of the goats as well as the amino acid profile in order to present a more comprehensive profile of the quality of chevon from South African indigenous goats.

7.2 RESULTS

7.2.1 Fatty Acid Composition

Fatty acid concentrations and percentages in the LL of the South African indigenous goats are shown in Table 7.1. Not all fatty acids were detectable in all the LL samples. The most prevalent fatty acids were palmitic acid (C16:0), the C18 series and myristic acid (C14:0) which occurred in upwards of 93% of the samples. Eicosenoic (C20:1) and lauric (C12:0) acids were the least ubiquitous, occurring in 32% and 24% of the samples, respectively.

The most abundant fatty acids were oleic acid (C18:1), linoleic acid (C18:2) and C16:0, respectively. The three made up 74.4% of the total fatty acid content of the LL samples. Myristic acid, C20:1 and C12:0 were the least abundant, each constituting less than 1% of the total weight of the fatty acids. Using the experimental fatty acid profile, 98.5% of the fatty acids were identified.

Sex, age and pre-slaughter conditioning effects were tested only for the fatty acids occurring in more than 70% of the samples. Sex had no significant effect (P>0.05) on fatty acid concentrations, ratios and proportions (Table 7.2). Age of the goats tended to affect concentrations of C18:0 (P=0.060) and arachidic acid (C20:0) (P=0.065), and the UFA/SFA (P=0.057) and PUFA/SFA (P=0.081) ratios (Table 7.3) only. Stearic acid (C18:0) tended to be most abundant in full-mouthed goats and least concentrated in LL of kids. Arachidic acid tended to increase with the age of the goats from a mean of 1.17mg/g in milk-teethed kids to about twice as much in the 8-teeth group. The UFA/SFA ratio tended to be low in the 4-to-6 teeth group and PUFA/SFA ratio tended to be high amongst the milk-teethed kids. The proportions of the fatty acids did not significantly differ across the age groups (P>0.05) (Table 7.4). However, the SFA percentage tended to be lower in the milk-teethed kids than the older goats (P=0.062).

CHAPTER 7

Table 7.1 The occurrence, mean concentration (mean ± S.D. mg/g), range of concentration and proportions (mean ± S.D. percentage) of fatty acids in the *M. longissimus lumborum* of South African indigenous goats

Fatty acid	Occurrence (No of samples)	Concentration (mg/g)			% by weight of total fatty acids
		Mean ± S.D.	Min	Max	Mean ± S.D.
C12:0 Lauric	19	0.09 ± 0.24	0.00	1.09	0.23 ± 0.73
C14:0 Myristic	76	0.27 ± 0.31	0.01	2.61	0.69 ± 0.97
C16:0 Palmitic	78	7.99 ± 3.12	2.84	17.58	16.65 ± 3.64
C16:1 Palmitoleic	71	2.57 ± 1.36	0.57	7.87	5.14 ± 1.68
C17:0 Margaric	54	1.40 ± 0.84	0.07	3.56	2.90 ± 1.35
C17:1 Heptadecenoic	54	0.88 ± 0.52	0.05	2.06	1.98 ± 1.34
C18:0 Stearic	78	4.86 ± 2.06	1.62	10.52	10.01 ± 1.91
C18:1 Oleic	78	20.89 ± 7.89	7.65	45.04	43.13 ± 4.44
C18:2 Linoleic	78	8.16 ± 3.34	1.88	20.20	17.62 ± 5.45
C18:3 Linolenic	73	0.49 ± 1.74	0.03	14.91	0.70 ± 0.81
C20:0 Arachidic	41	2.19 ± 1.26	0.07	4.74	4.74 ± 2.38
C20:1 Eicosenoic	25	0.08 ± 0.05	0.01	0.22	0.22 ± 0.17
UNID	41	0.47 ± 0.64	0.00	2.51	1.06 ± 1.47
SFA	78	15.26 ± 5.98	5.84	32.55	31.88 ± 6.79
UFA	78	32.48 ± 11.15	10.83	73.18	67.53 ± 6.60
MUFA	78	23.84 ± 9.06	7.72	53.61	49.18 ± 5.61
PUFA	78	8.65 ± 3.62	2.12	20.82	18.35 ± 5.74
Total Fatty acids	78	48.00 ± 15.79	19.66	100.69	
UFA/SFA	78	2.26 ± 0.66	0.44	5.22	
PUFA/SFA	78	0.65 ± 0.43	0.10	3.56	

NB: Saturated fatty acids (SFA); unsaturated fatty acids (UFA); monounsaturated fatty acids (MUFA); polyunsaturated fatty acids (PUFA)

Table 7.2 Effect of sex on the concentration (mg/g) and proportions (%) of fatty acids in the *M. longissimus lumborum* of South African indigenous goats

Fatty acid	*P*-values of sex main effects	
	Fatty acid concentration (mg/g)	Fatty acid proportions (%)
C14:0 Myristic	0.4553	0.4878
C16:0 Palmitic	0.4174	0.2467
C16:1 Palmitoleic	0.7511	0.9286
C18:0 Stearic	0.5246	0.9262
C18:1 Oleic	0.4283	0.4531
C18:2 Linoleic	0.5619	0.4009
C18:3 Linolenic	0.4459	0.2488
C20:0 Arachidic	0.3860	0.4555
Total	0.2695	
Saturated fatty acids	0.2878	0.6489
Unsaturated fatty acids	0.5168	0.4976
Monounsaturated fatty acids	0.5226	0.4410
Polyunsaturated fatty acids	0.6043	0.5695
UFA/SFA	0.7461	
PUFA/SFA	0.7313	

NB: Saturated fatty acids (SFA); unsaturated fatty acids (UFA); polyunsaturated fatty acids (PUFA)

Table 7.3 Effect of age on the fatty acid concentration (mean ± S.D. mg/g) in the *M. longissimus lumborum* of South African indigenous goats

Fatty acid	Fatty acid concentration (mg/g) per age class				*P*-values
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
C14:0	0.46 ± 0.69	0.24 ± 0.17	0.29 ± 0.17	0.17 ± 0.10	0.9562
C16:0	6.18 ± 1.80	7.87 ± 7.74	7.33 ± 3.18	9.96 ± 3.09	0.3302
C16:1	2.17 ± 1.15	2.34 ± 1.07	2.40 ± 1.39	3.30 ± 1.67	0.5346
C18:0	3.52 ± 1.47	4.82 ± 1.99	4.45 ± 1.91	6.20 ± 1.98	0.0603
C18:1	16.18 ± 5.03	21.96 ± 7.74	17.69 ± 7.64	25.47 ± 7.28	0.1571
C18:2	8.18 ± 2.99	8.47 ± 3.97	6.62 ± 2.00	9.25 ± 3.27	0.6674
C18:3	1.71 ± 4.39	0.21 ± 0.15	0.30 ± 0.31	0.33 ± 0.43	0.3617
C20:0	1.17 ± 0.88	2.02 ± 1.16	2.09 ± 1.17	3.30 ± 1.17	0.0648
Total	38.55 ± 10.08	48.74 ± 16.25	42.36 ± 14.74	57.75 ± 15.08	0.1966
SFA	11.30 ± 3.25	14.73 ± 5.88	15.09 ± 6.28	18.69 ± 5.63	0.2118
UFA	27.15 ± 7.79	33.70 ± 11.07	26.90 ± 10.30	38.88 ± 11.08	0.1877
MUFA	18.57 ± 6.18	25.02 ± 8.41	19.98 ± 8.95	29.28 ± 8.61	0.1217
PUFA	9.81 ± 4.44	8.68 ± 3.96	6.92 ± 2.02	9.59 ± 3.36	0.4325
UFA/SFA	2.47 ± 0.54	2.37 ± 0.50	1.92 ± 0.62	2.18 ± 0.53	0.0567
PUFA/SFA	0.82 ± 0.33	0.63 ± 0.25	0.53 ± 0.25	0.57 ± 0.25	0.0844

NB: Myristic acid (C14:0); palmitic acid (C16:0); palmitoleic acid (C16:1); stearic acid (C18:0); oleic acid (C18:1); linoleic acid (C18:2); linolenic acid (C18:3); arachidic acid (C20:0); saturated fatty acids (SFA); unsaturated fatty acids (UFA); monounsaturated fatty acids (MUFA); polyunsaturated fatty acids (PUFA)

Table 7.4 Effect of age on the fatty acid proportions (mean ± S.D %) in the *M. longissimus lumborum* of South African indigenous goats

Fatty acid	% of total weight of fatty acids per age class				*P*-values
	0 teeth	2 teeth	4 to 6 teeth	8 teeth	
C14:0	1.32 ± 2.08	0.57 ± 0.52	0.77 ± 0.61	0.34 ± 0.28	0.4878
C16:0	15.52 ± 3.29	15.09 ± 4.54	17.40 ± 6.11	17.10 ± 2.84	0.7280
C16:1	5.08 ± 1.62	4.89 ± 1.50	5.06 ± 1.87	5.52 ± 1.88	0.9721
C18:0	8.74 ± 2.56	9.81 ± 1.62	10.30 ± 1.98	10.61 ± 1.73	0.1333
C18:1	40.25 ± 6.41	44.82 ± 3.32	40.94 ± 6.17	43.80 ± 3.03	0.6457
C18:2	20.81 ± 6.43	17.49 ± 5.18	16.44 ± 5.05	16.40 ± 4.62	0.8355
C18:3	1.07 ± 1.00	0.49 ± 0.43	0.86 ± 1.09	0.62 ± 0.76	0.5373
C20:0	2.77 ± 1.71	4.51 ± 2.25	4.92 ± 2.63	5.84 ± 1.76	0.3750
SFA	28.48 ± 5.96	30.14 ± 4.59	35.67 ± 9.74	32.24 ± 5.80	0.0624
UFA	67.32 ± 8.82	69.32 ± 4.51	63.28 ± 9.12	67.36 ± 5.57	0.2768
MUFA	45.97 ± 7.54	51.31 ± 3.91	45.98 ± 7.94	50.32 ± 3.87	0.4680
PUFA	21.94 ± 6.63	18.00 ± 5.23	17.30 ± 5.56	17.04 ± 4.96	0.3064

NB: Myristic acid (C14:0); palmitic acid (C16:0); palmitoleic acid (C16:1); stearic acid (C18:0); oleic acid (C18:1); linoleic acid (C18:2); linolenic acid (C18:3); arachidic acid (C20:0); saturated fatty acids (SFA); unsaturated fatty acids (UFA); monounsaturated fatty acids (MUFA); polyunsaturated fatty acids (PUFA)

The main source of variation in both fatty acid concentration and proportions was pre-slaughter conditioning (Tables 7.5 and 7.6). Pre-slaughter conditioned goats tended to have higher concentration of C18:1 (P=0.060), and hence UFA (P=0.060) and MUFA (P=0.056). As a result, the UFA/SFA ratio of the pre-slaughter conditioned goats was 1.6 times higher than that of the non-conditioned goats (P=0.030).

Proportionally, the pre-slaughter conditioned goats had significantly less C14:0 and combined SFA than the non-conditioned ones (P<0.01). Conversely the pre-slaughter conditioned goats had a significantly higher proportion of C18:1 (P=0.0004), and hence a higher proportion of MUFA (P=0.0004) than the non-conditioned goats.

The first order interaction effects of sex and age class, sex and pre-slaughter conditioning and, age class and pre-slaughter conditioning on the fatty acid concentrations (Table 7.7) and percentages (Table 7.8) were all not significant (P>0.05).

