CHAPTER 6

6 THE EFFECT OF ELECTRICAL STIMULATION ON CHEVON QUALITY

6.1 INTRODUCTION

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

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

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

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6.2 RESULTS

6.2.1 Animal and Carcass Characteristics of Experimental Animals

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

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

6.2.2 Effect of Electrical Stimulation on Chevon Quality

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

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

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

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

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

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

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

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

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

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

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

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

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

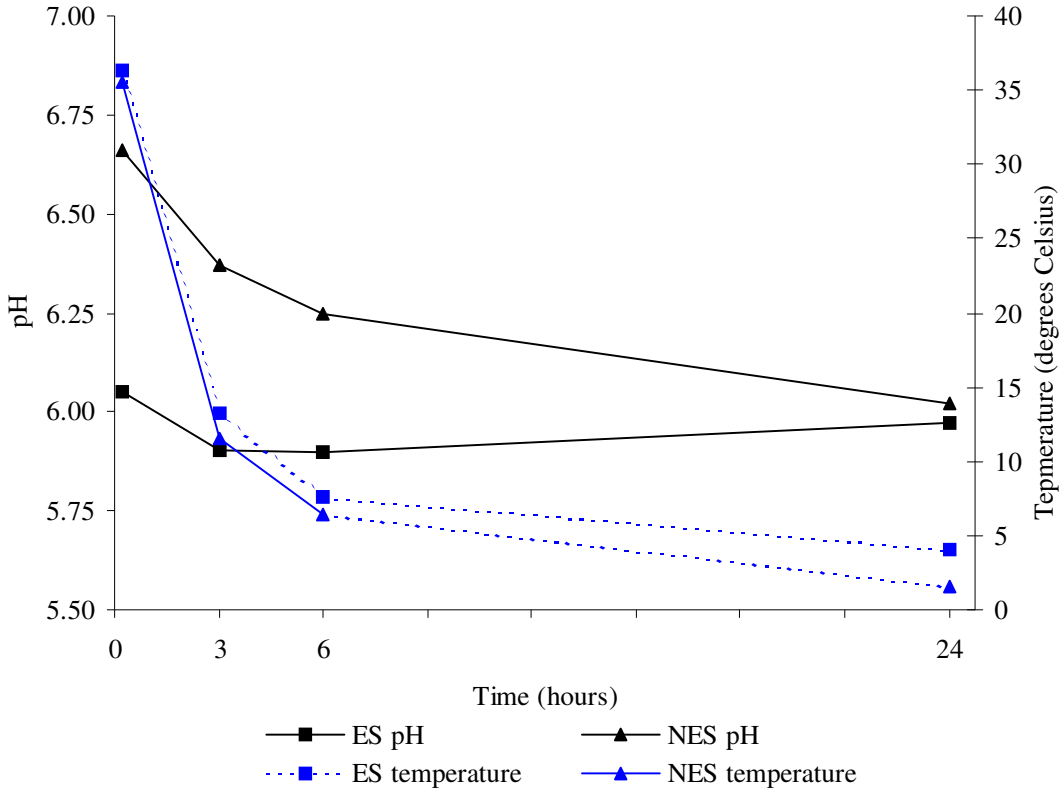

Figure 6.1 The effect of electrical stimulation on pH and temperature (°C) profiles of the *M. longissimus thoracis et lumborum* of South African indigenous goats

