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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

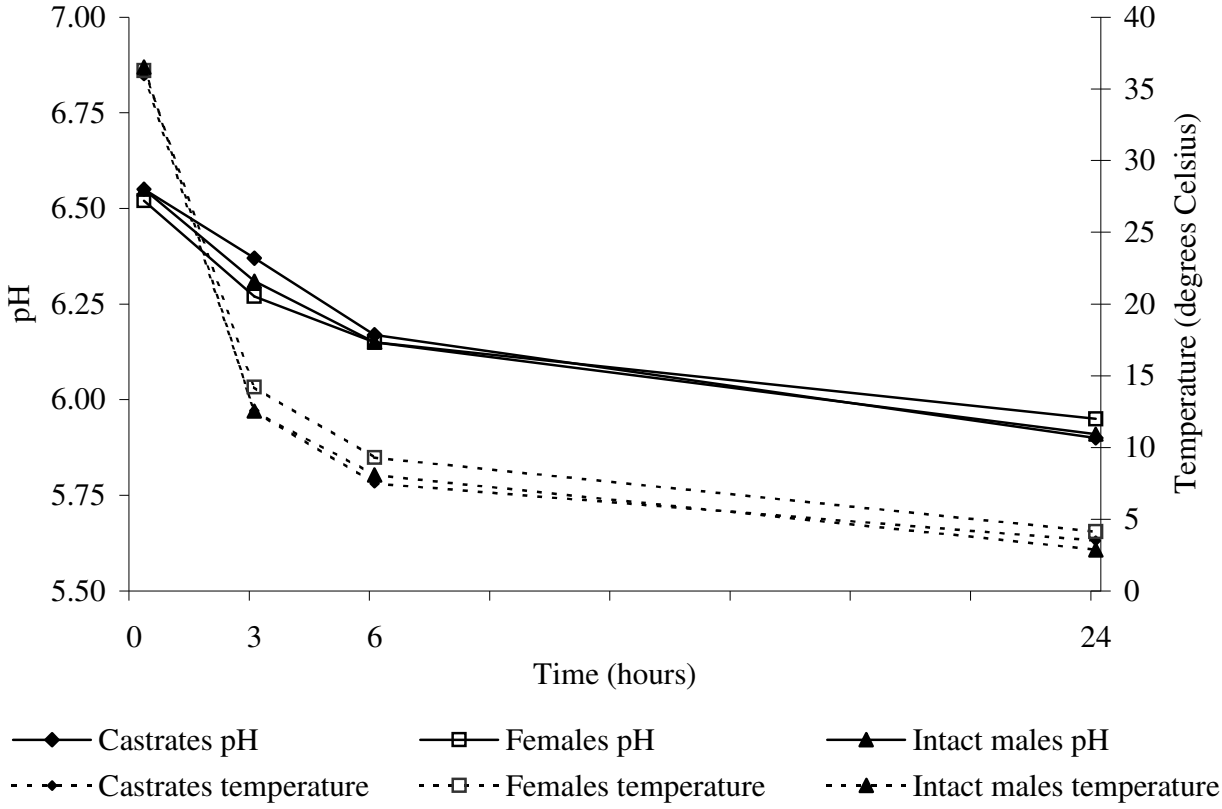

Figure 5.1 Effect of sex on pH and temperature (°C) profiles of the *M. longissimus thoracis* of goat South African indigenous goats

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)

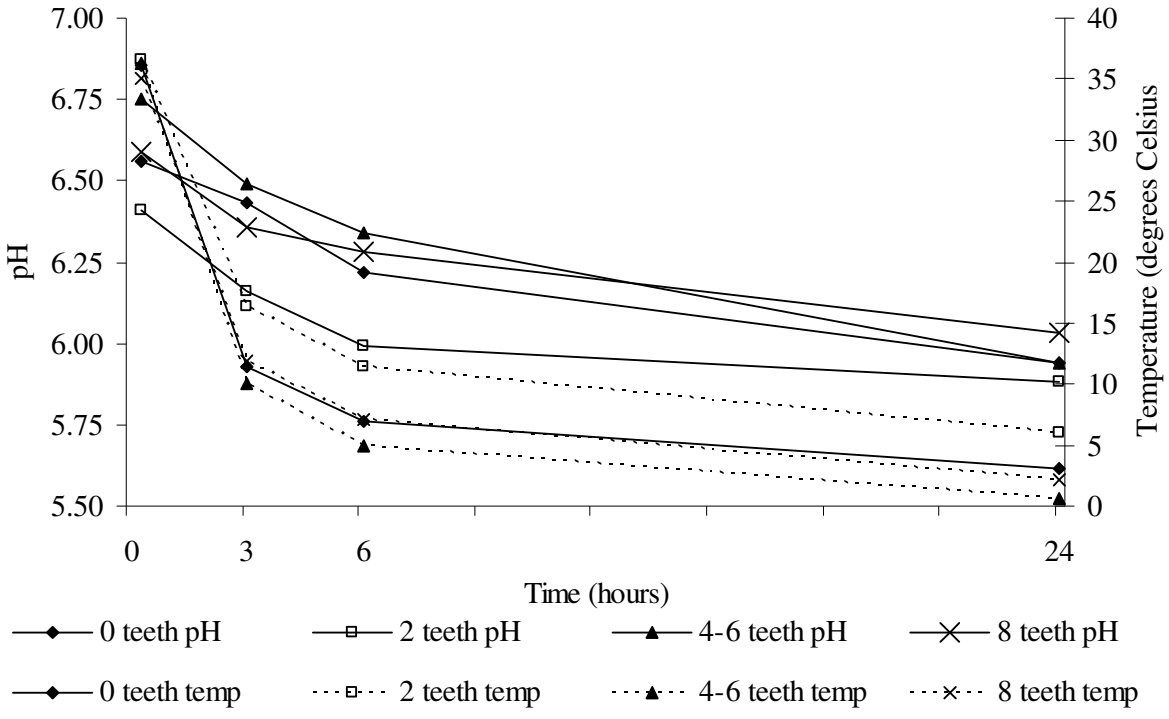

Figure 5.2 Effect of age on pH and temperature (°C) profiles of the *M. longissimus thoracis* of South African indigenous goats

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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

