UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Natural and Agricultural Sciences

Effects of electrical stimulation and delayed chilling on carcass and meat quality of indigenous and Boer goats in South Africa

By

Pamela Pophiwa

BSc. (hons) Agriculture; MSc. Animal Science

Submitted in partial fulfilment of the requirements for the degree Ph.D. (Animal Science)

In the Faculty of Natural & Agricultural Sciences
University of Pretoria
Pretoria

January 2017

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Natural and Agricultural Sciences

SUMMARY

Effects of electrical stimulation and delayed chilling on carcass and meat quality of indigenous and Boer goats in South Africa

By

Pamela Pophiwa

Promotor: Professor E.C. Webb
Co-promotor: Dr L. Frylinck

Department of Animal and Wildlife Sciences
Faculty of Natural and Agricultural Sciences
University of Pretoria
For the degree Ph.D. Animal Science

This study investigated the effects of electrical stimulation and delayed chilling on carcass and meat quality of indigenous and Boer goats in South Africa. Ten goats per breed were randomly selected from typical indigenous and Boer goats. The goats were slaughtered and dressed according to standard abattoir procedures. The goat carcasses were split into left and right sides along the vertebral column. Electrical stimulation (400 V for 30 seconds then chilling at 0 - 4 °C) or delayed chilling (10 - 15 °C for 6 hours, 0 - 4 °C until 24 hours) were applied to the carcass sides. Muscle fibre characteristics, the concentration of glycolytic metabolites, pH/temperature profiles, water holding capacity (WHC), thawing losses, evaporative losses, drip losses, cooking losses, surface myoglobin pigments, instrumental colour, sarcomere lengths and Warner Bratzler shear force (WBSF) values were evaluated on samples of both the *m. longissimus dorsi* (LD) and *m. semimembranosus* (SM).

Carcasses of Boer goats were on average 2.9 kg heavier (P <0.001) than carcasses of indigenous goats. Dressing percentage was not different between the two goat breeds (47.5 ± 0.55%). Chilling losses were higher (P <0.01) in carcasses of Boer goats (4.81 ± 0.19%) than in carcasses of indigenous goats (4.03 ± 0.12%).

The goat muscles were predominantly oxidative, with an average composition of 47 - 51%, 22 - 27% and 22 - 29% for red, intermediate and white fibres, respectively. The LD samples of indigenous goats had smaller (P <0.05) intermediate fibre cross sectional areas (2670 µm^2 *vs.* 3510 µm^2) and a higher (P <0.05) percentage of oxidative fibres (50.9% *vs.* 40.7%) than corresponding Boer goat samples. The composition of SM fibres of the two goat breeds were similar.

Electrical stimulation hastened the rate of pH decline and muscle energy metabolism whilst delayed chilling showed slow but steady changes in pH and metabolic concentrations. Both slaughter procedures allowed carcasses to enter into *rigor mortis* without the risk of cold shortening (pH ~6 at temperatures above 10 °C). The measured sarcomeres (1.98 - 2.12 µm) confirmed that cold shortening did not occur under slaughter conditions set for this study.

The average muscle ultimate pH values were ~5.8, with no significant differences between the two goat breeds or carcass treatments. The LD samples of delayed chilling treatment recorded higher instrumental colour values than corresponding samples of electrical stimulation treatment. The LD samples of electrical stimulation had higher evaporative losses (20.5 ± 0.93% *vs.* 17.9 ± 0.65%) and total cooking losses (20.9 ± 0.97% *vs.* 18.2 ± 0.65%) than corresponding samples of delayed chilling treatment. The WBSF values of the LD samples (4.03 - 4.53 kg) were not different (P >0.05) between the two goat breeds or carcass treatments. There were no significant differences between the two treatments in instrumental colour, surface myoglobin pigments or moisture parameters of the SM samples. Electrical stimulation was effective in improving the tenderness of the SM samples, particularly in Boer goats. This study showed that both indigenous and Boer goats can yield meat with acceptable objective properties, if appropriate slaughter conditions are practised.