7.2.2 Amino Acid Composition

The amino acid composition of the kids (milk-teeth), young castrated males (2-to-4 teeth), young females (2-to-4 teeth) and does (8-teeth) were mostly similar (Table 7.9). Only alanine and tyrosine were significantly affected by the class of the goats (P<0.05). Both amino acids were least concentrated in LL of 2-to-4 teeth females and most concentrated in LL of mature does. The most abundant amino acid was glutamic acid, which averaged 13.65g/100g. Following glutamic acid were lysine, aspartic acid and leucine whose concentrations averaged 8.01g/100g, 7.88 g/100g and 7.08g/100g, respectively. Arginine, alanine and threonine averaged 5.65 g/100g, 4.95 g/100g and 4.70g/100g, respectively. Valine (4.07g/100g), isoleucine (3.92g/100g), glycine (3.87g/100g), serine (3.86g/100g) and phenylalanine (3.54g/100g) were all in a similar range of concentrations. Methionine (2.25g/100g), cysteine (0.93g/100g) and tryptophan (0.89g/100g) were the least concentrated amino acids.

Table 7.5 Effect of pre-slaughter conditioning on the fatty acid concentration (mean ± S.D. mg/g) in the *M. longissimus lumborum* of South African indigenous goats

	Mean concentration per pre-slaughter conditioning group		
Fatty acid	Non-conditioned	Conditioned	*P*-values
C14:0 Myristic	0.34 ± 0.38	0.16 ± 0.10	0.3491
C16:0 Palmitic	7.25 ± 2.99	9.09 ± 3.03	0.2306
C16:1 Palmitoleic	2.33 ± 1.24	2.87 ± 1.47	0.3247
C18:0 Stearic	4.49 ± 1.97	5.43 ± 2.09	0.4772
C18:1 Oleic	17.96 ± 6.72	25.32 ± 7.52	0.0602
C18:2 Linoleic	7.04 ± 1.93	9.87 ± 4.25	0.2685
C18:3 Linolenic	0.66 ± 0.29	0.24 ± 0.33	0.9335
C20:0 Arachidic	2.24 ± 1.27	1.86 ± 1.24	0.3631
Total	42.76 ± 13.51	55.47 ± 16.67	0.7782
Saturated fatty acids	14.65 ± 6.00	16.19 ± 5.91	0.9898
Unsaturated fatty acids	27.88 ± 8.74	39.00 ± 11.57	0.0597
Monounsaturated fatty acids	20.49 ± 7.90	28.90 ± 8.43	0.0560
Polyunsaturated fatty acids	7.70 ± 2.73	10.09 ± 4.31	0.3303
UFA/SFA	2.73 ± 2.05	4.31 ± 2.50	0.0304
PUFA/SFA	0.59 ± 0.29	0.66 ± 0.26	0.7782

NB: Saturated fatty acids (SFA); unsaturated fatty acids (UFA); polyunsaturated fatty acids (PUFA)

Table 7.6 Effect of pre-slaughter conditioning on the fatty acid proportions (mean ± S.D. percentage) in the *M. longissimus lumborum* of South African indigenous goats

	Mean % of total weight of fatty acids per pre-slaughter conditioning group		
Fatty acid	Non-conditioned	Conditioned	*P*-values
C14:0 Myristic	0.92 ± 1.16	0.31 ± 0.23	0.0021
C16:0 Palmitic	16.68 ± 4.60	15.49 ± 4.38	0.3950
C16:1 Palmitoleic	5.04 ± 1.62	5.21 ± 1.83	0.6703
C18:0 Stearic	10.14 ± 2.11	9.69 ± 1.70	0.4448
C18:1 Oleic	41.05 ± 5.17	45.76 ± 2.78	0.0004
C18:2 Linoleic	17.30 ± 5.55	17.75 ± 5.09	0.6857
C18:3 Linolenic	0.87 ± 0.90	0.44 ±0.57	0.7748
C20:0 Arachidic	4.94 ± 2.41	3.25 ± 1.64	0.7499
Saturated fatty acids	33.54 ± 7.83	29.03 ± 3.23	0.0211
Unsaturated fatty acids	64.94 ± 7.72	70.52 ± 4.32	0.1015
Monounsaturated fatty acids	46.71 ± 6.59	52.35 ± 3.23	0.0004
Polyunsaturated fatty acids	18.23 ± 5.95	18.17 ± 5.18	0.6331

Table 7.7 Interaction effects of age and sex, sex and pre-slaughter conditioning and conditioning and age on fatty acid concentration of the *M. longissimus lumborum* muscle of South African indigenous goats

	P-values of first order interactions		
Fatty acid	Age(sex)[1]	Sex*conditioning	Conditioning(age)[2]
C14:0 Myristic	0.3323	0.4926	0.7215
C16:0 Palmitic	0.7983	0.6102	0.8459
C16:1 Palmitoleic	0.6782	0.6039	0.9065
C18:0 Stearic	0.6498	0.4070	0.7073
C18:1 Oleic	0.5264	0.3450	0.8564
C18:2 Linoleic	0.1414	0.4695	0.1335
C18:3 Linolenic	0.4502	0.5885	0.8123
C20:0 Arachidic	0.2124	-	-
Total	0.5475	0.2695	0.9073
Saturated fatty acids	0.6183	0.1986	0.8082
Unsaturated fatty acids	0.4103	0.3767	0.7468
Monounsaturated fatty acids	0.5097	0.4037	0.8430
Polyunsaturated fatty acids	0.4018	0.5504	0.1741
UFA/SFA	0.0936	0.2560	0.5906
PUFA/SFA	0.1050	0.4366	0.1351

NB: 1- sex effects were nested in age effects (refer to § 3.3.2)

2- Age effects were nested in conditioning effects (refer to § 3.3.2)

Significant interaction effects ($P<0.05$) are in bold face

NB: Saturated fatty acids (SFA); unsaturated fatty acids (UFA); polyunsaturated fatty acids (PUFA)

Table 7.8 Interaction effects of age and sex, sex and pre-slaughter conditioning and conditioning and age on fatty acid proportions of the *M. longissimus lumborum* muscle of South African indigenous goats

	P-values of first order interactions		
Fatty acid	Age(sex)[1]	Sex*conditioning	Conditioning(age)[2]
C14:0 Myristic	0.2698	0.1020	0.2422
C16:0 Palmitic	0.2552	0.1832	0.4583
C16:1 Palmitoleic	0.6988	0.9745	0.9862
C18:0 Stearic	0.3938	0.8968	0.4998
C18:1 Oleic	0.5666	0.9333	0.2132
C18:2 Linoleic	0.2688	0.5630	0.3545
C18:3 Linolenic	0.6544	0.2552	0.8089
C20:0 Arachidic	0.4091	-	-
Saturated fatty acids	0.1589	0.1677	0.4656
Unsaturated fatty acids	0.1425	0.1552	0.3452
Monounsaturated fatty acids	0.6920	0.4137	0.1279
Polyunsaturated fatty acids	0.3938	0.5376	0.3261

NB: 1- sex effects were nested in age effects (refer to § 3.3.2)

2- Age effects were nested in conditioning effects (refer to § 3.3.2)

Significant interaction effects ($P<0.05$) are in bold face

NB: Saturated fatty acids (SFA); unsaturated fatty acids (UFA); polyunsaturated fatty acids (PUFA)

Table 7.9 Amino acid composition (mean ± S.D. g/100g) of *M. longissimus lumborum* muscle of South African indigenous goat kids, young goats and does

	amino acid concentration (g/100g)				
Amino acid	Kids	Female	Castrates	Does	*P*-value
Histidine	2.26 ± 0.14	2.44 ± 0.13	2.48 ± 0.24	2.55 ± 0.20	0.3110
Threonine	4.64 ± 0.14	4.67 ± 0.12	4.67 ± 0.15	4.82 ± 0.18	0.5510
Valine	3.97 ± 0.12	4.02 ± 0.16	4.06 ± 0.21	4.24 ± 0.11	0.1871
Methionine	2.22 ± 0.07	2.23 ± 0.07	2.29 ± 0.10	2.25 ± 0.04	0.6870
Isoleucine	3.93 ± 0.11	3.82 ± 0.16	3.86 ± 0.20	4.07 ± 0.17	0.3192
Leucine	7.03 ± 0.22	6.83 ± 0.33	7.10 ± 0.11	7.34 ± 0.31	0.2376
Phenylalanine	3.63 ± 0.16	3.50 ± 0.15	3.43 ± 0.07	3.61 ± 0.11	0.3611
Lysine	8.36 ± 0.31	8.11 ± 0.26	7.52 ± 0.34	8.04 ± 0.24	0.1079
Tryptophan	0.99 ± 0.07	1.00 ± 0.03	0.79 ± 0.15	0.77 ± 0.28	0.3379
Cysteine	0.92 ± 0.01	0.94 ± 0.02	0.92 ± 0.03	0.93 ± 0.01	0.4415
Aspartic acid	7.65 ± 0.05	7.73 ± 0.30	8.01 ± 0.12	8.13 ± 0.17	0.0824
Glutamic acid	13.43 ± 0.10	13.25 ± 0.29	13.80 ± 0.42	14.14 ± 0.40	0.0627
Serine	3.76 ± 0.02	3.79 ± 0.17	3.89 ± 0.03	3.99 ± 0.10	0.1290
Glycine	3.76 ± 0.26	3.91 ± 0.40	3.93 ± 0.19	3.88 ± 0.14	0.7538
Arginine	5.53 ± 0.16	5.44 ± 0.09	5.67 ± 0.15	5.95 ± 0.27	0.0973
Alanine	4.83 ± 0.07^{ab}	4.82 ± 0.05^{a}	5.03 ± 0.03^{ab}	5.10 ± 0.05^{b}	0.0290
Proline	3.15 ± 0.12	3.27 ± 0.22	3.32 ± 0.08	3.34 ± 0.17	0.3613
Tyrosine	3.07 ± 0.08^{ab}	3.01 ± 0.15^{a}	3.24 ± 0.07 ^{ab}	3.27 ± 0.11^{b}	0.0396

CHAPTER 7

7.3 DISCUSSION

7.3.1 Fatty Acid Composition

The proportion of identified fatty acids in this study was high. This implies that the standards profile employed in the analysis included most of the fatty acids that occurred in the intramuscular fat of the caprine LL muscle.

A comparison of the present results to Banskalieva's et al. (2000) compilation, Mahgoub et al. (2002) and Tshabalala et al. (2003) shows that South African indigenous goats had similar proportions of the major fatty acids to most of the earlier studies. The proportions of C16:0 and C18:0 tended to be on the lower side of the reported ranges of 15% to 31% and 12% to 20%, respectively. Oleic acid was within the reported range of 28% to 48%. On the contrary, C18:2 was above the 4% to 15% range and C18:3 on the lower end of the 0.17% to 3.15% range. Such high concentration of C18:2 have been reported for ostrich intramuscular fat, whose C18 series comprise about 10% C18:0, 30% C18:1, 16%, C18:2 and less than 2% C18:3 (Hoffman and Fisher, 2001; Girolami, Marsico, D'Andrea, Braghieri, Napolitano and Cifuni, 2003).

Chevon and ostrich are both lean red meats, which typically have relatively high phospholipid content (Enser et al., 1998) and, muscle phospholipids have high concentration of C18:2. For example, some reported values of C18:2 in phospholipids were about 11% of total fatty acids in forage-fed beef and 20% in grain-fed beef (Marmer et al., 1984; Larick and Turner, 1989; Webb, DeSmet, Van Nevel, Martens and Demeyer, 1998). Corresponding values reported for reindeer were 21% and 28%, respectively (Wiklund, Pickova, Sampels and Lundström, 2001b) while the levels in neutral lipids were less than 2% for both beef and venison.