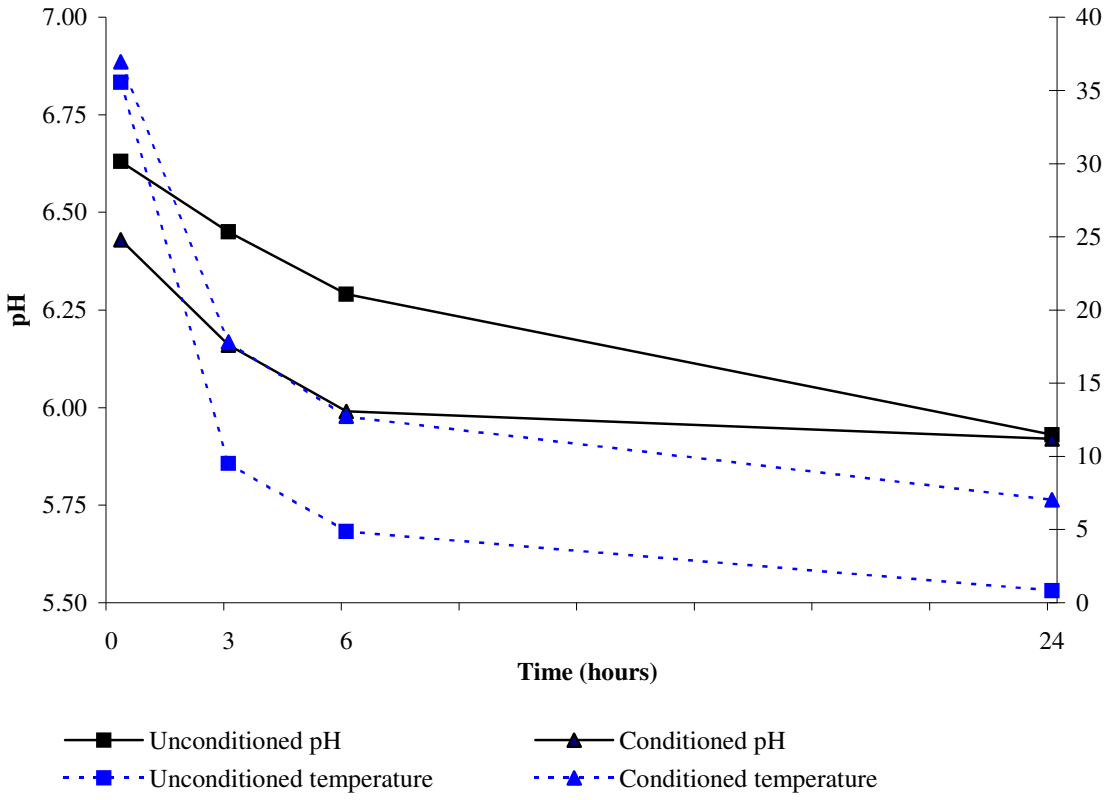

Figure 5.3 Effect of pre-slaughter conditioning on pH and temperature (°C) profiles of the *M. longissimus thoracis* of South African indigenous goats