DECLARATION

I, Pamela Pophiwa declare that this thesis which I hereby submit for the degree Ph.D. (Animal Science) at the University of Pretoria is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signed…….

Date…….

ACKNOWLEDGEMENTS

I would like to thank the following persons and institutions for making it possible to complete this work.

- Professor E. C. Webb for his guidance, support and encouragement throughout this Ph.D. study.
- Dr L. Frylinck, for her guidance, support and technical assistance.
- Department of Animal and Wildlife Sciences, University of Pretoria, for giving me the opportunity to pursue my studies.
- Mr R. Coetzee and Mrs C. Swanepoel (Hatfield experimental farm), for their technical assistance.
- Agriculture Research Council (ARC), for research facilities. I would also like to thank the personnel at ARC-Meat Science Department namely, Dr P. Strydom, Dr P. Heinze, Dr M. Hope-Jones, J. D. Snyman and J. Anderson for their technical assistance.
- National Research Foundation (NRF), Project SF88758, for financial assistance.
- Dr D. Somwe, for his assistance in rearing the goats and collection of samples.
- Dr A. O' Neill, for her advice and assistance in collection of samples.
- Mrs Nkau and Mrs Steenkamp, for their administrative assistance.
- My husband Nedson, for his love and support.
- My girls Landi and Sama, for giving me time to work on my project.
- Lastly, my parents and sisters, for inspiring me to complete what I started.

Aspects of this work have been peer reviewed at the 48th Congress of South African Society for Animal Science (SASAS), and published as a research paper.

Journal article

Pophiwa, P., Webb, E. C., & Frylinck, L. (2016) Meat quality characteristics of two South African goat breeds after applying electrical stimulation or delayed chilling of carcasses. *Small Ruminant Research, 145,* 107-114.

Conference papers

Pophiwa P., Webb E.C. & Frylinck, L. (2015). An overview of goat meat production 1. Carcass characteristics and meat quality of Boer and indigenous goats. *48th Congress of South African Society for Animal Science*, Empangeni, South Africa.

Abstract included in Summaries of the 48th Congress of South African Society for Animal Science: Paper abstracts (pp. 55). Available on SASAS website http://www.sasas.co.za

Pophiwa P., Webb E.C. & Frylinck, L. (2015). An overview of goat meat production 2. Effects of electrical stimulation on goat meat quality. *48th Congress of South African Society for Animal Science*. Empangeni, South Africa.

Abstract included in Summaries of the 48th Congress of South African Society for Animal Science: Poster abstracts (pp. 126). Available on SASAS website http://www.sasas.co.za

LIST OF ABBREVIATIONS

AMSA	American Meat Standards Association
ARC	Agricultural Research Council
ADP	Adenosine diphosphate
AMP	Adenosine monophosphate
ATP	Adenosine triphosphate
CCW	Cold carcass weight
CIE	*Commission International De L' Eclairage*
CP	Creatine phosphate
CSA	Cross sectional areas
DFD	Dark firm dry meat
DP	Dressing percentage
DM	Dry matter
FAO	Food and Agriculture Organization
GLM	General linear model
G-6-P	Glucose-6-phosphate
GP	Glycolytic potential
HCW	Hot carcass weight
KOH	Potassium hydroxide
LD	*m. longissimus dorsi*
LW	Live weight
M.	Musculature
MANOVA	Multivariate analysis of variance
MSA	Meat Standard Australia
NDA	National Department of Agriculture
pH_u	Ultimate pH
PSE	Pale Soft Exudative
PUFA	Polyunsaturated fatty acids
RPM	Revolutions per minute
SA	South Africa
SDH	*Succinate dehydrogenase*
SEM	Standard error of means
SM	*m. semimembranosus*
V	Volts
WBSF	Warner Bratzler shear force
WHC	Water holding capacity

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

1 INTRODUCTION

1.1 Project title

Effects of electrical stimulation and delayed chilling on carcass and meat quality of indigenous and Boer goats in South Africa

1.2 Project theme

Meat Science focusing on goat meat (chevon) quality.