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

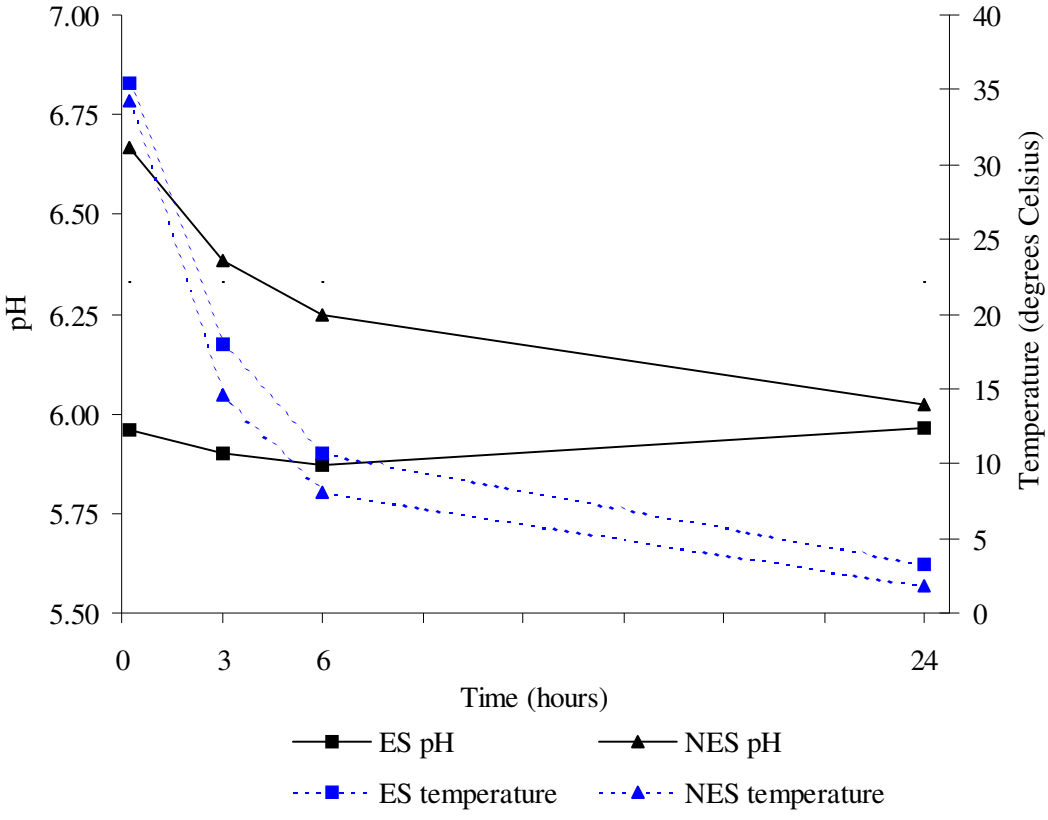

Figure 6.2 The effect of electrical stimulation on pH and temperature profiles of the *M. semimembranosus* of South African indigenous goats