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

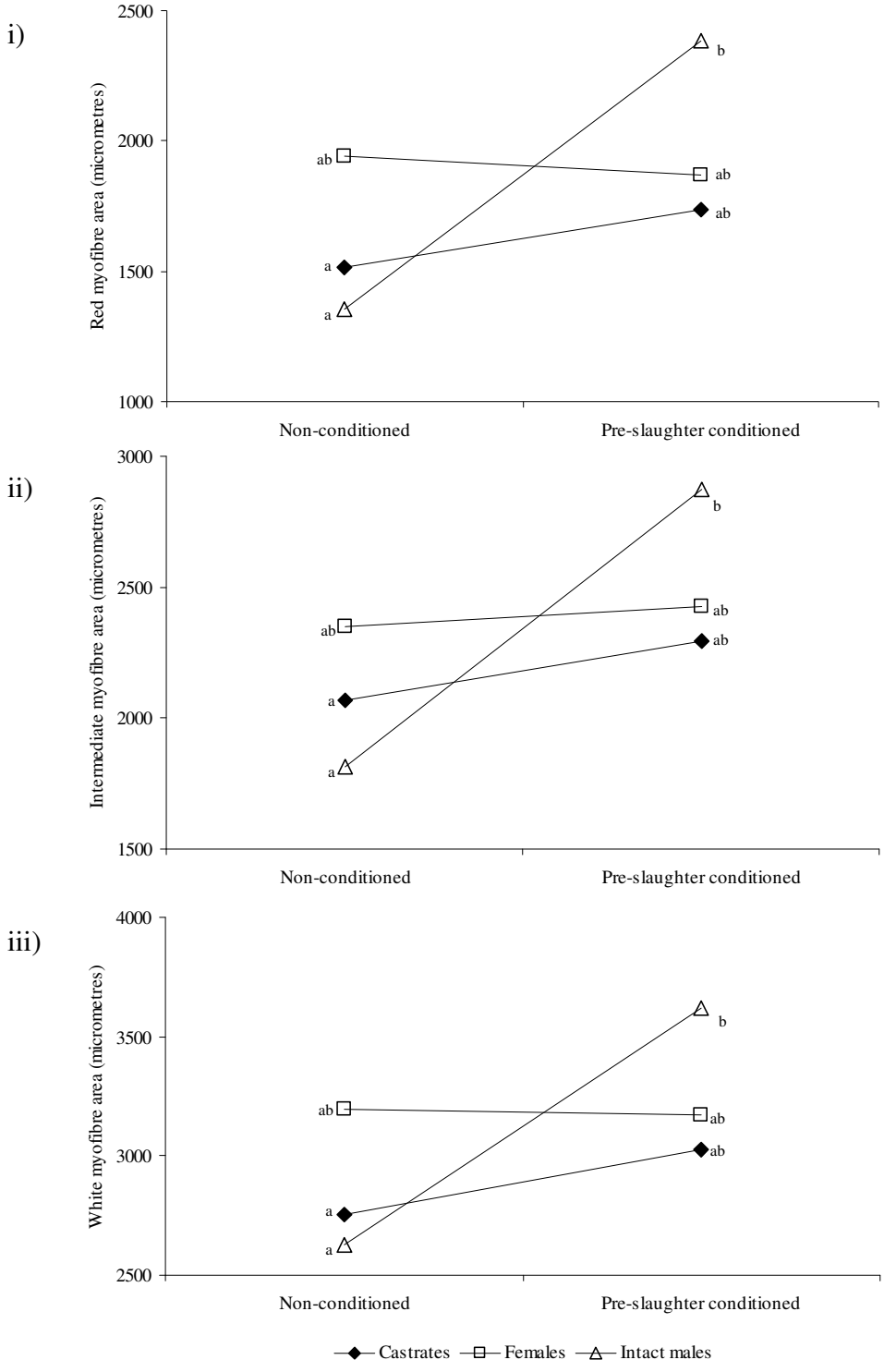
	Interaction effects		
	Age(sex)[1]	Sex*conditioning	Conditioning(age)[2]
pH_0	0.5674	0.0864	0.1517
pH_3	0.2276	0.6477	0.5105
pH_6	0.1240	0.8042	0.3424
pH_{24}	0.8736	0.5614	0.5967
Sarcomere length (µm) 24hr	0.8006	0.3531	0.6065
Sarcomere length (µm) 96hr	0.9018	0.6301	0.9243
MFL‡ (µm) 24hr	0.5302	0.5182	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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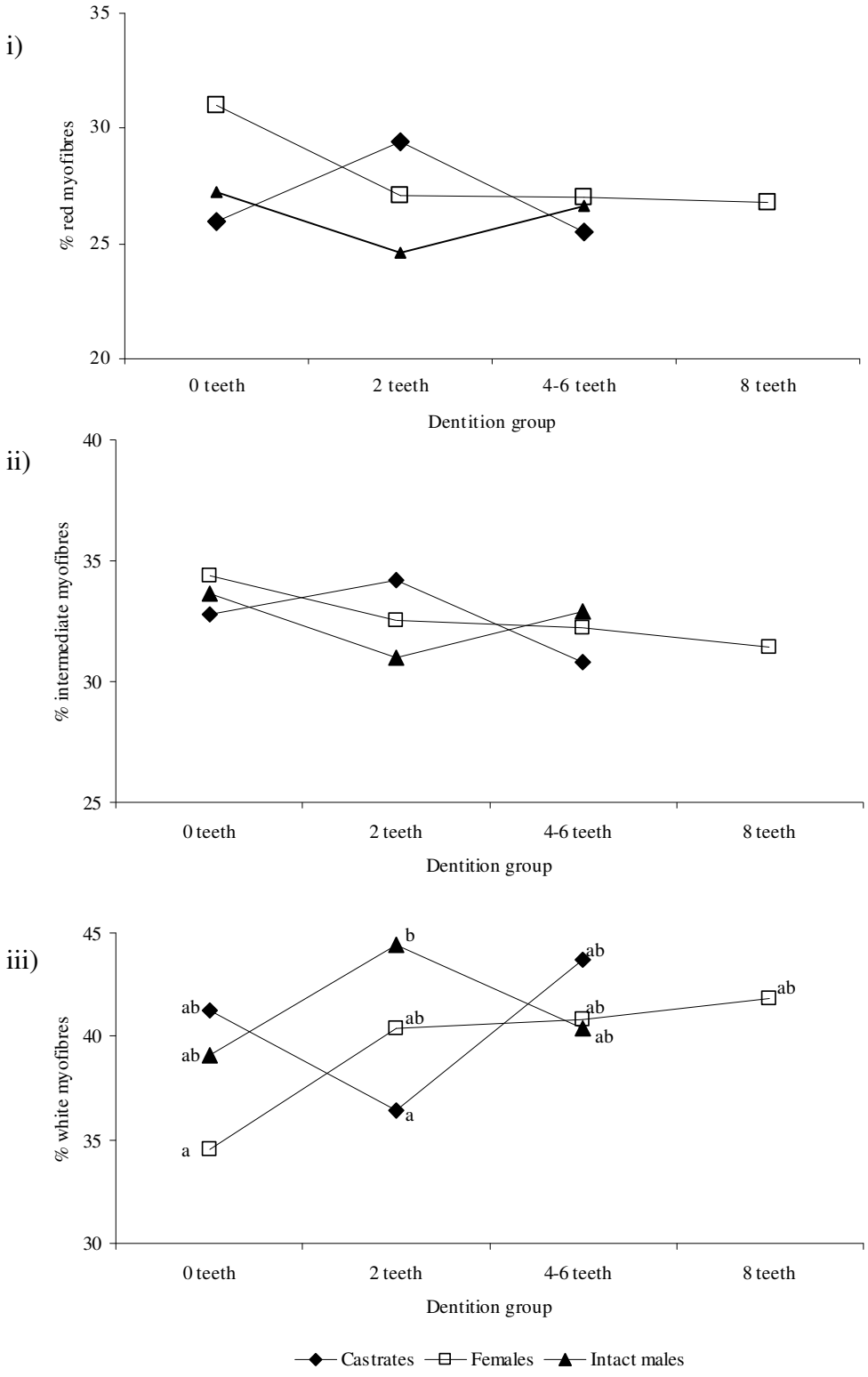
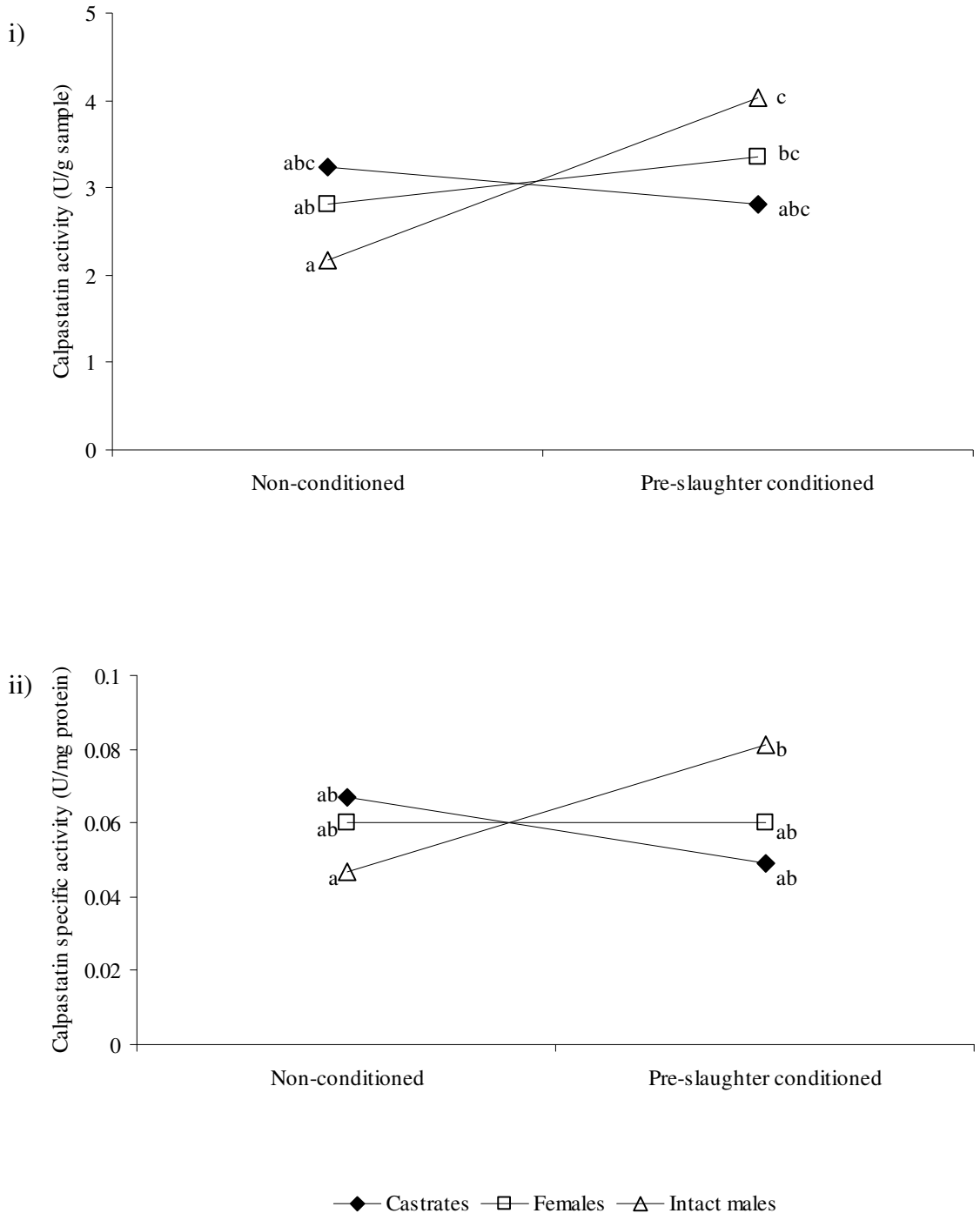