1.3 Aims

The aims of the study were to:

1) Study how selected carcass characteristics affect the development of goat meat quality.
2) Evaluate the extent to which breed influences the conversion of muscle to meat and meat quality of goats.
3) Assess the objective properties of goat meat after electrical stimulation or delayed chilling of carcasses.

The following objectives were investigated, namely whether or not:

1) Slaughter weight, carcass weight, dressing percentage and chilling losses differ between the indigenous and Boer goats of A-age class.
2) Histological, histochemical, biochemical and objective properties of both the *m. longissimus dorsi* and *m. semimembranosus* vary between the indigenous and Boer goats.

3) Electrical stimulation is a better alternative compared to delayed chilling of carcasses in improving the conversion of muscle to meat and the resultant meat quality attributes of both the *m. longissimus dorsi* and *m. semimembranosus* of goats.

1.4 Motivation

Goats (*Capra hircus*) are the most abundant ruminant livestock species, distributed across all regions and ecosystems (Devendra, 2010). Most goats are found in developing countries where they play an integral role in food security, socio-economic development and environmental stability (Peacock, 2005). Worldwide, goat production has steadily increased over the past years to more than one billion heads and it will continue to increase due to the growing demand for goat products (FAO, 2015).

In South Africa, there are about 6.2 million goats, kept primarily for meat, milk and mohair production (FAO, 2015). Opportunities exist for the goat industry of South Africa to expand. For instance, increase in bush encroachment, recurrent droughts and prolonged dry seasons that are currently experienced in South Africa favour goat production. This is due to the fact that goats relatively tolerate drought and can survive on browse which is dominant under these conditions (Peacock, 2005). Goat farming is also a feasible option in peri-urban and small scale farming areas where the plot sizes are too small and the resources are constrained for other livestock enterprises. In addition, goat meat is very lean and it is relatively higher in polyunsaturated fatty acids (PUFAs) compared to other types of red meat (Sheridan, Hoffman & Ferreira, 2003). These characteristics are known to reduce the risk of cardio-vascular diseases. In a “nutshell”, goat meat production could be a profitable venture due to the fact that goats are capable of producing lean and nutritious meat at comparatively low cost and under harsh environmental conditions.

Despite all the merits of goats, goat meat is not popular on the commercial markets of South Africa. A survey on consumer behaviour towards various types of meat indicated that goat meat is one of the least preferred meat type in South Africa (Simela, 2005). Low preference for goat meat is related to traditional conceptions of off-smells, off-flavours unappealing colour and perceived toughness.

The toughness of goat meat compared to lamb/mutton is well documented (Griffin, Orcutt, Riley, Smith, Savell & Shelton, 1992; Schnöfeldt, Naudé, Bok, van Heerden, Smit & Boshoff, 1993a; Sen, Santra & Karim, 2004; Lee, Kannan, Eega, Kouakou & Getz, 2008; Shija, Mtenga, Kimambo, Laswai, Mushi, Mgheni, Mwilawa, Shirima & Safari, 2013). Researchers agree that the toughness goat meat is mainly due to the effects of cold shortening if the carcasses are chilled too quickly (Webb, Casey & Simela, 2005; Santos, Silva & Azevedo, 2008; Kadim & Mahgoub, 2012; Kannan, Lee & Kouakou, 2014). Goat carcasses are small and they have a thin subcutaneous fat layer which permit rapid dissipation of heat in early *post mortem* phase, leading to cold shortening and subsequent muscle toughening (Gadiyaram, Kannan, Pringle, Kouakou, McMillin & Park, 2008). Previous studies have reported sarcomeres shorter that 1.7 µm, an indication of cold shortening in muscles of rapidly chilled goat carcasses (McKeith, Savell, Smith, Dutson & Shelton, 1979; King, Voges, Hale, Waldron, Taylor & Savell, 2004; Simela, Webb & Frylinck, 2004a; Kannan, Gadiyaram, Galipalli, Carmichael, Kouakou, Pringle, McMillin & Gelaye, 2006). Thus the commercial chilling procedure (0 - 4°C for 24 hours) is not ideal for goat carcasses as it has detrimental effects on the resultant meat quality.