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

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

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

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

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

6.2.2.3 Effects of electrical stimulation and ageing on chevon quality

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

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

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

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

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

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

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

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

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

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

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

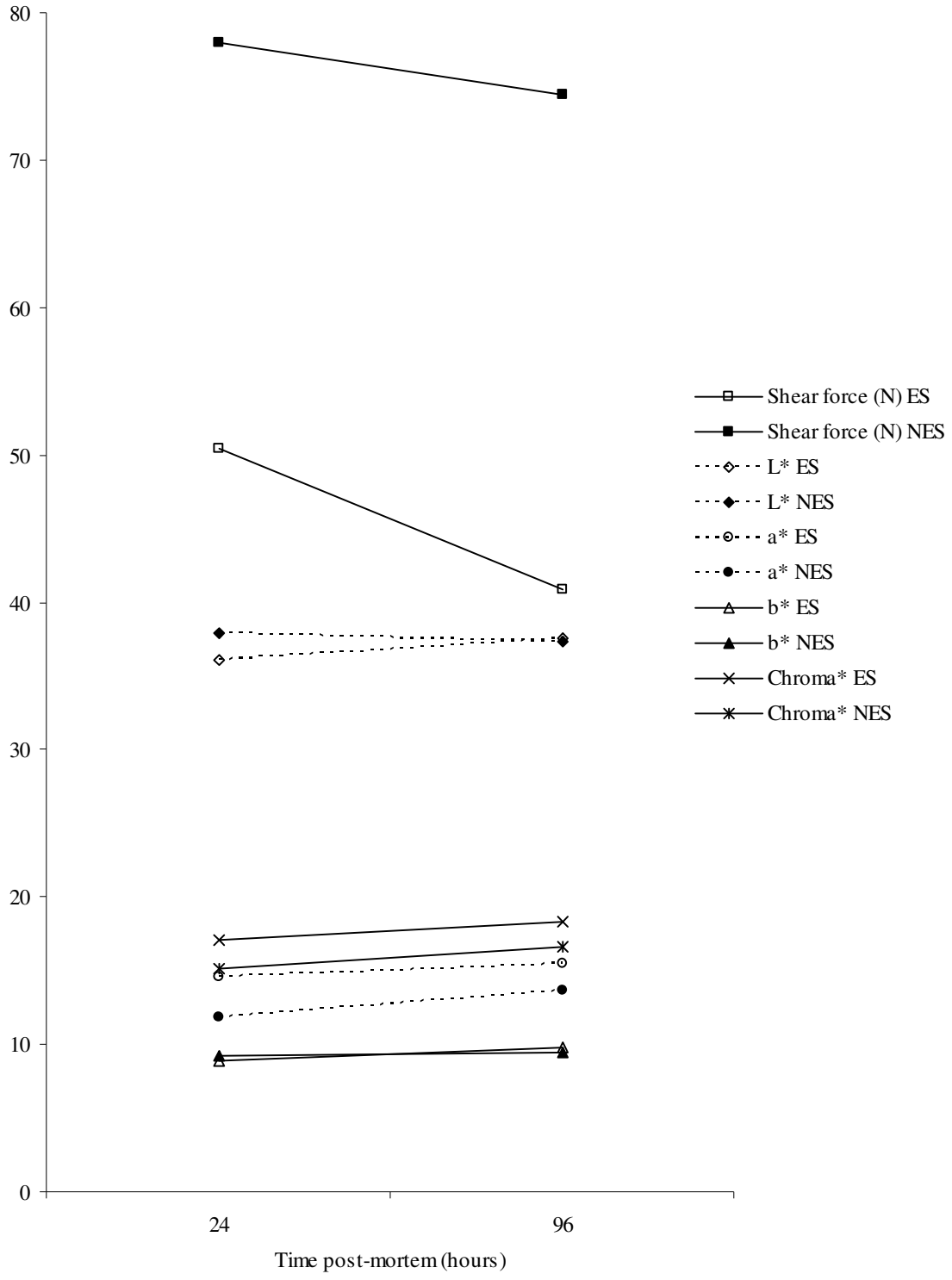

Figure 6.3 Effect of ageing and electrical stimulation on shear force (N) and colour co-ordinate values of the *M. semimembranosus* of South African indigenous goats