NB: Points within a graph with different letters 'a' or 'b' differ significantly ($P<0.05$).

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)

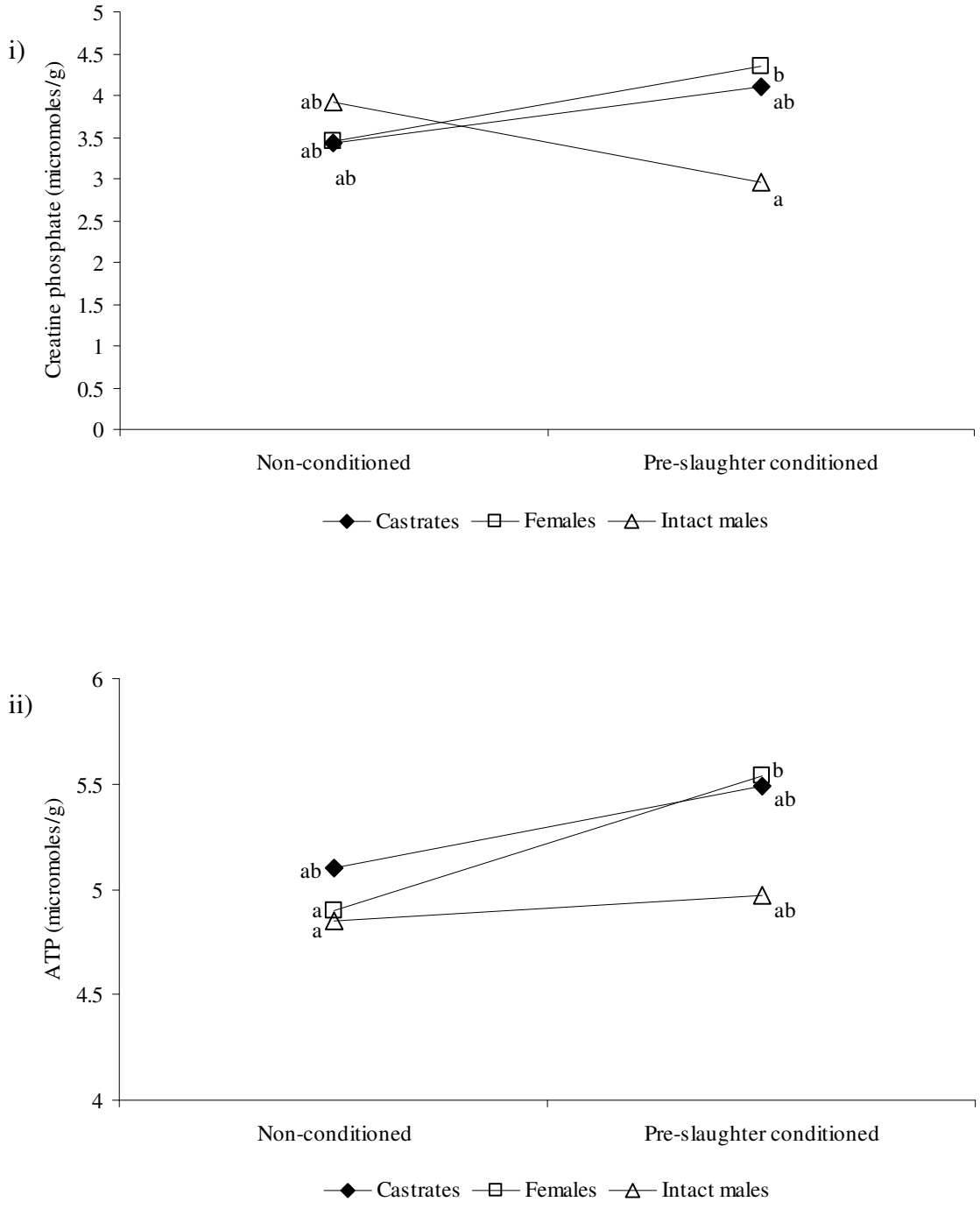
Sex by pre-slaughter conditioning effect on concentration of creatine phosphate was significant (P=0.046) (Figure 5.7i). Within the non-conditioned goats, creatine phosphate concentration was similar amongst the three sexes (P>0.05). The means were 3.41±0.54µmol/g, 3.44±1.08µmol/g and 3.92±1.00µmol/g 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)