Although the concentration of C18:2 usually increases with feeding of grain-based diets, the proportion was not changed by pre-slaughter conditioning in this study. However the proportion of C14:0 was three times lower in the pre-slaughter conditioned goats. Similarly, C12:0 percentages suggest that the content of this fatty acid was highly influenced by pre-slaughter conditioning. The fatty acid averaged 0.62% in non-conditioned goats and only 0.05% in the pre-slaughter conditioned group. (Statistical analyses were not performed on C12:0 because it was detected in only 19 of the 78 samples). Oleic acid and MUFA increased significantly with pre-

slaughter conditioning. Such dietary effects on C14:0 and MUFA have been reported previously for fattened sheep (Casey, van Niekerk and Spreeth, 1988) and for goats (Johnson et al., 1995). The dietary effects are a seemingly advantageous change in fatty acid profile to a more healthful one since the fatty acids that decrease (C12:0 and C14:0) are considered highly hypercholesterolaemic (Lichtenstein et al., 1998) while those that increase are at least neutral in that effect (Voet and Voet, 1990).

There are several considerations in the balance of fatty acids for beneficial effects to meat consumers. One is the PUFA/SFA ratio, which, in the present study, fell above the minimum of 0.45 that is recommended for British consumers (Enser et al., 1998). Another consideration is the proportion of what are termed desirable fatty acids, which are C18:0 and all unsaturated fatty acids (Banskalieva et al., 2000). In this study the desirable fatty acids constituted 77.5% of the LL muscle fatty acids. This value is within the range of 61 to 80% in the studies reviewed by Banskalieva et al. (2000) and higher than the 67.45% from Mahgoub et al. (2002) and the 66.4% of Tshabalala et al. (2003). Corresponding values that have been reported for beef and lamb/mutton range between 63% and 71% (Banskalieva et al., 2000).

In recent years interest has been in the n-3 and n-6 PUFA isomers and their proportions within human diets. The ratio of the n-6/n-3 fatty acids in lipids depends on the concentrations of their respective precursor fatty acids, C18:2 and C18:3. The average C18:2/C18:3 ratio is the present study was 16.6, a high value that is in the range associated with grain-based diets (Enser et al., 1998). According to Enser (2001), grain feeding has shifted the n-6/n-3 ratio from about two in ruminants on forages to between 7 and 20 in ruminants on grain-based diets. Therefore, while grain feeding has the desirable effect of reducing SFA that are implicated in coronary heart disease and enhancing the production of the neutral UFA, it has the adverse effect of raising the n-6 PUFA. High n-6 PUFA content is undesirable because these fatty acids yield eicosanoids with more powerful thrombotic tendencies than n-3 PUFA derivatives, which would predispose consumers to coronary diseases (Enser, 2001).

Reported results of the effects of sex on fatty acid composition have been variable. Johnson et al. (1995) reported lower muscle lipid content, PUFA percentage and a higher PUFA/SFA ratio for intact males compared to females. In concord with these findings, intact males in Mahgoub et al.

(2002) had higher concentration of C18:2, C18:3, C15:0 but lower concentration of C17:0, C16:0, C18:0 and C18:1 than females. No age effects were observed in this study. However, where sex and/or age effects occur on fatty acid percentages, they are usually attributed to differences in the degree of fatness between males and females and/or the different age groups rather than direct effects on the fatty acid proportions as such (Mahgoub et al., 2002). Females tend to be fatter than intact males, and hence to have a lower phospholipid to triacylglycerides ratio than the leaner males, and consequently, proportionately less PUFA. Similarly, as fatness increases with age, differences observed in fatty acid profile post-weaning tend to be reflective of increased fatness.

The oxidative stability of meat depends on the balance between oxidative substrates, such as PUFA, pro-oxidants and anti-oxidants (Morrisey et al., 1998). The high PUFA and MUFA content of chevon may compromise its shelf life.

7.3.2 Amino Acids

Compared to the amino acid profiles of lamb, ostrich, beef and chicken (Gilka et al., 1989; Sales and Hayes, 1996 and Lawrie, 1998), goat amino acid proportions tended to be lower.

According to Schweigert (1987), the amino acid composition of a protein remains remarkably constant independent of cut. There is nevertheless, a contention that it is feasible that differences in amino acids may occur between muscle locations, breeds and animals of different ages (Lawrie, 1998) as well as with different diets and muscle proportions (Gilka et al., 1989). In Gilka et al. (1989) tyrosine was the amino acid most influenced by monensin and lasalocid supplementation. Alanine was among several amino acids that varied with muscle type in ostrich, which included valine, leucine, methionine and glycine (Sales and Hayes, 1996). In the present study there is a suggestion of age effects on the concentration of tyrosine and alanine but the impact of the variation on the nutritive value of the muscle is unlikely to be substantial, more so that they are both non essential amino acids. On the whole, the present results suggest that there is negligible variation within the amino acid profile of caprine LL muscle.

On a whole meat basis however, the amino acid composition may be affected considerably by the fat content. This was aptly demonstrated by Sheridan et al. (2003) wherein Boer goats with

20.2% intramuscular fat had greater concentrations of eleven (namely; aspartic acid, threonine, glutamic acid, proline, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine and lysine) out of 18 amino acids that were profiled than Mutton Merino lambs with an intramuscular fat content of 36.8%.

The essential amino acid profile of chevon would adequately meet the dietary amino acid requirements of adult consumers that were proposed by Pellet and Young (1990). The estimated dietary requirements and concentrations obtained in the present study compare well (Table 7.10).

Table 7.10 Essential amino acid concentration in chevon from South African indigenous goats (mean ± S.D. g/100g) compared to dietary requirements of adult consumers

	Concentration (g/100g)	
Amino acid	Chevon†	dietary requirements of adults‡
Alanine	4.94 ± 0.13	3.8
Leucine	7.07 ± 0.29	6.5
Lysine	8.01 ± 0.40	5.0
Methionine & cysteine	3.18 ± 0.08	2.5
Phenylalanine & tyrosine	4.43 ± 0.26	6.5
Threonine	4.70 ± 0.15	2.5
Tryptophan	0.89 ± 0.18	1.0
Valine	4.07 ± 0.14	3.5

† Overall means from present study

‡ Pellet and Young (1990).

7.4 SUMMARY

Chevon from South African indigenous goats was found to have high concentration of PUFA, particularly C18:2, which were similar to values reported for ostrich. Consequently the PUFA/SFA ratio was high and typical of grain-fed ruminants. High C18:2/C18:3 suggested that the n-6/n-3 fatty acid ratio would be much higher than the recommended ratio of less than four.

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Most of the fatty acid proportions fell within the ranges that have been reported for chevon and other red meat species. Age and sex of the goats had no significant effect on the fatty acid profile. However, pre-slaughter conditioning resulted in lower concentration of C14:0 and total SFA, and increased concentration of C18:1 and hence MUFA but did not affect the PUFA content.

The amino acid proportions suggest that within the caprine LL muscle there is no variation in the amino acid profile. Chevon would adequately meet consumer dietary amino acid requirements of adult consumers.

8 ACCEPTABILITY OF CHEVON TO SOUTH AFRICAN CONSUMERS

8.1 INTRODUCTION

Most of the earlier sensory studies of chevon employed trained taste panels and generally showed that chevon and chevon products are of high quality (Breukink and Casey, 1989; Schönfeldt et al., 1993a and b; Tshabalala et al., 2003). These findings are in line with objective evaluations of the meat, which have consistently proved that it can be of satisfactory quality (e.g. Smith et al., 1978; McKeith et al., 1979; Swan et al., 1998; Kannan et al., 2001). Trained sensory panels function as laboratory instruments, and hence their deductions usually match results of instrumental evaluations of chevon quality. Notwithstanding these objective reports, acceptance of chevon to the 'untrained' consumer of the meat depends on more than just the technical quality and descriptive sensory analysis factors (Issachou, 1996). Therefore, while laboratory methods can provide precise and reliable information concerning technical and sensory attributes (intensity scores) only consumers can provide information about the acceptance of the meat (Muñoz and Chambers IV, 1993). Thus sensory evaluation of selected chevon samples by consumers was carried out in order to determine the acceptability of chevon to South African consumers in terms of the acceptance of the aroma, flavour and tenderness, intended frequency of consumption and preference for the meat in comparison to the more readily available mutton. The evaluation was carried out in two series. In series I, chevon from castrated and female goats and mutton, all from animals with 2-to-6 permanent incisors were compared. In series II, chevon from male kids (0 permanent incisors) and does (8 permanent incisors) and mutton from sheep with 2-to-6 permanent incisors were compared (§ 3.2.7 refers).

8.2 RESULTS

8.2.1 Meat quality characteristics of the chevon samples

In series I, the 2- to-6 teeth castrates were significantly heavier (ca.5.04kg) at slaughter (P=0.017) and yielded cold carcasses that were significantly (ca. 2.45kg) heavier (P=0.047) than the females (Table 8.1). During chilling, carcasses of the castrates lost about 0.57% less weight than those of the females (P=0.038). The two sex groups however did not significantly differ (P>0.05) in all other carcass characteristics, histological, histochemical, metabolic and proteolytic properties.

Table 8.1 Slaughter weight, carcass, histological, histochemical, metabolic and proteolytic characteristics of the 2-to-6 teeth castrate and female South African indigenous goats that were used in sensory evaluations (Means ± S.D.)

Characteristics	Castrates	Females	*P*-value
N	15	15	
Carcass:			
Slaughter weight (kg)	36.97± 5.76	31.93 ± 4.35	0.0169
Cold carcass weight (kg)	15.53 ± 2.98	13.08 ± 2.81	0.0465
Dressing out %	41.80 ± 2.62	40.56 ± 3.76	0.5069
Chilling losses %	2.52 ± 0.75	3.09 ± 0.84	0.0381
Total lean%	63.66 ± 3.50	63.37 ± 2.95	0.9669
Total bone %	20.75 ± 2.09	21.58 ± 2.59	0.4306
Total carcass fat %	14.78 ± 4.95	14.26 ± 4.17	0.4807
Kidney knob and channel fat (g)	474 ± 243	410 ± 242	0.5338
Intramuscular fat %	4.07 ± 1.00	4.03 ±1.73	0.6833
Crude protein %	23.76 ± 0.63	23.52 ± 0.92	0.7237
Histological and histochemical:			
Sarcomere lengths (24hrs)	1.85 ± 0.11	1.81 ± 0.22	0.7716
Myofibrillar fragment lengths (24hrs)	17.24 ± 2.06	18.28 ± 2.23	0.1249
Myofibrillar fragment lengths (96hrs)	17.01 ± 2.65	17.45 ± 2.85	0.6783
Red myofibre area (μm^2)	1 658 ± 417	1 905 ± 834	0.9826
Intermediate myofibre area (μm^2)	2 253 ± 432	2 392 ± 635	0.5557
White myofibre area (μm^2)	3 005 ± 554	3 318 ± 977	0.4450
% Red myofibres	27.37 ± 3.40	27.65 ± 3.16	0.6784
% Intermediate myofibres	33.80 ± 3.87	32.30 ± 3.83	0.2136
% White myofibres	38.83 ± 4.97	40.05 ± 4.55	0.1979
Metabolic and proteolytic:			
pH_3	6.18 ± 0.25	6.29 ± 0.21	0.3616
pH_{24}	5.89 ± 0.14	5.86 ± 0.11	0.6777
Glycolytic potential (µmol/g)	110.89 ± 26.08	97.97 ± 16.55	0.1017
Glycogen (µmol/g)	31.42 ± 12.02	29.88 ± 8.49	0.6784
Lactate (µmol/g)	41.48 ± 26.19	32.56 ± 9.96	0.7767
Calpastatin activity (U/g sample)	2.98 ± 1.08	3.14 ± 0.87	0.7089
Calpastatin specific activity (U/mg protein)	0.057 ± 0.025	0.055 ± 0.018	0.9010

In the second series (Table 8.2), the does were 34% heavier than the kids at slaughter (P=0.007). However, because the does dressed out 6.23% less than the kids (P=0.002) and lost 0.51% more during chilling (P=0.029), there were no significant differences (P>0.05) between the carcass weights of the two groups. The mean cold carcass weight was 16.13 ± 2.77kg.

The separable tissue proportions of the does and kids were mostly similar (P>0.05), except that the does tended to have more KKCF (P=0.052). The younger goats had a significantly higher CP% (P=0.037) than the older ones.