It is necessary to develop strategies that maximises the conversion of muscle to meat and improve the resultant meat quality attributes. Already a potential market exists from migrants and Hindu communities who consume goat meat on a regular basis, health conscious consumers who prefer lean meat and adventurous consumers who may want to try new

products. In addition, there are no known cultural or religious prohibitions against goat meat consumption, hence chevon can be accepted by people of diverse backgrounds.

Previous studies have shown that electrical stimulation can improve the quality of goat meat (Savell, Smith, Dutson, Carpenter & Suter, 1977; King et al., 2004; Biswas, Das, Banerjee & Sharma, 2007; Gadiyaram et al., 2008; Cetin, Bingol, Colak & Hampikyan, 2012; Kadim, Mahgoub & Khalaf, 2014). The major disadvantage with electrical stimulation is that it is expensive to install and to maintain (Hopkins, 2011), therefore it may not be readily adopted by small scale abattoirs. In such situations, delaying the chilling of carcasses can be the only alternative of avoiding the deleterious effects associated with rapid chilling of carcasses. Information on the beneficial effects of delayed chilling on the quality of goat meat is limited, but, it has been reported to improve the organoleptic properties of lamb (Fernández and Vieira, 2012).

In principle, both electrical stimulation and delayed chilling of carcasses have the potential to improve the quality of goat meat. However, the application of these techniques in goats slaughtered under commercial conditions is limited. Considering that there are emerging markets for goat meat in South Africa, there is a need for more studies which evaluate carcass and meat quality of goats using the recommended slaughtering technologies. This study investigated the effects of electrical stimulation and delayed chilling on carcass and meat quality of indigenous and Boer goats in South Africa. The information generated from this study gives an indication of the quality of goat meat that can be marketed in South Africa and provides basis to further improve the product quality.

1.5 Hypotheses

The tested null hypotheses were:

H_0: The indigenous and Boer goats of South Africa have similar carcass, muscle and meat quality characteristics under similar slaughter conditions.

H_0: Electrical stimulation and delayed chilling of carcasses have similar effects on the conversion of muscle to meat and the resultant meat quality attributes of goats.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

The concept of meat quality is complex since many factors from the time of conception to consumption interact to affect the ultimate quality of meat (Casey & Webb, 2010). Various intrinsic and extrinsic factors that affect goat meat production and quality have been the focus of numerous reviews (Warmington & Kirton, 1990; McMillin & Brock, 2005; Webb et al., 2005; Casey & Webb 2010; Goetsch, Merkel & Gipson, 2011). A review by Goetsch et al. (2011) highlighted that desired carcass and meat quality can only be guaranteed by a holistic approach that combines good animal genetics, nutrition and management practices. This chapter discusses fundamental processes in the development of goat meat quality and how *post mortem* handling procedures affect the ultimate quality of goat meat. Emphasis is on key factors that might be relevant in interpreting the results of this study.

2.2 Breeds for goat meat production in South Africa

South Africa has a variety of indigenous and improved goat breeds that used for meat production. Indigenous goats is a collective term for unimproved local varieties of goats. These varieties are not defined but they are usually associated with the geographical area where they are found or by the ethnic group who own them (Visser, Hefer, van Marle-Köster & Kotze, 2004). The indigenous goats exhibit a wide variation in their size, coat colour and other traits such as horns and ears.

In terms of numbers, the unimproved indigenous goats constitute about 63% of the total goats in South Africa (DAFF, 2012). They are found mostly in the communal areas where their productivity is usually constrained by poor management (Masika & Mafu, 2004). However these indigenous goats of South Africa are appraised for their ability to adapt to harsh climatic conditions and to efficiently utilise limited and poor quality feed resources (Webb & Mamabolo, 2004). The indigenous goats are mainly slaughtered in the informal market, thus the informal sector drives the chevon industry of South Africa (NAMC, 2005). In recent years, the commercialisation of indigenous goats has been of interest in the agricultural sector of South Africa (Ramsay & Donkin, 2000). Hence there is a need for more studies which explore the potential of these unimproved indigenous goats for commercial chevon production.