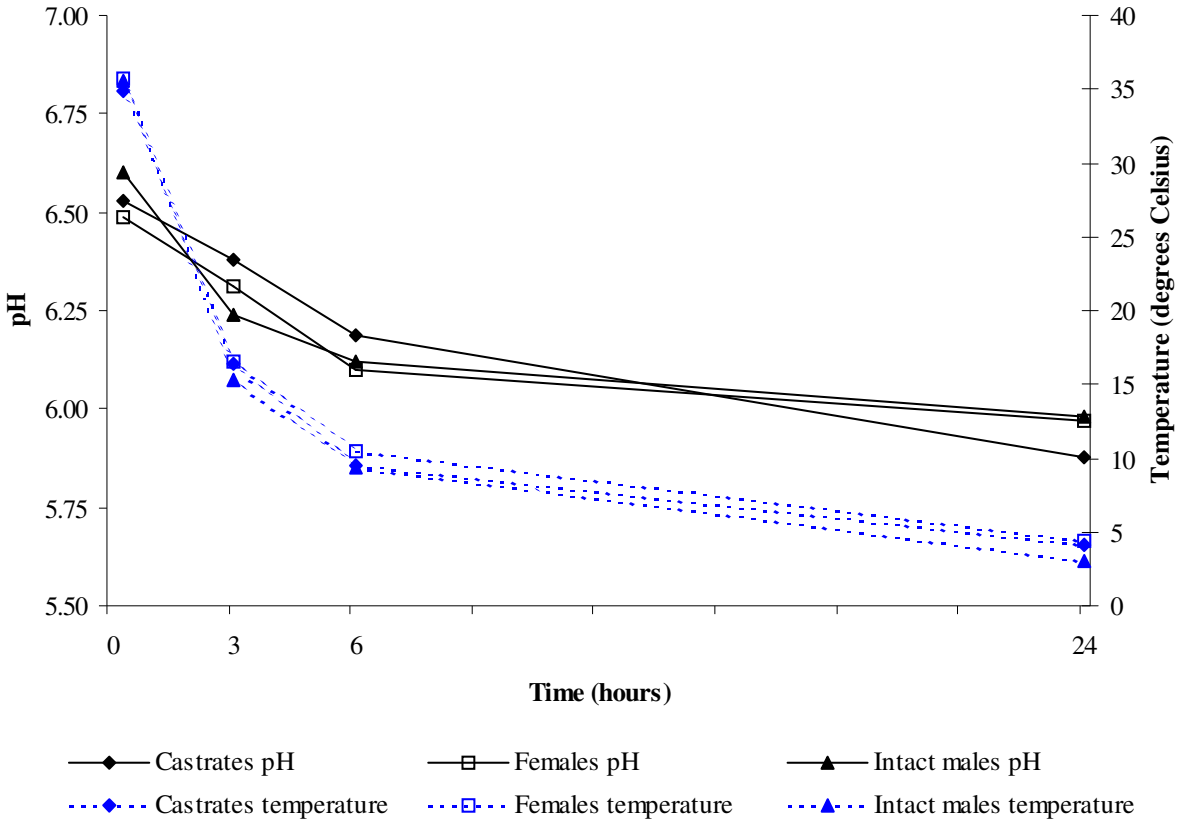

Figure 5.8 Effect of sex on pH and temperature (°C) profiles the *M. semimembranosus* of South African indigenous goats

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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)

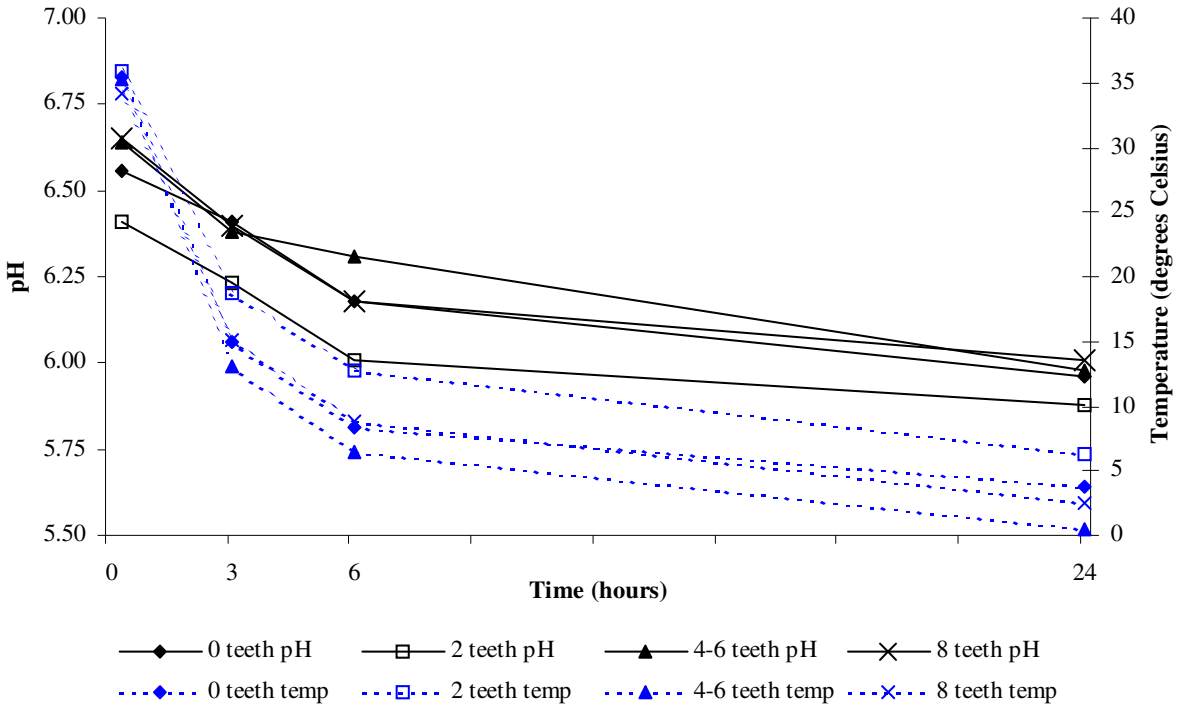

Figure 5.9 Effect of age on pH and temperature (°C) profile of the *M. semimembranosus* of South African indigenous goats

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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