In terms of myofibre characteristics, the kids and does differed significantly only in red and white myofibre percentages (P<0.01). The younger goats had a 15% higher proportion of red and a 17% lower proportion of the white myofibres in the LT. The intermediate myofibres tended to abound in the LT of kids than of the does (P=0.052).

Initial GP concentrations of the does and the kids did not significantly differ (P>0.05). The mean was 84.93 ± 20.99µmol/g. However the initial glycogen and lactate concentrations tended to be lower (P=0.068) and higher (P=0.068), respectively, in LT of does than those of kids. Consequently the pH_3 of does was a significant 0.37 units lower than that of the kids (P=0.016). Ultimately, both groups had high pH_{24} values (>5.8) but that of the does was a significant 0.21 units higher (P=0.015) compared to that of the kids.

Calpastatin activity per gram and calpastatin specific activity were similar between the 2-to-6 teeth castrates and females (P>0.05). The averages were 3.73U/g and 0.074U/mg protein, respectively.

Cooking losses of each meat type are shown in Table 8.3. Mutton samples lost significantly more weight (P=0.019) during cooking than chevon samples from female goats of the first series (2-6 permanent incisors). Losses from samples in the second series did not significantly differ (P>0.05).

Table 8.2 Slaughter weight, carcass, histological, histochemical, metabolic and proteolytic characteristics of South African indigenous goats kids and does that were used in the sensory evaluations (means ± S.D.)

Characteristics	Kids	Does	*P*-value
N	6	9	
Carcass:			
Pre-slaughter weight (kg)	30.50 ± 5.78	40.94 ± 3.29	0.0066
Cold carcass weight (kg)	14.61 ± 2.68	17.16 ± 2.46	0.1115
Dressing out %	47.96 ± 1.03	41.73 ± 3016	0.0018
Chilling losses %	1.03 ± 0.47	1.54 ± 0.38	0.0291
Total lean%	58.22 ± 6.13	56.37 ± 3.43	0.5956
Total bone %	19.12 ± 1.73	18.09 ± 2.62	0.2155
Total carcass fat %	21.84 ± 7.07	24.50 ± 2.70	0.6797
Kidney knob and channel fat (g)	726 ± 328	1 092 ± 301	0.0516
Intramuscular fat %	4.38 ± 1.61	6.74 ± 2.97	0.1891
Crude protein %	23.58 ± 1.01	21.76 ± 1.36	0.0370
Histological and histochemical:			
Sarcomere lengths (24hrs)	1.84 ± 0.24	1.87 ± 0.15	0.8596
Myofibrillar fragment lengths (24hrs)	18.58 ±1.97	18.40 ± 1.67	0.8596
Myofibrillar fragment lengths (96hrs)	15.98 ± 1.19	16.09 ± 1.69	0.9530
Red myofibre area (μm^2)	1 939 ±391	1 870 ± 472	0.6797
Intermediate myofibre area (μm^2)	2 554 ± 524	2 552 ± 581	0.8596
White myofibre area (μm^2)	3 261 ± 663	3 407 ± 770	0.7691
% Red myofibres	28.27 ± 1.78	24.65 ± 1.86	0.0080
% Intermediate myofibres	36.09 ± 2.99	32.03 ± 2.49	0.0516
% White myofibres	35.64 ± 3.55	43.03 ± 2.83	0.0056
Metabolic and proteolytic:			
pH_3	6.42 ± 0.22	6.05 ± 0.26	0.0155
pH_{24}	5.92 ± 0.10	6.13 ± 0.15	0.0153
Glycolytic potential (µmol/g)	89.75 ± 14.60	81.73 ± 24.68	0.5956
Glycogen (µmol/g)	30.98 ± 3.54	18.72 ± 12.10	0.0675
Lactate (µmol/g)	22.30 ± 9.19	39.56 ± 20.99	0.0675
Calpastatin activity (U/g sample)	3.65 ± 0.89	3.80 ± 1.21	0.5165
Calpastatin specific activity (U/mg protein)	0.070 ± 0.021	0.078 ± 0.028	0.5956

Table 8.3 Cooking losses (%) from the chevon and mutton samples that were employed in the sensory evaluations

Meat type*	Series I*		Series II*	
	No of samples cooked	Cooking losses (%) (Mean ± S.D.)	No of samples cooked	Cooking losses (%) (Mean ± S.D.)
Female goats	15	16.23 ± 5.48[a]	10	20.22 ± 5.02
Male goats	15	19.11 ± 4.98[ab]	11	22.44 ± 6.21
Sheep	13	22.58 ± 4.94[b]	9	26.15 ± 4.43
P- value		0.0186		0.0851

* In series I all animals had between 2 and 6 permanent incisors. The male goats were all castrates. In series II male kids had no permanent incisors and were a mixture of intact and castrated males. Female goats had 8 permanent incisors and sheep had 2 to 6 permanent incisors.

[a, b] Means in the same column with different superscripts differ significantly ($P<0.05$).

8.2.2 Profile of consumer panels and effects on acceptability ratings

The profiles of the consumer panels used in each series are described in Table 3.2 (§ 3.2.7.2 refers). The effects of consumer population category, gender, age and level of education on the acceptability of the sensory attributes are presented in Table 8.4 and Figure 8.1 for series I of the sensory evaluations. Black and white consumers in series I did not significantly differ in their acceptance of the sensory attributes ($P>0.05$). The consumers rated the attributes as "acceptable", with mean hedonic scores between 3.80±0.749 and 3.95±1.15.

Female consumers awarded significantly higher scores ($P<0.05$) than male consumers for the acceptability of tenderness, flavour and hence overall acceptability (Figure 8.1). Scores by female consumers were in the "extremely acceptable" range (between 4 and 5) while those by males were in the "acceptable" range (between 3 and 4).

Acceptance of aroma and overall acceptability by the 21 to 30 years old group were significantly lower ($P<0.05$) compared to ratings by the older consumers by at least 0.4 units in each case.

Table 8.4 ***P*-**values for the analysis of variance for the effects of consumer population category gender, age and level of education on ratings of aroma, flavour, tenderness and on overall acceptability in the first series of evaluations*

Sensory attribute	Series mean (± S.D.)	*P*-values			
		Population category	Gender	Age	Level of education
Aroma	3.82 ± 0.88	0.6294	0.0651	0.0005	<0.0001
Tenderness	3.90 ± 0.93	0.4684	<0.0001	0.2966	0.1227
Flavour	3.94 ± 0.97	0.8364	0.0282	0.1038	0.0054
Overall acceptability	3.88 ± 0.73	0.5591	0.0006	0.0136	0.0003

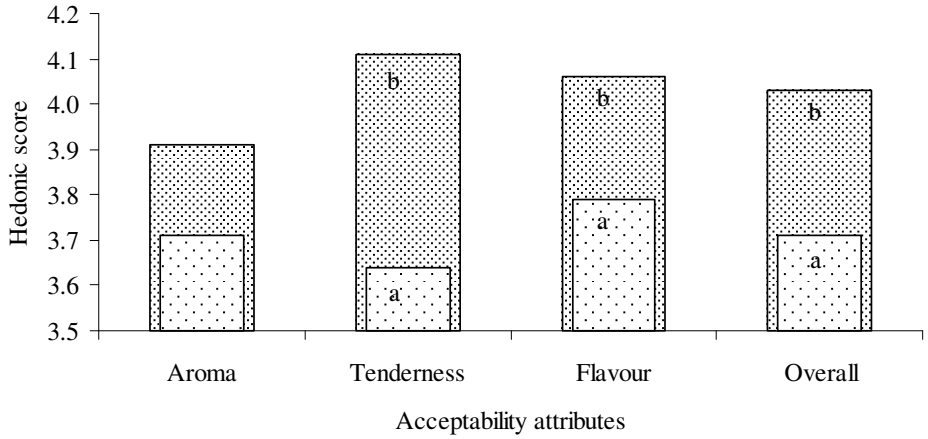
NB In series I meat samples were from castrated and female goats, and sheep with between 2 and 6 permanent incisors.

Mean scores for tenderness and flavour were not significantly affected by the age of the consumers ($P>0.05$). Mean scores for flavour ranged from 3.9±0.94 to 4.09±1.11 and tenderness scores varied between 3.82±0.97 to 4.02±0.76.

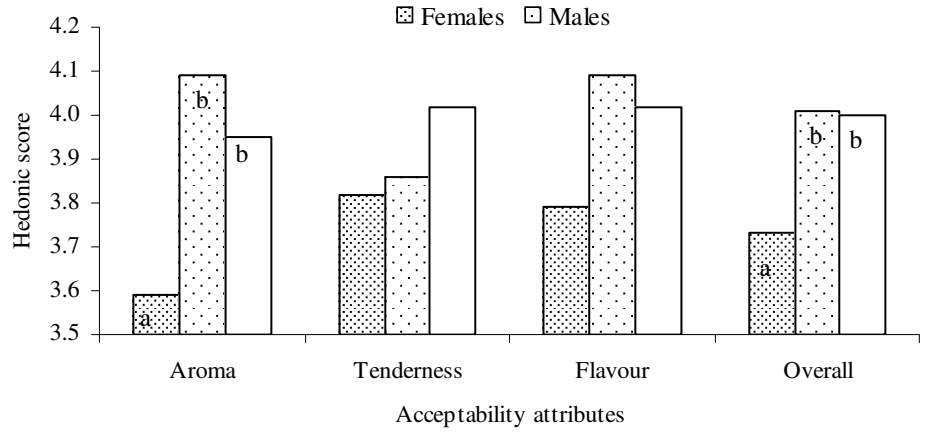
Consumers with up to primary level of education generally awarded high scores for sensory attribute acceptability. The mean scores ranged from 4.22±0.85 for tenderness, 4.37±0.78 for aroma to 4.48±0.85 for flavour, and hence 4.36±0.78 for overall acceptability. The scores were significantly higher ($P<0.001$) than those awarded by consumers with a tertiary level of education for aroma (3.64±0.80), flavour (3.83±0.92) and overall acceptability (3.77±0.66). The group with a primary level of education only differed significantly from that with a secondary level of education in the rating of flavour acceptability and the overall acceptability. Mean acceptance of flavour and overall acceptably by the latter group were 3.99±0.82 and 3.77±0.66, respectively.