The commercial sector is dominated by improved goat breeds which were developed specifically for meat production. These include the Boer, Kalahari red and the Savanna goat breeds (Visser et al., 2004). Except for the variation in colour, these three varieties have similar characteristics (Pieters, van Marle-Köster, Visser & Kotze, 2009). The Boer goats constitute the bulk of goats marketed through the South African formal channels, thus it is estimated that only 0.55% is slaughtered in the commercial sector (DAFF, 2012). The Boer goat is a large framed breed characterised by good conformation, rapid growth and superior meat production traits. The breed standards specify a white body, a red head with an evident white blaze and red ears as shown in Fig. 2.1. Malan (2000) reviewed the history, origin and characteristics of the South African Boer goat breed.

Figure 2.1 A typical South African Boer goat exhibiting white coat, red head with a white blaze and red ears. Image courtesy of SA Boer Goat Breeders' Association: http://www.boerboksa.co.za.

2.3 Carcass characteristics of goats

2.3.1 Slaughter and carcass weight of goats

Growth rate of goats is highly variable with subsequent effects on carcass and meat quality characteristics (Gökdal, 2013). Varying estimates of live weight have been reported for goats (Table 2.1). Live weight varies with factors such as breed, age, sex, physiological state, plane of nutrition and marketing purpose. According to Webb (2014), goats are generally subdivided into three categories, namely dwarf, small and large framed goat breeds. Small framed goats weigh between 15 kg and 30 kg at about 15 months of age, large goats may weigh up to 55 kg at a similar age whilst dwarf goats rarely weigh more than 25 kg at 15 to 24 months of age (Webb, 2014).

Table 2.1 Slaughter weight, carcass weight and dressing percentage reported for various goat breeds

Breed or genotype	Slaughter weight (kg)	Carcass weight (kg)	Dressing percentage (%)	Remarks	Reference
Boer × Angora	26.0 (200 days)†	10.9	51.0	Genotype effects	Dhanda, Taylor and Murray (2003)
Boer × Feral	25.5 (174 days)	11.5	54.0		
Boer × Saanen	27.7 (154 days)	16.9	51.7		
Feral	24.9 (193 days)	11.1	53.9		
Saanen × Angora	26.1 (176 days)	10.9	51.4		
Saanen × Feral	26.8 (164 days)	11.8	53.2		
Alpine × Hair	37.7	12.9	39.4	Breed effects	Gökdal (2013)
Saanen × Hair	32.8	13.3	40.5		
Hair	28.8	11.	38.5		
Batina	29.3	11.9	39.8	Breed effects	Kadim, Mahgoub, Al-Ajmi, Al-Maqbaly, Al-Saqri and Ritchie (2003)
Dhofari	29.9	12.5	41.8		
Jabal Akdhar	31.1	13.1	39.8		
Small East Africa	12.9 - 14.8	5.4 - 6.6	42.0 - 48.3	Nutrition effects	Safari, Mushi, Mtenga, Kifaro and Eik (2011)
South Africa indigenous goats	27.8 (0 teeth)	11.8	42.2	Age effects	Simela, Webb and Bosman (2011)
	33.1 (2 teeth)	13.7	41.0		
	36.6 (4 - 6 teeth)	15.2	41.4		
	42.7 (8 teeth)	16.9	39		

†Values in parentheses indicate the age of goats

Simela and Merkel (2008) provided estimates for live weights of mature goats of different breeds, with the lightest live weight in West African dwarf (18 - 20 kg) and heaviest in Boer goats (94 - 114 kg). Boer goats are known to have rapid growth and superior meat production traits. These goats can weigh up to 120 kg when mature and in good condition (Malan, 2000). Although indigenous goats of South Africa are relatively smaller than Boer goats, they are considered as large goats. For instance, Simela et al. (2011) reported live weights of about 42 kg for mature South African indigenous goats.