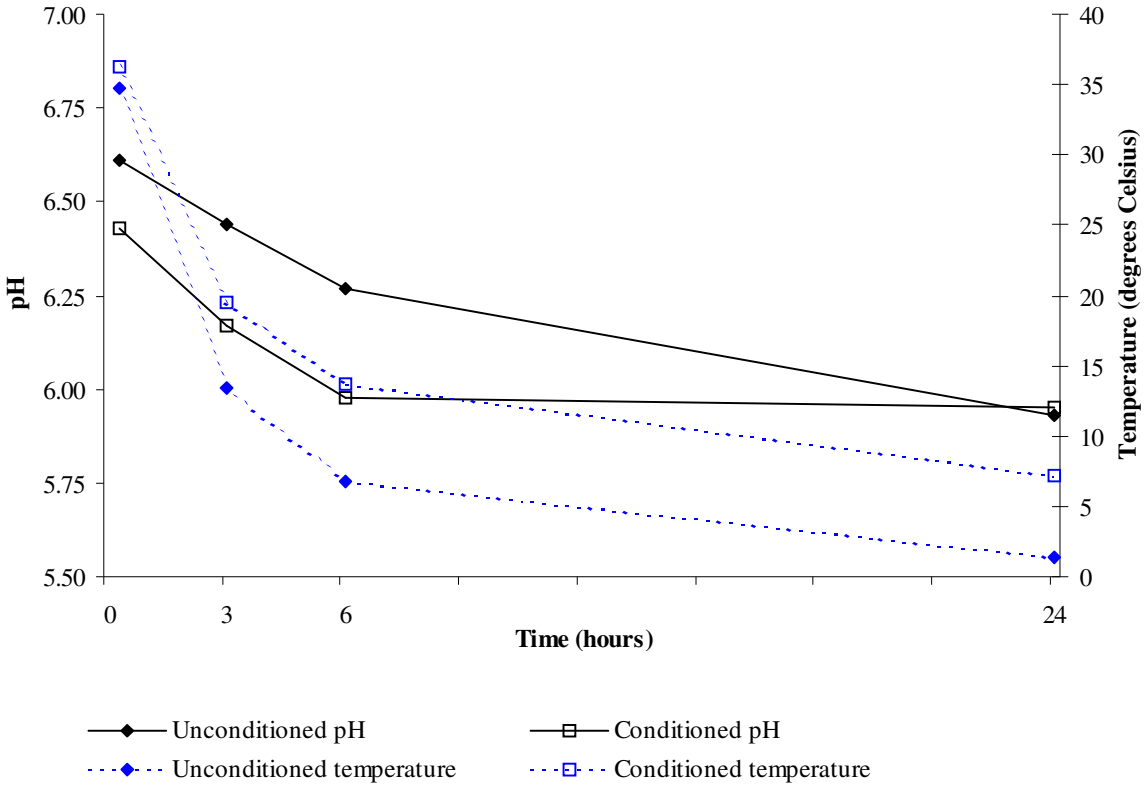

Figure 5.10 Effect of pre-slaughter conditioning on pH and temperature (°C) profile of the *M. semimembranosus* of South African indigenous goats

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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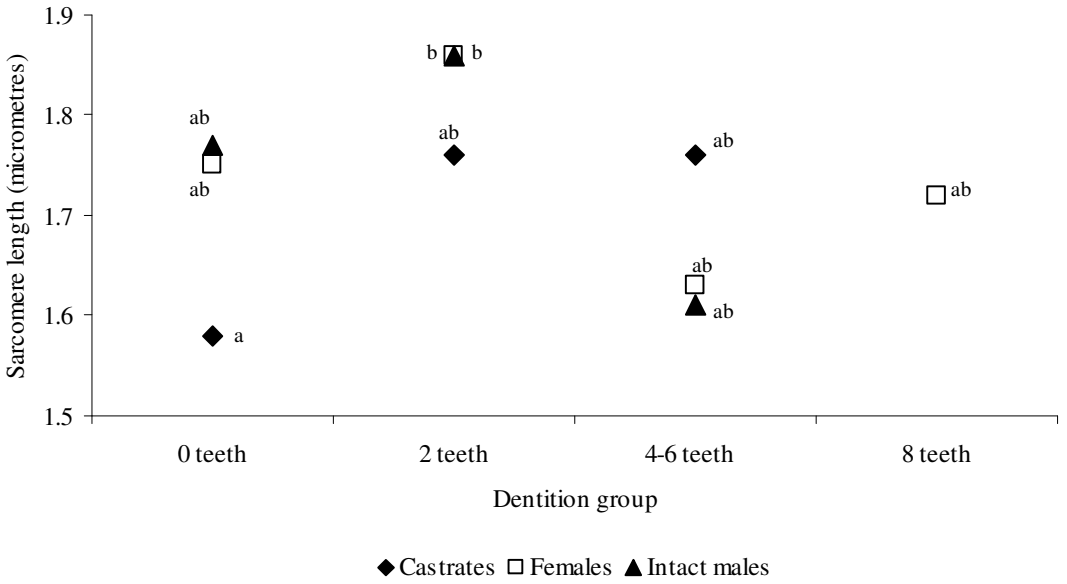
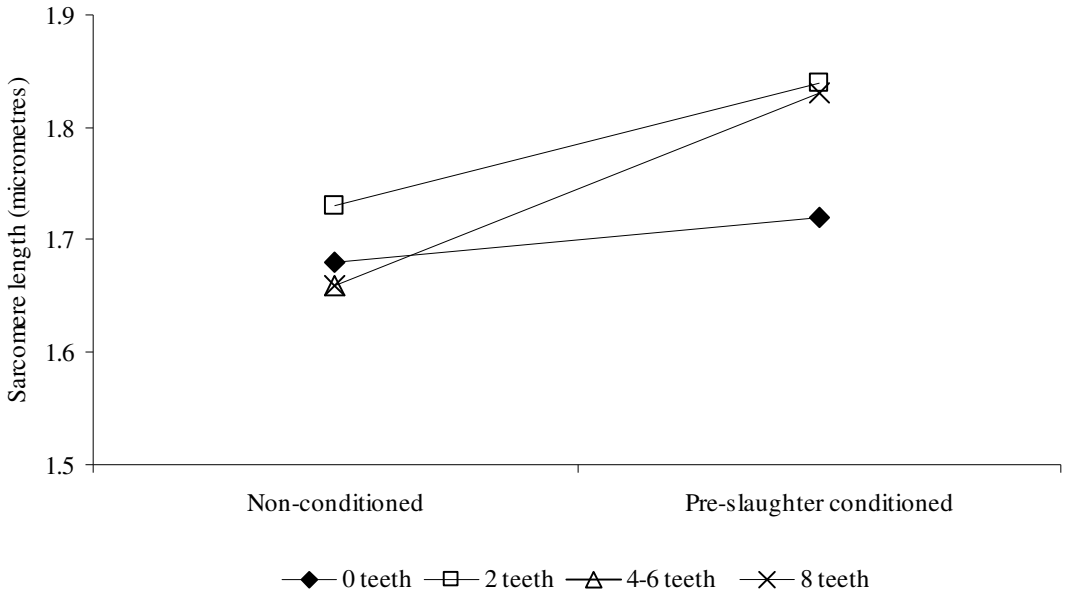
i)