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6.3 DISCUSSION

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

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

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

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

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

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

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

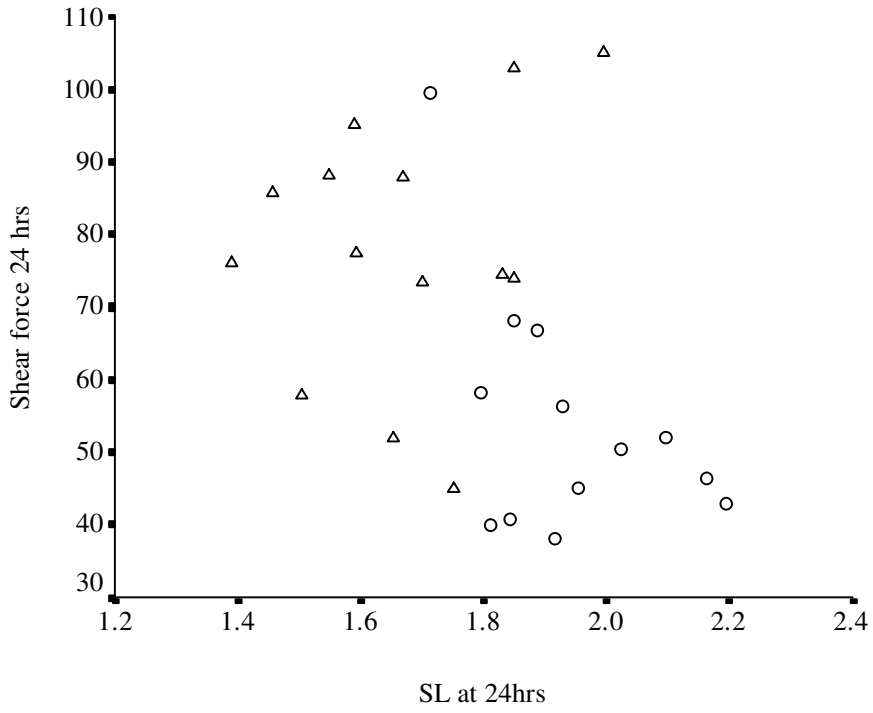

Figure 6.4 Relationship between 24-hour shear force (N) and sarcomere length (µm) of *M semimembranosus* of electrically stimulated (○) and non-stimulated (△) carcasses of South African indigenous goats

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

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

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

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

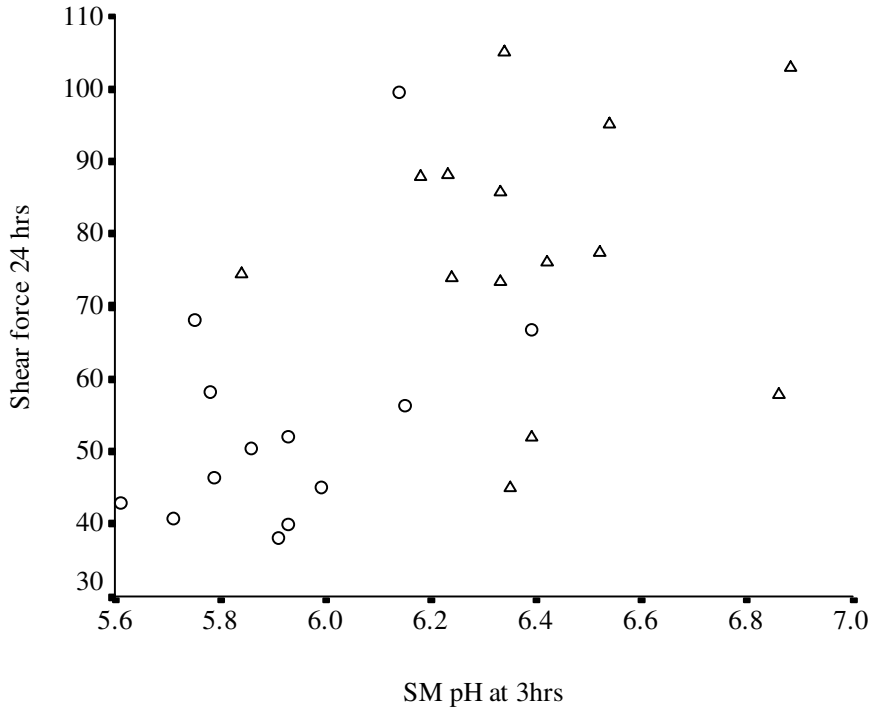

Figure 6.5 Relationship between 24-hour shear force (N) and 3-hour pH of *M. semimembranosus* of electrically stimulated (○) and non-stimulated (△) carcasses of South African indigenous goats

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

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

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

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

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

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

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

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

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

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

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

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

6.3.2 Effect of Electrical Stimulation on Cooking Losses and Colour

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

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

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

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

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

6.4 SUMMARY

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

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

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