A wide range of goat carcass weight have been reported (Table 2.1). The target carcass weight depends on the marketing purpose. For example, goat meat is marketed as capretto or chevon. Capretto is obtained from small carcasses of 6 - 12 kg and it is popular in France, Latin America, the Mediterranean region and western parts of India (Dhanda et al., 2003; Webb, 2014). Chevon is obtained from older goats and it is the usual preference in Africa. Chevon of better quality is obtained from carcasses weighing at least 15 kg (Simela & Merkel, 2008). However, carcasses weighing more than 20 kg, which are obtained from older goats, are perceived as tough, stringy and strongly flavoured (Webb, 2014).

2.3.2 Dressing percentage of goats

Dressing percentage is an important indicator of carcass yield (Warmington & Kirton, 1990). Dressing percentages vary with factors such as age, weight, level of nutrition, the degree of gut fill at slaughter, head and skin weight and the dressing procedure (Kadim et al., 2003; Simela et al., 2011; Gökdal, 2013). The dressing percentage of goats tends to be lower than that of sheep, most likely as a result of lower fat content of goat carcasses (Tshabalala, Strydom, Webb & de Kock, 2003; Sen et al., 2004). According to Warmington and Kirton (1990), dressing percentage of goats is usually between 35% and 53%, although Tshabalala et al.

(2003) reported higher dressing percentages of about 56% for Boer and South African indigenous goats.

2.3.3 The quality of goat carcasses

Typically, goat carcasses have more than 60% dissectible lean meat and 5 - 14% dissectible fat (Hogg, Mercer, Mortimer, Kirton & Duganzich, 1992). Subcutaneous fat is poorly developed in goats and fat accretion occurs at a later stage compared to other livestock species and some goat breeds may not attain appreciable subcutaneous fat levels (Mahgoub & Lu, 1998; Tshabalala et al., 2003; Simela et al., 2011). Considering that there is a growing demand for lean and nutritious meat and meat products, the low fat content of goat carcasses can be used in a marketing strategy to promote goat meat. On the other hand, the poor subcutaneous fat cover of goat carcasses can have negative effects on the quality of goat meat. Researchers agree that the small carcasses and thin subcutaneous fat layer permit rapid dissipation of heat in early *post mortem*, predisposing goat carcasses to cold shortening and subsequent muscle toughening (Smith, Carpenter & Shelton, 1978; Webb et al., 2005; Kannan et al., 2006; Santos et al., 2008; Mushi, Safari, Mtenga, Kifaro & Eik, 2009; Kadim & Mahgoub, 2012; Kannan et al., 2014). Another consequence of thin subcutaneous fat cover is that goat carcasses are susceptible to high moisture loss during chilling. Chilling losses in goat carcasses are normally in the range of 2.3 - 3% (Webb et al., 2005). High chilling losses are undesirable because they reduce the weight and the quality of carcasses. Chilling conditions should therefore be carefully considered in order to minimise evaporative losses in goat carcasses.

2.3.4 Implication of carcass characteristics on the marketing of goat meat

In United States of America, there are established standards for retail cuts of goat meat (McMillin & Brock, 2005). However, the general trend in South Africa is to fabricate goat

carcasses into cuts similar to lamb (Webb et al., 2005). This may have many implications on marketing and consumer acceptance of goat meat. A study by Tshabalala et al. (2003) showed that the proportion and distribution of lean, fat and bone in primal cuts differ between sheep and goat carcasses. The dorsal trunk of goats also tend to be smaller and bony than that of sheep (Sen et al., 2004). The implication of this is that the rib and loin cuts from goat carcasses would be less meaty than similar cuts obtained from sheep. Therefore it is important to value the uniqueness of goats and establish standards in the presentation of chevon cuts.