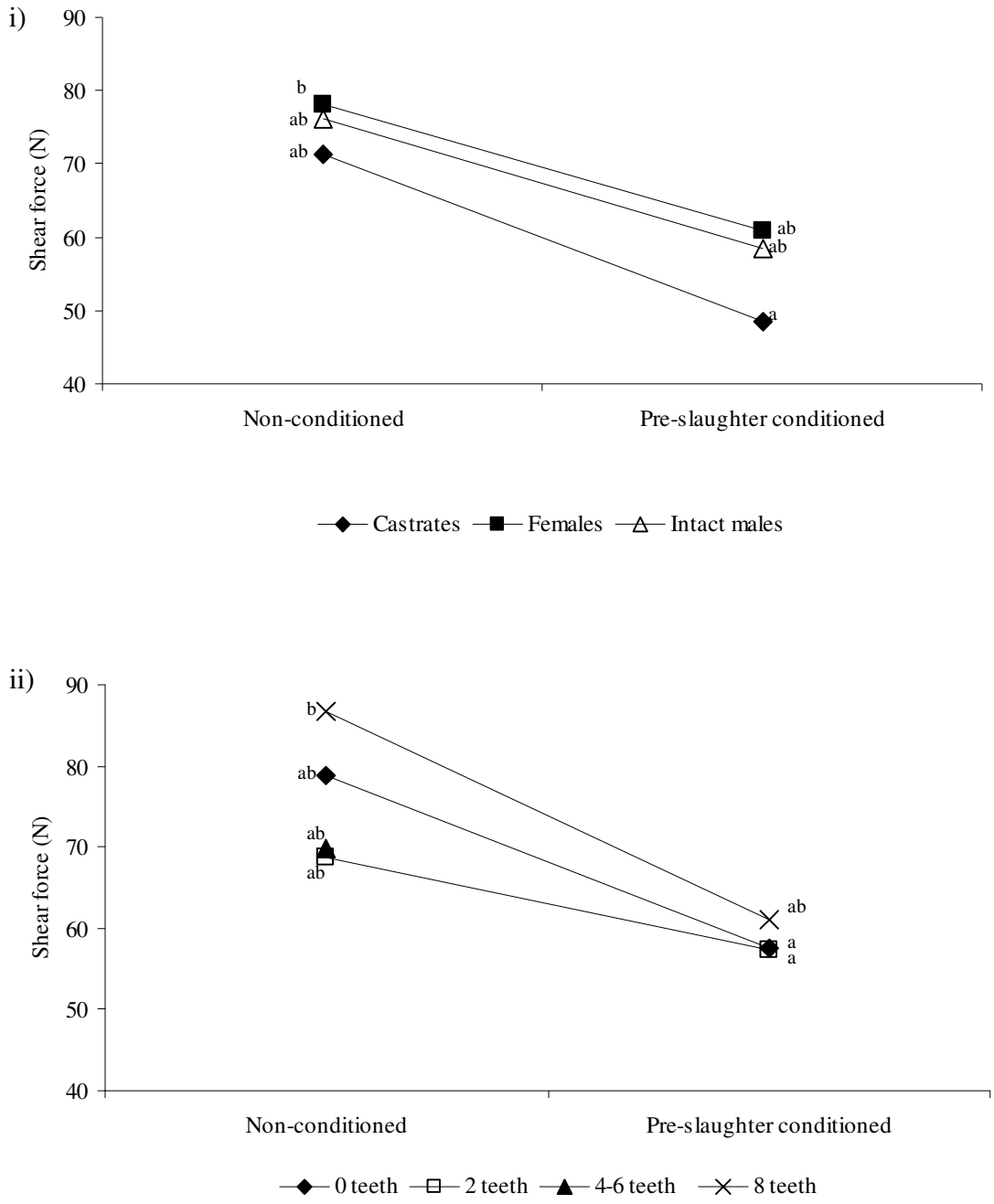


ii)



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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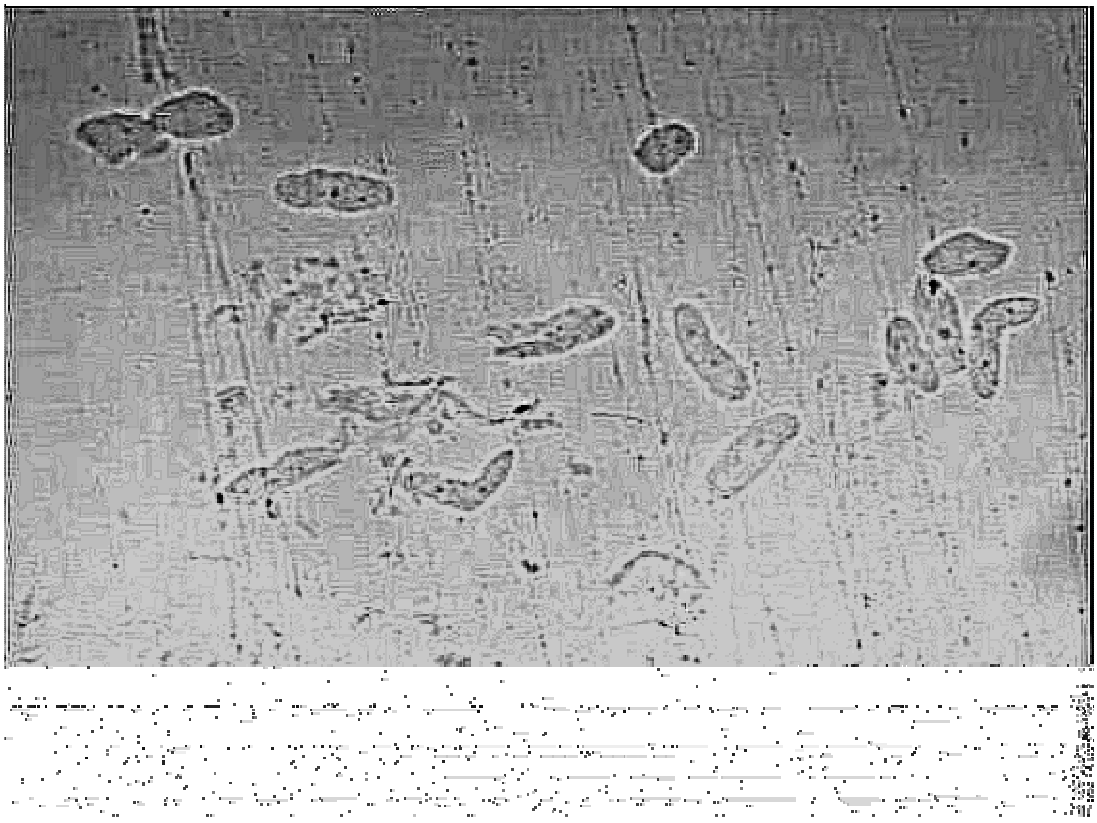