The majority of consumers (60.7%) in series I indicated that they would eat any of the meats as frequently as once a week or more (Table 8.5). The median for the distribution of the scores was 4.00 and the 25 to 75 percentile range 3.00 to 5.00.

i)



ii)



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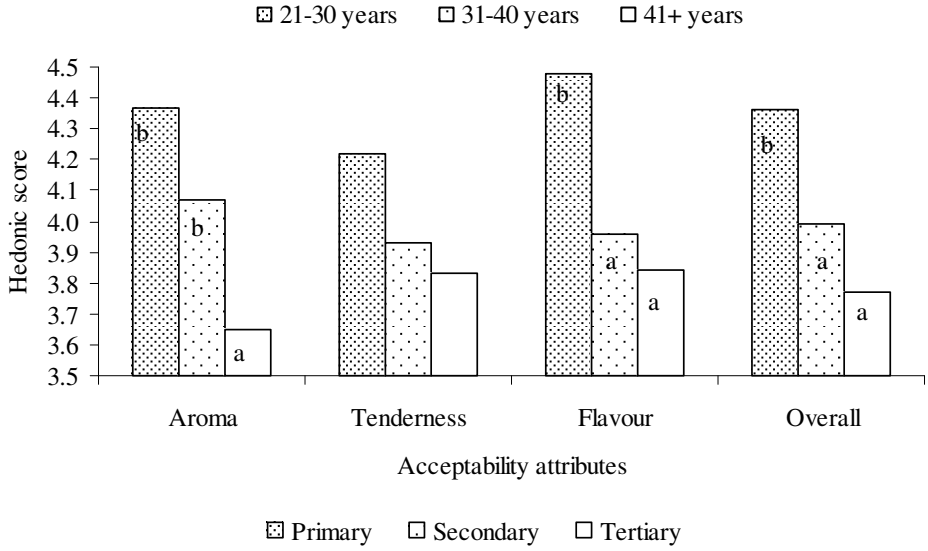


NB Bars within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$)

Figure 8.1 The effect of consumer i) gender, ii) age and iii) level of education on the ratings of sensory attributes of meat samples employed in series I of sensory evaluations

Table 8.5 Distribution of ratings for intended frequency of consumption with consumer population groups, gender, age and level of education for series I of sensory evaluations

Main effect	% of consumers per intended frequency of consumption					*P*-value
	Never	When no other food is available	Occasionally	Once a week	Daily	
Mean	3.6	7.5	28.2	29.4	31.3	
Population group						
Black	5.8	11.7	20.0	26.7	35.8	0.0740
White	1.5	3.5	35.6	31.8	27.3	
Gender						
Females	2.2	6.5	27.5	29.0	34.0	0.1263
Males	5.3	8.8	28.9	29.8	27.2	
Age (years)						
21-30	5.4	9.0	34.2	26.1	25.2	
31-40	3.5	10.5	17.5	26.3	42.1	0.0278
>40	1.2	3.6	27.4	35.7	32.1	
Level of education						
Primary	7.4	-	11.1	18.5	63.0	
Secondary	1.8	8.8	15.8	31.6	42.1	0.0001
Tertiary	3.6	8.5	35.1	30.4	22.6	

Ratings for the intended frequency of consumption were affected by age (P=0.028) and level of education of the consumers (P=0.0001). A smaller proportion (51.3%) of consumers between 21 and 30 years of age would consume any of the meats at least once a week compared to 68.4% of the 31 to 40 year olds and 67.8% of the consumers over 40 years of age. However, the medians (4.00) and 25 to 75 percentile ranges (3.00 to 5.00) were the same for the three age groups.

A high proportion of consumers with a primary level of education (81.5%) would consume meat at least once a week. This proportion declined with an increasing level of education to 73.7% of those with secondary and 53.0% of those with a tertiary education. A sizeable proportion of those with tertiary education (35.1%) would consume meat occasionally (about once a month). The medians and 25 to 75 percentile ranges for the food action ratings by consumers with primary, secondary and tertiary level of education were, respectively 5.00 and 4.00-5.00; 4.00 and 3.00-5.00, and 4.00 and 3.00- 4.00.

In series II, rating of sensory attributes significantly varied with population category of the consumers (Table 8.6, Figure 8.2). Black consumers awarded significantly higher scores for all the sensory attributes than white consumers ($P<0.05$). The difference was large (+0.44) and highly significant ($P=0.0002$) between the mean tenderness scores and smaller between mean flavour (+0.26) and mean aroma (+0.22) scores. Mean overall acceptability scores between the two groups significantly differed by 0.3 ($P=0.004$).

Unlike in series I, tenderness scores by male consumers in series II were significantly ($P=0.020$) higher than those by female (+0.26) consumers. There were however no significant differences in ratings for aroma, flavour and in the overall acceptability score ($P>0.05$). As in series I, consumers who were between 21 and 30 years old generally rated acceptability of the sensory attributes lower than the older groups. The younger group's ratings for aroma and overall acceptability were at least 0.3 units lower ($P<0.001$) than the ratings by the groups above 30 years old. Ratings for tenderness significantly differed between the 21 to 30 years old and over 40 years groups only by 0.5 units. There were no significant consumer age effects ($P>0.05$) on the ratings for flavour acceptability.

Level of education was highly significant in the ratings of sensory attributes in series II ($P<0.0001$). Consumers with tertiary education awarded the lowest scores for each attribute (3.64±0.80 for aroma, 3.57±0.94 for tenderness, 3.83±0.90 for flavour and overall acceptability of 3.68±0.71). These means were 0.3 to 0.45 lower than the ratings by consumers with secondary level of education, whose scores were in turn 0.5 to 0.7 lower than those of consumers with primary level of education.

Table 8.6 *P*-values for the analysis of variance for the effects of consumer population category gender, age and level of education on ratings of aroma, flavour, tenderness and overall acceptability in the second series of samples*

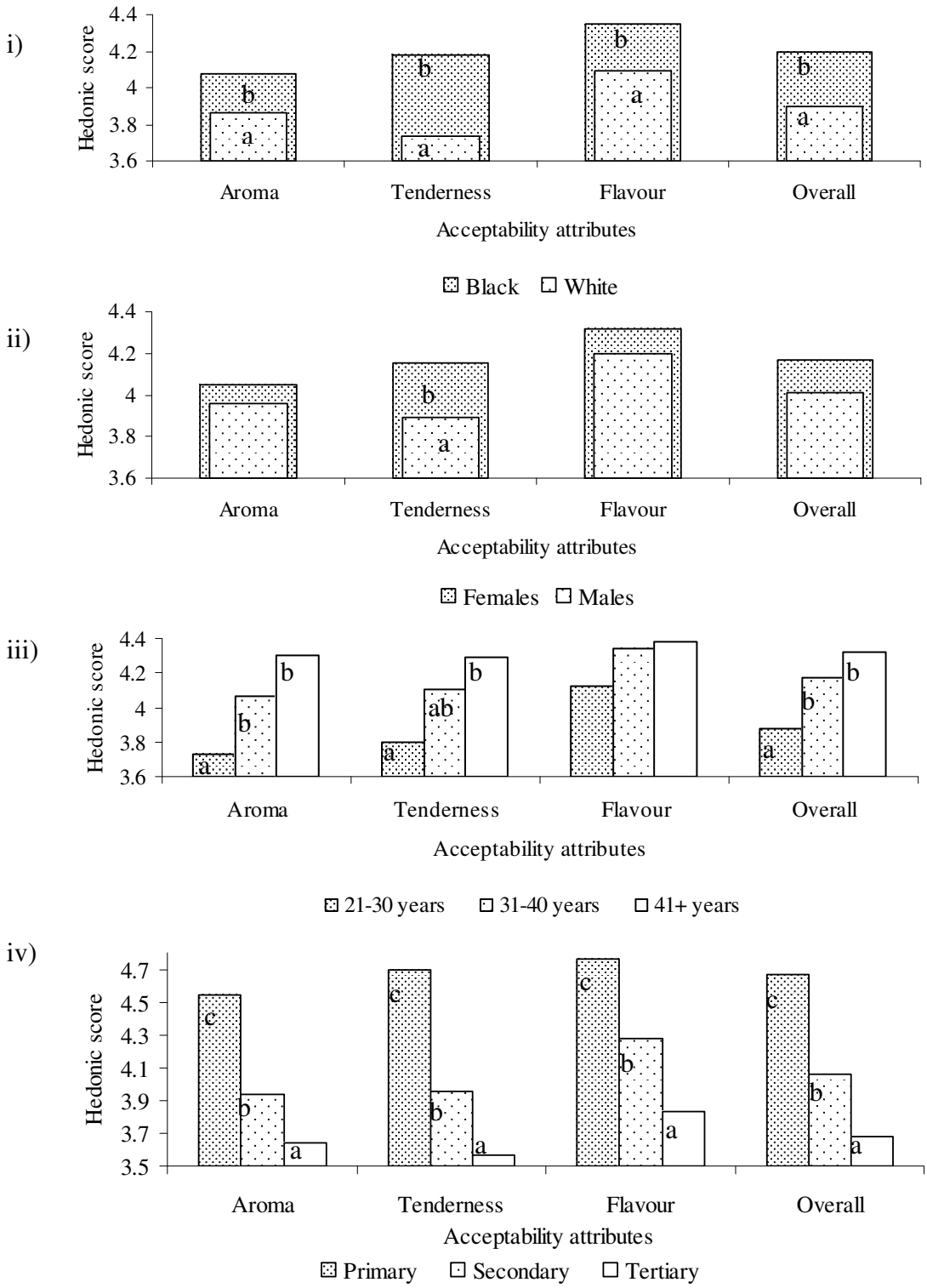
Sensory attribute	Series mean (± S.D.)	*P*-values			
		Population category	Gender	Age	Level of education
Aroma	4.02 ± 0.95	0.0339	0.3390	<0.0001	<0.0001
Tenderness	4.05 ± 0.97	0.0002	0.0197	0.0006	<0.0001
Flavour	4.27 ± 0.90	0.0115	0.2215	0.0564	<0.0001
Overall acceptability	4.11 ± 0.80	0.0004	0.0826	0.0002	<0.0001

NB. In series II male goats had no permanent incisors and were a mixture of intact and castrated males. Female goats had 8 permanent incisors and sheep had 2 to 6 permanent incisors.

All consumer attributes significantly affected the food action ratings for frequency of consumption in series II (Table 8.7). Generally more black (82.2%) than white consumers (62.5%) would eat meat at least once a week (P=0.0001). The medians of the scores were 4.00 for each group and the 25 to 75 percentile ranges were 4.00 to 5.00 for the black and 3.00 to 5.00 for the white consumers.

A higher proportion of male consumers (80.9%) would eat meat as frequently as weekly or more compared to females (69.1%). The medians for the food action ratings were 4.00 in each case and the 25 to 75 percentiles 4.00 to 5.00 for male and 3.00 to 4.00 for female consumers.

The older the consumers, the higher the intended frequency of consumption (P<0.0001) was. The frequencies for once a week or more were 70.8%, 73.6% and 85.7% respectively for 21-30 years, 30- 40 years older than 40 years old consumers. The medians were 4.00 for each age group but the percentiles were 3.00 to 4.00, 3.00 to 5.00 and 4.00 to 5.00 for the 21-30, 31-40 and over 40 year old groups, respectively.



NB Bars within a graph with different letters 'a', 'b' or 'c' differ significantly ($P<0.05$)

Figure 8.2 The effect of consumer i) population category, ii) gender, iii) age and iv) level of education on the ratings of sensory attributes of meat samples employed in series II

Table 8.7 Distribution of ratings for intended frequency of consumption with consumer population groups, gender, age and level of education for series I of sensory evaluations

Main effect	% of consumers per intended frequency of consumption					*P*-value
	Never	When no other food is available	Occasionally	Once a week	Daily	
Mean	0.6	2.4	20.5	38.8	37.6	
Population group						
Black	0.4	1.7	15.6	39.8	42.4	0.0002
White	1.0	4.2	32.3	36.5	26.0	
Gender						
Females	0.8	2.4	27.6	46.3	22.8	<0.0001
Males	0.5	2.5	16.2	34.3	46.6	
Age (years)						
21-30	0.8	1.0	25.0	45.	25.8	
31-40	1.0	3.9	21.6	32.4	41.2	0.001
>40	-	-	14.3	38.1	47.6	
Level of education						
Primary	1.0	1.0	3.1	39.6	55.2	
Secondary	-	-	21.1	41.5	37.4	<0.0001
Tertiary	0.9	6.5	35.2	35.2	22.2	

Conversely, the higher the level of education, the lower the intended frequency of consumption for the meats ($P<0.0001$) was. Virtually all consumers with primary level of education (94.8%) would consume meat at least once a week. The median food action rating for this group was 5.00 and the 25 to 75 percentile range was 4.00 to 5.00. Amongst consumers with secondary and tertiary level of education, respectively 78.9 % and 57.4% of them would consume meat at least

once a week. In the latter case 35.2% of consumers would eat meat occasionally. The median food ratings by consumers with secondary and tertiary level of education were 4.00 each, while the 25 to 75 percentile ranges were 4.00 to 5.00 and 3.00 to 5.00, respectively.