2.4 Muscle biology and the biochemistry controlling the development of meat quality

The development of meat quality is largely influenced by muscle energy metabolism (Scheffler & Gerrard, 2007). Muscle fibre characteristics are known to have an effect on energy metabolism, both in live animal and during the conversion of muscle to meat (Karlsson, Klont & Fernandez, 1999). Therefore, there is a strong link between muscle fibre characteristics, energy metabolism and meat quality. In goats, published information on muscle fibre characteristics and energy metabolism during the conversion of muscle to meat is very limited. This section discusses the biology of skeletal muscles and the biochemistry underlying the conversion of muscle to meat, in general.

2.4.1 Muscle fibre characteristics

2.4.1.1 Classification of muscles and muscle fibre types

The general structure of a skeletal muscle is described by Lawrie and Ledward (2006). Skeletal muscles are composed of three main fibre types which distinguished by their colour, morphological, contractile and metabolic properties (Klont, Brocks & Eikelenboom, 1998). Depending on the method of classifying (Gauthier, 1969; Brooke & Kaiser, 1970; Ashmore &

Doerr, 1971), the three distinct fibre types are namely, red (type I or β red), intermediate (type IIA or α red) and white (type IIB or α white). A review by Lefaucheur (2010) discusses the characteristics of each muscle fibre type in detail.

Red fibres are slow to contract and they can sustain prolonged low intensity exercises (Lefaucheur, 2010). They contain numerous mitochondria to support their oxidative metabolism (Lee, Joo & Ryu, 2010). They are poor in glycogen, but rich in triglycerides and myoglobin (Lefaucheur, 2010). The red fibres have a small diameter and many capillaries throughout their structure (Karlsson et al., 1999). By contrast white fibres are fast twitch and they can sustain brief and intense contractions (Lefaucheur, 2010). They are poor in triglycerides and myoglobin, but rich in creatine phosphate and glycogen to support their glycolytic metabolism (Lee et al., 2010). The white fibres are associated with low vascularisation and they have a large diameter (Lefaucheur, 2010). Intermediate fibres are fast contracting and they have an intermediate (oxidative/glycolytic) metabolic capacity (Lee et al., 2010).

Muscles are classified as either red or white, depending on the dominant fibre type. Red muscles contain predominately red and intermediate fibres whilst white muscles contain primarily white fibres (Karlsson et al., 1999). The muscle fibre composition is usually related to the function of the muscle. For example, postural muscles have a high demand for oxygen to sustain stamina, hence they are usually oxidative in order to support their metabolism (Totland & Kryvi, 1991). Red muscles appear to be dark because they are rich in myoglobin, which facilitates the transportation of oxygen from haemoglobin in the capillaries to the interior of the cell (Brandebourg, 2013). Muscles involved in locomotion are more glycolytic in order to sustain rapid contraction (Braden, 2013).

Within an individual muscle, there may be cross sectional and longitudinal variations in fibre composition. According to Totland and Kryvi (1991), the percentage of red fibres

increases from superficial areas towards the deeper areas of a muscle. Work by Hunt and Hedrick (1977) showed that the inner *m. semitendinosus* tend to be more oxidative than the outer parts of that muscle. A study by Morita, Iwamoto, Fukumitsu, Gotoh, Nishimura and Ono (2000) demonstrated that there are longitudinal differences in fibre composition of the *m. longissimus* with the middle part being more glycolytic than the cranial and caudal parts. The highlighted intra-muscular variations in fibre type composition suggest that representative sampling procedures should be considered for meat quality evaluations (Klont et al., 1998).

2.4.1.2 Factors affecting muscle fibre characteristics

Fibre characteristics of a specific muscle may be affected by factors such as breed, genotype, sex, age and/ or weight, nutrition, ambient temperature and exercise (Karlsson et al., 1999; Lefaucheur, 2010).