Figure 5.13 Sarcocyst infection in muscle prepared for myofibrillar length determination and viewed under a visual image analyser (40x magnification)

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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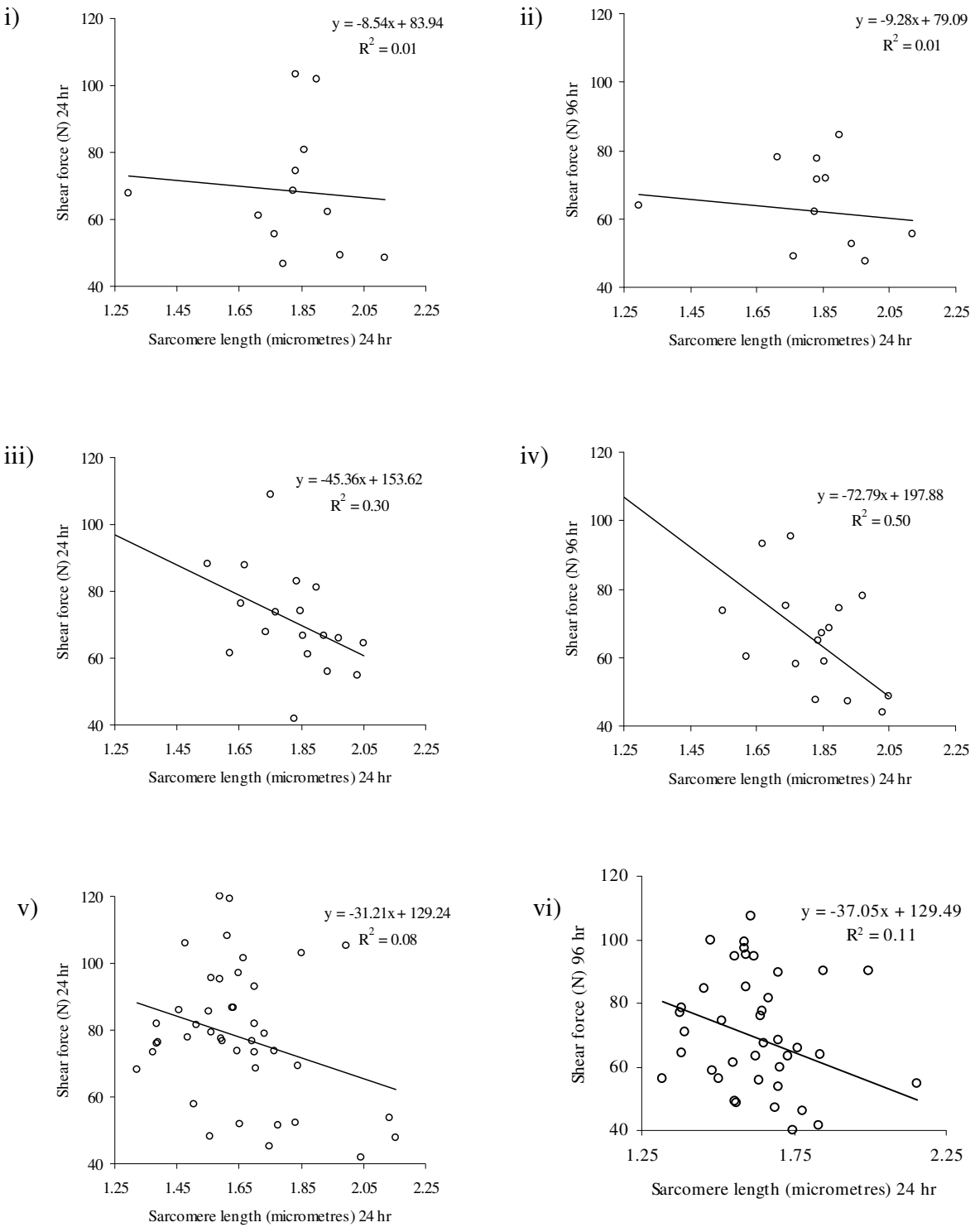


Figure 5.14 Relationship between shear force (N) and 24-hour sarcomere length (µm) of goat *M. semimembranosus* with pH_3 <6.1 (i, ii); 6.1 to 6.3 (iii, iv) and >6.3 (v, vi)

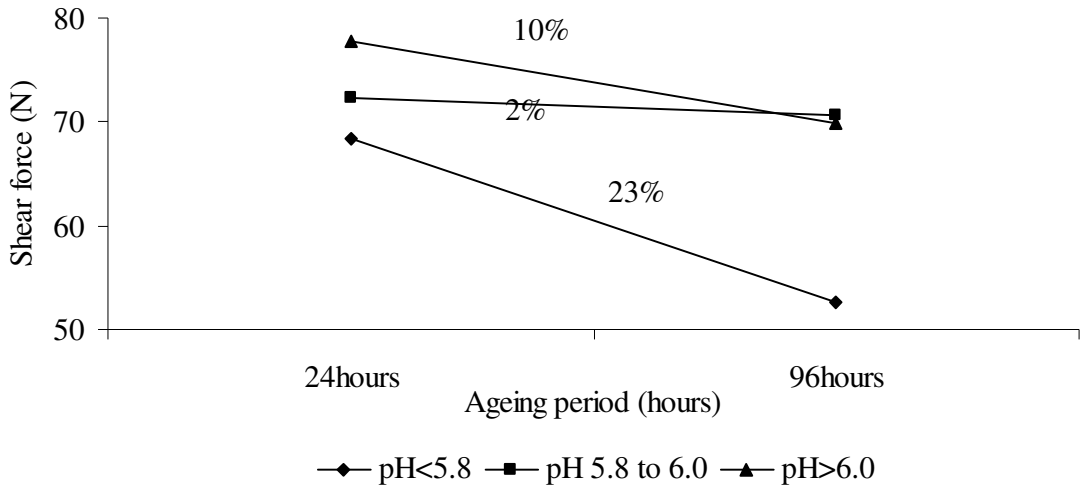
5.3.3.3 Shear force values and the effect of pHu on tenderness

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.

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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.