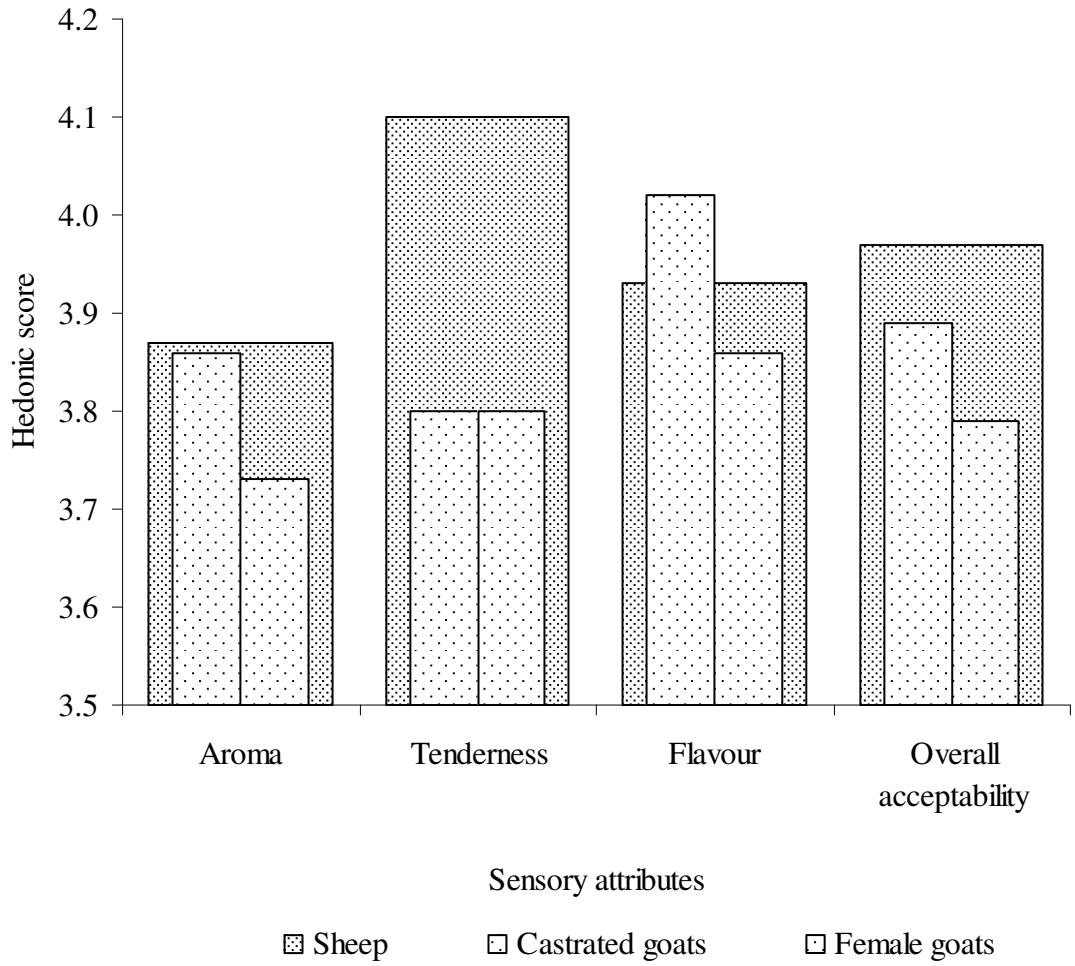
There were no significant effects of consumer gender, age, population group and level of education ($P>0.05$) on preference for any of the three types of meat presented to consumers in each series. The *P*-values of the maximum likelihood analysis of variance for the two series are shown in Table 8.8.

Table 8.8 Maximum likelihood analysis for effect of consumer gender, age, population category and level of education on meat preferences.

	Degrees of freedom	Series I		Series II	
		χ^2	*P*-value	χ^2	*P*-value
Gender	3	7.18	0.0664	0.81	0.8471
Age	6	2.89	0.8224	6.62	0.7282
Population group	3	2.42	0.4902	2.91	0.4058
Level of education	3	1.51	0.6791	5.49	0.1395

8.2.3 Acceptability of sensory attributes and consumption intent for the different meat types

In the first series there was a tendency for mutton to be rated as more tender ($P=0.055$) than chevon from either the castrates or female goats (Figure 8.3). However, there were no differences in the acceptability of flavour and aroma of chevon and mutton to consumers ($P>0.05$). Consequently there were no significant differences in the overall acceptability of the three meat types ($P>0.05$). Neither were there any differences in the intended frequency of consumption ($P>0.05$). Mean ratings for the acceptability of each of the sensory attributes and medians for consumption intent were high. The ratings averaged between 3.73-3.88, 3.80-4.10, 3.86-4.02 and 3.79-3.97 for aroma, tenderness, flavour and overall acceptability, respectively. The medians for consumption intent were 4.00 and the 25 to 75 percentile between 3.00 and 5.00 for each meat type. The ratings imply that the consumers found each of the three meat types ‘ acceptable’ and would eat any of them as often as once a week.

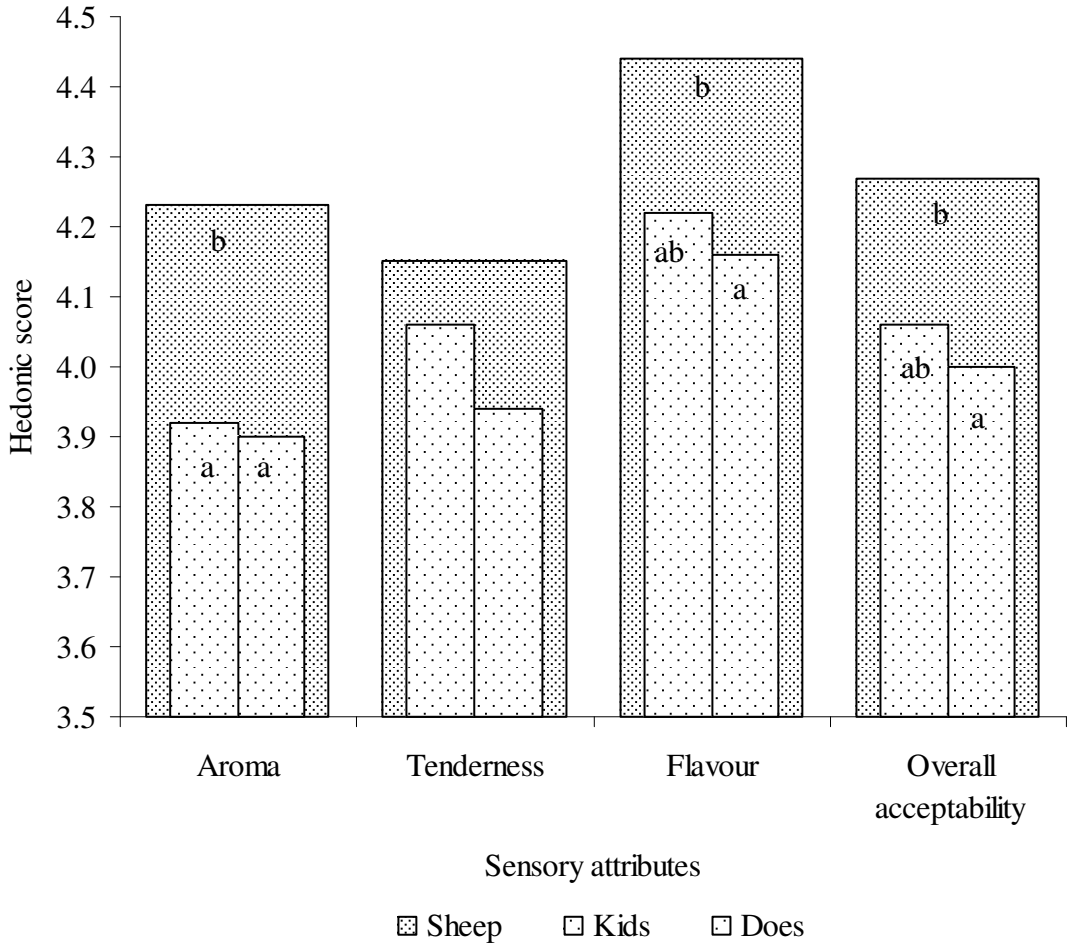


NB Hedonic scores for aroma, tenderness, flavour and overall acceptability range from 5 (extremely acceptable) to 1 (extremely unacceptable).

Figure 8.3 Acceptability of chevon from 2-to 6 teethed castrates and female goats compared to mutton from sheep of similar age

For the second series of samples (Figure 8.4), consumers rated aroma of mutton significantly more acceptable than that of chevon from the old does and kids (P=0.013). Aroma of mutton was rated "extremely acceptable" (4.23±0.89) while that of chevon from the kids (3.92±0.98) and does (3.90±0.96) were "acceptable". There was a tendency (P=0.050) for the flavour of mutton to be more acceptable than that of chevon from the does. Acceptability ratings for the flavour of mutton, chevon from kids and does were, respectively 4.44±0.77, 4.22±0.99 and 4.16±0.91. There were however no significant differences (P>0.05) between the samples for the acceptability of tenderness. The average ratings were between 3.94±0.98 and 4.15±0.90. Overall, mutton was more acceptable than chevon from old does but not that from kids (P=0.039). The

overall acceptability scores were 4.27±0.71, 4.06±0.87 and 4.00±0.80 for mutton, chevon from kids and chevon from does, respectively. Ratings of the acceptability of all the sensory attributes did not differ significantly between the does and kids (P>0.05).



NB Means of the same attribute with different letters 'a' or 'b' differ significantly (P<0.05) Hedonic scores for aroma, tenderness, flavour and overall acceptability range from 5 (extremely acceptable) to 1 (extremely unacceptable).

Figure 8.4 Acceptability of chevon from milk-teethed male kids and old does compared to mutton from 2-to-6 teethed females

Intended frequency of consumption was affected by meat type in series II (P=0.017). Consumers would eat mutton more often than chevon from old does but not significantly more often than chevon from kids. Consumption intent for chevon from kids and that from does did not differ (P>0.05). The medians for the food action ratings for consumption intent were 4.00 for each meat type. The 25 to 75 percentile ranges were 3 to 5 for both goat meat types and 4 to 5 for mutton.

Ratings of sensory attributes indicated that all the meats were "acceptable" (hedonic scores between 3 and 4) to "extremely acceptable" (hedonic between 4 and 5). Most consumers eat each of the meat types as often as once a week.

Acceptance of all sensory attributes significantly correlated with consumption intent ($P<0.001$). The Spearman's correlation coefficients for aroma, tenderness, flavour and overall acceptability with consumption intent were, respectively 0.41, 0.44, 0.48 and 0.55 in the first series and 0.52, 0.51 0.56 and 0.62 in the second series of sensory analyses. In both series the acceptance of flavour had a stronger correlation with consumption intent than either tenderness or aroma.

8.2.4 Consumer preferences for the different meat types

In series I, there were no significant differences ($P>0.05$) in the preference for any of the meat types (Figure 8.5). In the second series preference for mutton and chevon from kids did not differ significantly ($P>0.05$) but consumers preferred mutton above chevon from old does ($P<0.05$, Figure 8.6).

Stepwise discriminant analysis to determine in order of importance the variables that influence preference was highly significant ($P<0.0001$) in both series and validity of back classification for these attributes was also good. In series I, tenderness of chevon from the female goats was the most discriminating variable along with flavour of both chevon types and the aroma of mutton. Using the four variables 61.4% of the samples could be correctly classified (Table 8.9).

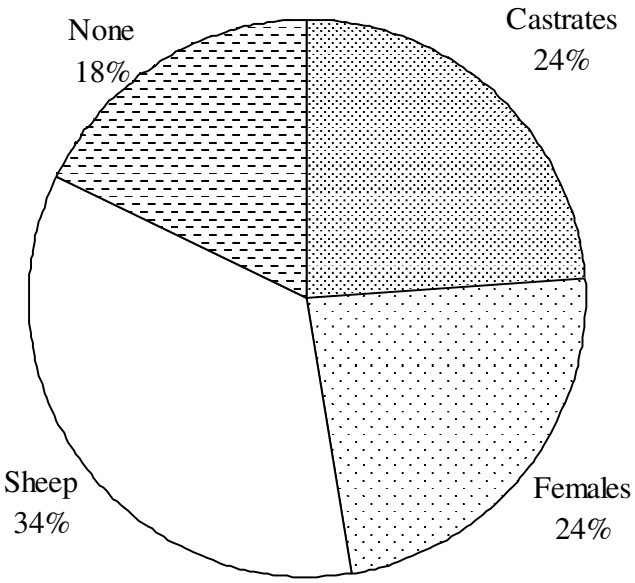
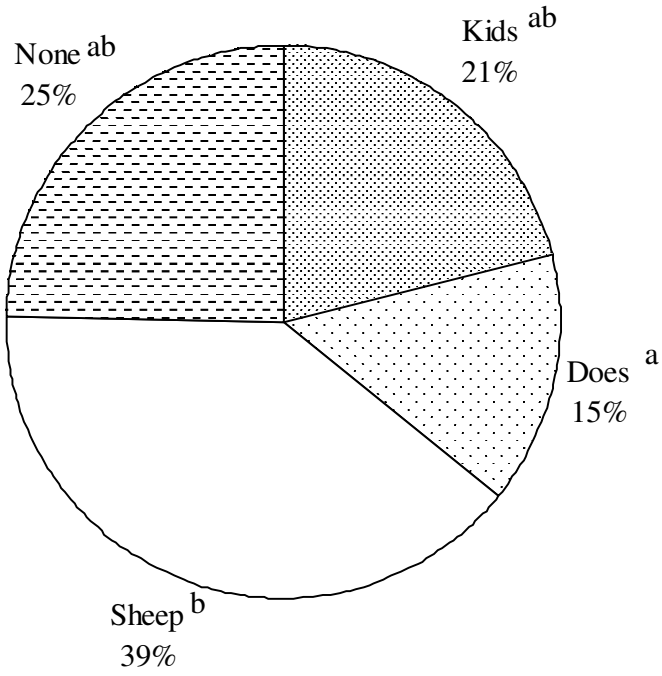


Figure 8.5 Consumer preference for chevon from 2-to-6 teethed female and castrated goats compared to mutton from sheep of similar age



NB Preferred meat types with different letters 'a' or 'b' differ significantly

Figure 8.6 Consumer preference for chevon from milk teethed male kids and old does compared to mutton from 2-to-6 teethed sheep

Table 8.9 Classification of preferences for chevon from 2-to-teethed castrated and female goats and mutton from sheep of similar age using discriminant variables

Group	% correctly classified	Number of preferred samples correctly classified			
		Castrates goats	Females goats	Sheep	None
Castrates goats	55.0	11	3	2	4
Females goats	70.0	0	14	2	4
Sheep	64.3	3	2	18	5
None	53.3	3	3	1	8

In the second series, aroma of chevon from kids was the most discriminating factor along with aroma of chevon from does, tenderness of the does and mutton and flavour of mutton. The five variables could be used to correctly classify 67% of the samples (Table 8.10).

Table 8.10 Classification of preferences for chevon from milk teethed male kids and old does and mutton from 2-to-6 teethed sheep using discriminant variables

Group	% correctly classified	Number of preferred samples correctly classified			
		Kids	Does	Sheep	None
Kids	52.2	13	4	3	4
Does	62.5	2	10	0	4
Sheep	65.1	7	2	30	5
None	74.1	3	2	2	20

In both series, no single attribute was identified as influencing preference for any of the samples. This could be due to the fact that all the sensory attributes of all the samples were rated as highly acceptable on the scale and that the differences between the samples were very small.

8.3 DISCUSSION

Consumer level of education was clearly the most influential factor on consumer acceptance of the sensory attributes and consumption intent in the present study. This factor may be equated to level of income to some extent (Dawkin, Mcmillin, Phelps, Gebrelul, Beyer and Howard, 2000) and possibly to the degree of experience with various types of foods. The findings imply that

highly educated consumers are more particular about accepting sensory attributes than groups with a lower level of education. Age and gender were statistically quite important but population category was relevant only in the second series of analysis where the meat types were markedly different in quality.

Generally all sensory attributes were highly acceptable, with mean acceptability scores that ranged between 3 and 4. Consumption intent was considerably high too, with all groups registering a median food action rating of 4.00, which denoted that consumers in either series would eat any of the meat types at least once a week.

The 2-to-6 teeth castrated male and female goats had similar carcass and meat quality attributes. In line with that, consumers found meat samples from either sex group equally acceptable to the extent that preferences for the chevon from the two sources were equal.

Except for a slight tendency for mutton to be rated more tender than chevon from castrates, chevon of the 2-6 teeth goats compared very well to mutton in terms of acceptability of the sensory attributes, consumption intent and preference by the consumers. Differences between mutton and chevon in tenderness are often reported (e.g. Pike et al., 1973a; Griffin et al., 1992; Schönfeldt et al., 1993a; Tshabalala et al., 2003). The differences have been ascribed to that caprine muscles tend to have a coarser structure with thicker myofibres than ovine muscles (Gaili et al., 1972; Gaili and Ali, 1985). Secondly, because the meat is much leaner, the sensation of tenderness due to intramuscular fat content is limited with chevon (Schönfeldt et al., 1993a; Lawrie, 1998). However, aside from the slight difference in tenderness between mutton and chevon in the present study, both meat types were equally acceptable to consumers when sheep and goats of similar age were compared.

The second series comparison was designed to include goats that should be used in the chevon market and those that commonly dominate the market. All the goats that were used in the second series of sensory evaluation were conditioned on the University Farm prior to slaughter and hence were in good body condition. This is reflected in the high body weights of the kids despite the fact that they were only between 6 and 9 months old, and the high fat content of the two groups. The differences in the myofibre type percentages were typical of differences that occur with the age of the animal (Ashmore et al., 1972; Brandstetter et al., 1998a).

Some of the old female goats (5 out of 9) were electrical stimulated for another trial (Chapter 6 refers) and hence the low pH_3 and tendency for high lactate and low glycogen content soon after slaughter. High pHu values seem typical of chevon, particularly that from old goats (§ 5.3.1 refers).

The comparative sensory evaluation of chevon from kids and does and mutton clearly indicated that chevon from old does was less acceptable to the consumers than mutton. The findings corroborate studies which employed trained sensory panels and showed that chevon from older goats is not of high quality overall (e.g. Pike at al., 1973b; Smith et al., 1978). These findings most likely expound the negative perceptions that prevailed on the quality of chevon produced under commercial slaughter conditions in Zimbabwe during the1990s.

Most of the chevon supplied to the urban markets of Zimbabwe was slaughtered through large commercial abattoirs and sold through retail outlets. Slaughter stocks supplied to the abattoirs were dominated by old does (Hatendi, 1993; Simela, 1996; Simela *et al.*, 2000c). For example, in a survey of the 1995 to 1996 slaughter records of a major commercial abattoir, 58% were females, consisting mainly of old does. At the abattoirs, all goat carcasses were graded according to a government gazetted schedule with four grades; Super, Choice, Standard and Inferior (Government of Zimbabwe, 1995). Super and Choice grades were reserved for well-finished young goats but most of the old females tended to grade Standard or Inferior. In fact in the 1995/96 survey female goats constituted only 33% of the top two grades. All in all less than 20% of the slaughtered population fell in the top two grades. A survey of the retail outlets indicated that the retailers preferred to receive and sell chevon from carcasses of the top two grades because they felt that the carcasses kept well and were less prone to dehydration. Low grade carcasses were said to dry and darken quickly. However, because the market was dominated by the less desirable old goats, some retailers viewed goats as yielding small, low grade carcasses and the meat as smelly. Therefore they would not sell chevon. Chevon production in Zimbabwe was thus a classic example of how the supply of inappropriate animals in the goat market affects consumer perceptions. It is probably for the same reason that some South African consumers describe chevon as stringy, smelly and tough (USAID/South Africa and ARC-ANAPI, 1998a; Figure 2.1i).

Other cases where chevon has been found unacceptable is when it came from very young/small animals. Examples are the studies Smith et al. (1978) were 3 to 5 month old kids yielded meat that was perceived to be tougher, less juicy and less flavourful than chevon from yearling goats. Tshabalala (2000) found that patties from indigenous goat kids (11kg cold carcass weight) were less tender and less juicy (sensory scores of less than 4.4 on a 1 to 9 hedonic scale) than patties from the heavier boar goat kids (13.5kg cold carcass weight) and lamb (20kg cold carcass weight).

It is noteworthy that in both series in the present study, differences only occurred between chevon and mutton and not between the two types of chevon (Figures 8.3 to 8.6). This highlights the uniqueness of chevon and emphasises previous reports that it is not interchangeable with mutton on sensory attributes (Pike et al., 1973a; Schönfeldt et al. 1993a, b; Swan et al., 1998). Despite the differences most consumers would eat either chevon or mutton as often as once a week at least.

Within the goat species, sex and age seem to have little impact of the meat quality (see also Chapters 5 and 6), and hence the lack of differentiation between the sex and age groups in the sensory evaluations in the present study. Gaili et al (1972) reported findings similar to this study when comparing sensory attributes of chevon from milk teethed kids and older goats. The lack of differences could be attributed to that indigenous goats have not been especially selected for meat production. As such, most of the changes with age during their growth and development are geared towards survival rather than meat production. Maximum saleable portions are reached at a very early stage in growth and development in goats whereas similar differentiation may continue to the two teeth stage in sheep (Norman, 1991).

From the current findings, it is evident that chevon is an acceptable meat in the South African market and can be as acceptable as mutton if the meat is from young goats of about a year to two years old. (milk teeth to 6 permanent incisors). One aspect that may undermine the acceptance of chevon to South African consumers is their general lack of exposure to the meat, which was demonstrated by the USAID-ARC survey of 1998 (Figure 2.2). However given the positive results of the current study and of the trained-panel sensory evaluations (Schönfeldt et al., 1993a, b; Breukink and Casey, 1989; Tshabalala et al., 2003) as well as the fact that the USAID-ARC study showed that a large proportion of the sampled population were willing to try out chevon

once it had been drawn to their attention, there is a potential to develop a market for chevon in South Africa.

8.4 SUMMARY

Amongst the consumer characteristics, the level of education was most important in terms of consumer acceptance of the sensory attributes as well as on the intended frequency of consumption for the meats. Consumer age and gender were important factors in some cases but population group was a significant factor in the judgement of meats of more diverse acceptability.

The sensory evaluations indicate that all meat types were highly acceptable to the consumers and they were willing to eat any of the meats at least once a week. The study indicated that chevon is acceptable to South African consumers and may be as acceptable as mutton if the meat is from goats of about two years old or younger.

CHAPTER 9

9 INTEGRATION, CONCLUSIONS & RECOMMENDATIONS

9.1 INTEGRATION

It has been established that there is a potential to improve chevon production and marketing within South Africa, Zimbabwe and possibly other neighbouring countries in the region, such as Botswana, Mozambique and Zambia (§ 1.4 refers). Achieving this task is however, hindered by multifaceted constraints. These constraints include unorganised collection and distribution of goats from the production areas, non-strategic location of slaughter facilities and poor animal handling throughout the marketing chain (Devendra, 1994; Seleka, 2001).

Further drawbacks to chevon production are a result of no flow of information relating to meat quality within the marketing chain. This has led to a lack of synchrony between market preferences and the type of goat supplied to the market (Simela et al., 1998). On one hand, rural goat producers tend to sell bigger and hence older goats in order to maximise the income earned per animal sold. Moreover, the goats sold are predominantly culled breeding females. On the other hand, retailers prefer carcasses that keep well under refrigeration, without dehydrating and deteriorating in colour. Consumers prefer meat that has an attractive colour, looks fresh and is tender when cooked (USAID/South Africa and ARC-ANAPI, 1998a).

The net effect of the poor handling of the goats during marketing and the incongruous producer and market needs has been that chevon markets are dominated by carcasses of unacceptable quality. The present study has explicated some of the reasons for poor chevon quality.

9.1.1 Relationship between Carcass and Meat Quality

Carcass and meat evaluations in the present study indicate that chevon of acceptable colour and tenderness, and that has not suffered cold shortening during post-mortem chilling may be obtained from goat carcasses that weigh about 15kg and have about 7% total carcass fat (Tables 5.11 and 5.23). Lighter weight carcasses (12.5 to 13kg) with low fat content (~6% or less) were not suitable for the experimental conditions of chilling. They had a slow rate of glycolysis, chilled too fast, suffered cold shortening and had poor colour quality 24-hours post-mortem. The lightweight carcasses also tended to yield tough chevon 24-hours post-mortem. Though

tenderness improved with ageing, colour differences between the light and heavier carcasses persisted to 96-hours post-mortem (Table 5.23). The lightweight carcasses would therefore not be suitable for processing under normal conditions of primary chilling in the commercial sector but are more likely to result in chevon that is perceived as 'tough when cooked' and 'looks dry' (Figure 1.2).

In the present study, measurement of carcass subcutaneous fat thickness was excluded because it was almost non-existent and difficult to measure for most of the non-conditioned goats. Moreover, it has been shown that subcutaneous fat cover is not a reliable parameter to include in goat carcass classification because it is too thin (<1mm) and in a very narrow range of values (Devendra and Owen, 1983; Simela et al, 1999).

Goats with two or more permanent incisors could achieve the ideal carcass weight and fatness of 15kg and 7%, respectively (Table 4.2). Carcasses of milk-teethed goats tended to be too small, though they could attain more than 7% carcass fatness. Carcasses of female goats also tended to be small with mean weight closer to that of carcasses that are susceptible to cold shortening compared to those of castrates and intact males (Table 4.1). Even so, female goat LT and SM did not suffer cold shortening, possibly because they were well insulated by the comparatively high carcass fat content (Table 4.8). On average, carcasses of non-conditioned goats were all too small, with a mean carcass weight that was less than 12.5kg whereas the pre-slaughter conditioned goats had mean carcass weight and fat content that were well above 15kg and 7%, respectively (Tables 4.3 and 4.18).

Pre-slaughter conditioning not only resulted in higher carcass yield (Tables 4.3) and meat yield (Table 4.17) but also improved goat carcass rate of cooling and pH decline under post-mortem chilling at about 4°C. It seems that intact males would respond better to pre-slaughter finishing off systems than females and castrates. This was reflected in the intact males' greater DO%, lower chilling losses (Figure 4.1), greater increases in myofibre areas with pre-slaughter conditioning (Figure 5.4) and the higher lean content of the intact male goat carcasses (Table 4.8). However, only young males that have not developed secondary sexual characteristics would be suitable for finishing off systems. Older intact males are less acceptable in the meat industry and so their carcasses are downgraded (e.g. Government of Zimbabwe, 1995; SAMIC, 2004).

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The present study reaffirmed earlier findings that indigenous goat breeds may attain marketable weights from as early as one year old, when they have two permanent incisors (Simela et al., 1999). Moreover, goats at that age yield carcasses that can process well under commercial conditions of primary chilling in the abattoir. Therefore, keeping the goats for too long beyond the 2-teeth stage may not be of economic benefit to the farmers (Simela et al., 1999) but may increase the risk of losing the animals to thieves, predation and diseases (Figure 1.1; Scoones, 1992; Sibanda, 1992; Simela, 1993; Láforte, 1999). The results also reaffirm the advantages of improved nutrition on carcass yield (Hatendi, 1993) and demonstrate that these extend to improved meat tenderness and colour as has been reported for beef (Keane and Allen, 1998). Intact males would probably be ideal for pre-slaughter conditioning because of their greater response to it than castrates and females.

9.1.2 Chevon Quality

The present study demonstrated that goats are particularly prone stress caused by pre-slaughter handling. Consequently most goat carcasses had very low glycolytic potential at slaughter and attained high pHu (≥5.8) regardless of age, sex and pre-slaughter conditioning. The present results further showed that high pHu and related quality traits are not intrinsic chevon characteristics but are a consequence of mishandling throughout the marketing chain, which results in high pH meat. This is deciphered from the fact that some carcasses did attain low pHu (<5.8) and these ones had a higher glycolytic potential and yielded meat that was more tender and had a better colour than that from carcasses with pHu ≥5.8.0.

Full-mouthed does (the 8-teeth group) tended to have higher pHu values (~6.0) than the younger goats. This adversely affected the colour of chevon from the does, resulting in low a* values (~ 12 or less) that are typical of DFD meat, and generally very tough meat (shear force >75N) that did not tenderise with ageing (Table 5.18; Figure 5.15). However, pre-slaughter conditioning (Figure 5.12) and electrical stimulation (Table 6.9) resulted in appreciably more tender chevon from the 8-teeth does. In the sensory evaluations, flavour and aroma of chevon from old does was the least acceptable and least preferred (Figures 8.4 and 8.6). The low acceptance may have been because of the DFD condition. In essence, the high proportion of carcasses with pHu>6 and the high proportion of culled females in slaughtered stock support anecdotal evidence that chevon is ‘dark’, ‘tough’, ‘has a bland taste’, ‘looks dry’ and ‘goes off quickly’ (Figure 1.2). All

these characteristics are typical of DFD meat, which seems to be more prevalent from old does. Therefore, the highly stressful highly stressful handling of goats from smallholder producers to the markets, in conjunction with the high proportion of old does amongst goats marketed for commercial slaughter could be the major contributors to the perception of chevon as poor quality meat (Figure 1.2; Simela, 2000).

Pre-slaughter conditioning, electrical stimulation and ageing were highly effective in improving the chevon quality despite its high pHu. Pre-slaughter conditioning effectively prevented cold shortening, resulted in low shear force values and better colour quality both at 24- and 96-hours post mortem (Table 5.19). Evidently, efforts to improve the condition of goats prior to slaughter would be futile if the animals are subsequently subjected to stressful handling. Pre-slaughter stress may have led to the low *M. longissimus* glycogen levels observed in the present study even for goats that were conditioned prior to slaughter. Continual change of environment and the long periods spent in transit under real market situations are therefore likely to have a more severe impact on glycolytic potential, pHu and related chevon quality characteristics than was observed herein (Warner et al., 1998; Kannan, et al, 2002b). Therefore finishing off systems for goats destined for slaughter should be coupled with minimum-stress pre-slaughter handling procedures in order to increase the likelihood of obtaining good quality chevon from the goats.

Ageing improved tenderness and colour of chevon from either NES or ES carcasses (Table 5.27; Figure 6.3). Electrical stimulation was highly effective in improving tenderness. At 24 hours post-mortem, mean shear force of ES carcasses was 35% lower than that of NES carcasses and decreased further by 19% during ageing to 96 hours. In contrast, tenderness of NES carcasses of castrated and female goats did not improve with ageing up to 96 hours (Figure 6.3). Electrical stimulation has been widely recommended for employment in the meat industry. The advantages of using ES in the goat meat industry would also include a reduction in the ageing time required for the meat to attain acceptable tenderness, and hence a reduction in carcass weight losses during storage, chances of surface spoilage, cost of refrigeration.

A major set back with ES is that it is considered expensive to install and maintain and therefore is unlikely to be readily adopted by the small-scale abattoirs, which are the major slaughterers of goats. In such situations, less expensive alternatives such as high temperature conditioning may

be considered. McKeith et al. (1979) found that this practice also improved tenderness and the eating quality of chevon. Use of high temperature conditioning should however be within the temperature boundaries recommended for good hygienic practices in order to produce chevon that is safe for human consumption. Other possibilities than need to be investigated are skin-on chilling or use of alterative carcass suspension methods.

The present study dispels the notion that chevon is unpalatable but shows that the meat is highly acceptable to South African consumers of diverse backgrounds, especially if it is from goats that are one to two years old (Figures 8.3 to 8.6). Based on fatty and amino acid profiles, chevon is healthful and nutritious regardless of the age and sex of the goats. The fatty acid profile is in accordance with recommendations for healthful eating while the amino acids would meet consumers' daily requirement for essential amino acids. These attributes of chevon are concordant with present day consumer demands for leaner and nutritious meat. To meet these demands, livestock farming is generally shifting towards the production of leaner carcasses of other species. Chevon may readily meet the required criteria without major adjustments to goat production systems, and hence its consumption should be promoted on this basis.

9.2 CONCLUSIONS

The objectives set out for this study were accomplished. Sex, age, and pre-slaughter condition all affected carcass characteristics of goats. However, sex had little effect on meat quality characteristics while age and pre-slaughter conditioning affected some of the chevon characteristics. Post-mortem ageing and electrical stimulation were both effective in improving meat quality, specifically tenderness and colour. Chevon is nutritionally well-balanced for human consumption in terms of fatty acid and amino acid composition. Chevon from goats of different/age sex groups is acceptable to South African consumers. The following conclusions are therefore drawn from the study:

- South African indigenous goats belong to the large breeds of Southern Africa that have a high potential for meat production.

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- South African indigenous goats may be slaughtered under commercial conditions, chilled at about 4°C and yield meat of acceptable quality if the carcasses are big (~15kg) and have a high fat content (~7% or more).

- Carcasses that are suitable for producing chevon under commercial conditions of primary chilling may be obtained from pre-slaughter conditioned goats, goats that have at least two permanent incisors and more likely from intact males and castrates than from females.

- Old does tend to yield chevon with DFD characteristics and therefore a poor colour, a tendency to be tough, and hence lower eating quality compared to younger animals.

- A fast rate of glycolysis (pH_3<6.1) and a slow rate of carcass chilling resulted in tender chevon with a more acceptable colour (higher a* value). Pre-slaughter conditioning, electrical stimulation and high carcass weight and fat content were highly effective in improving chevon tenderness and colour despite the high pHu of the meat.

- Post-mortem ageing also resulted in improved the colour and tenderness of chevon despite the high pHu.

- High pHu is not an intrinsic characteristic of chevon but is a result of pre-slaughter stress. As is the case with other species, goat carcasses with a low pHu yield chevon of acceptable quality while high pHu carcasses yield meat that is tough and has DFD characteristics.

- Chevon has healthful fatty acid and amino acid profiles regardless of age and sex of goats.

- Chevon is highly acceptable to South African consumers of diverse backgrounds, especially if the meat is from goats that are one to two years old.

9.3 IMPLICATION OF FINDINGS AND RECOMMENDATIONS

Based on the findings reported in the present study, it is recommended that the meat industry sets minimum standards for the production of chevon of acceptable quality. The criteria should be

based on carcass weight and fatness, chilling rate and ultimate pH attained. Strategies to attain these standards would have to be designed and implemented. They should include simple selection for goats of body condition, weight and age that are conducive to producing an acceptable carcass. More complex criteria could include minimum handling conditions for goats from the point of sale to slaughter in order to minimise stress to the animals and hence the occurrence of high pH chevon. Any goats that do not meet the set criteria should not be accepted for chevon production but the meat could be given another name. The broad implication is that an integrated farm-to-fork approach is required in order to ensure chevon of acceptable quality in the meat market.

Areas that are suggested for further research are:

- The biochemical pathways that lead to the high pHu of chevon and the minimum conditions under which goats may be transported without the risk of high pH meat.
- Factors affecting temporal changes in proteolytic enzymes and the effects of these on meat tenderness.
- The balance of anti-oxidants, oxidation substrates and pro-oxidants in chevon, particularly in view of the high PUFA content of the meat.
- Improving ways of on-farm assessment of live goats in order to ensure that they best suited for chevon production. These could include combinations of body condition scores, live weight and age.

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