A number of studies have examined breed differences in muscle fibre characteristics of other livestock species (Wegner, Albrecht, Fiedler, Teuscher, Papstein & Emder, 2000; Ruusunen & Puolanne, 2004; Bünger, Navajas, Stevenson, Lambe, Maltin, Simm, Fisher & Chang, 2009). Breed effects on muscle fibre characteristics may be related to differences in the degree of maturity (Bünger et al., 2009). For example, Dreyer, Naudè, Henning and Rossouw (1977) reported that muscles of Friesland cattle had larger fibre diameters and they had more white fibres than muscles of Afrikaner cattle. These authors attributed these differences in muscle fibre characteristics to better growth of Friesland cattle compared to Afrikaner cattle. The results of Marichal, Castro, Capote, Zamorano and Argüello (2003) also indicated that the proportion of oxidative fibres tend to decrease whilst the proportion of glycolytic fibres increase as body weight increases. The shift from oxidative to glycolytic fibres with increase in body weight is a result of general differentiation pathway of muscle fibre types during the early stages of muscle hypertrophy (Lefaucher & Vigneron 1986). Since the indigenous and

Boer goats have different growth rates, it might be predicted that they have divergent muscle fibre characteristics. It is therefore important to establish such breed differences in muscle fibre characteristics, particularly, whether they can be manipulated to improve the quality of goat meat.

Sex hormones have a profound influence on muscle fibre characteristics, particularly on total number and size of fibres (reviewed by Joo, Kim, Hwang & Ryu, 2013). Studies on the effect of castration on muscle fibre composition have indicated that muscle fibres of castrates tend to be smaller than those of entire animals (Dreyer et al., 1977). This is probably due to the fact that androgens stimulate muscle fibre hypertrophy. Other studies have shown that the proportion of oxidative fibres is relatively unaffected by castration, while the proportion of glycolytic fibres tend increase at the expense of oxidative-glycolytic fibres (Brandstetter, Picard & Geay, 1998). An explanation for these changes is probably related to the fact that androgens promote paucity of glycolytic fibres, hence muscles of entire animals tend to be more oxidative than those of castrates (Young & Bass, 1984).

The quality and quantity aspects of nutrition are known to have an influence on muscle development. For example, there is evidence which suggests that feed restriction leads to a reduction in muscle fibre size (Bee, Calderini, Biolley, Guex, Herzog, Lindemann, 2007). Brandstetter et al. (1998) found that severe energy restriction caused a glycolytic to oxidative change in muscle fibre types. This decrease in muscle glycolytic capacity is a consequence of the hypothyroidism caused by insulin deficiency during the period of undernutrition (Picard, Robelin & Geay, 1995).

Aalhus and Price (1991) showed that chronic endurance exercise in growing sheep resulted in a shift from glycolytic to oxidative muscle fibres. These researchers concluded that the increase in slow oxidative fibres may be due to acceleration of the normal growth pattern induced by exercise.

2.4.1.3 Fibre characteristics in relation to muscle biochemistry and meat quality

The morphology and composition of muscle fibres are known to influence meat quality attributes such as colour, water holding capacity, tenderness and juiciness (Lefaucheur, 2010). Previous studies have suggested that increasing the size of muscle fibres can have detrimental effects on meat tenderness (Crouse, Koohmaraie & Seideman, 1991). Other studies have shown that increasing the size of oxidative-glycolytic fibres, specifically, has detrimental effects on meat tenderness (Maltin, Warkup, Matthews, Grant, Porter & Delday, 1997). However, the universal relationship between muscle fibre size and tenderness is still controversial (Hwang, Kim, Jeong, Hur & Joo, 2010).

As previously mentioned, glycogen levels and energy metabolism pathways vary between muscle fibre types. Red muscle fibres have lower glycogen levels and are more equipped for oxidative metabolism than white fibres (Klont et al., 1998). Consistent with this fact, increasing the proportion of red fibres has been reported to decrease the rate and extent of pH decline, meat lightness and improve the water holding capacity of meat (Ryu & Kim, 2005). Consequently, red muscles are more susceptible to the development of dark, firm and dry (DFD) meat than white muscles (Klont et al., 1998).

Other factors may also contribute to variation in colour between red and white muscles. For example, red fibres have more myoglobin content than white fibres, giving red muscles a darker appearance than white muscles (Lefaucheur, 2010). Red fibres are also rich in mitochondria, which may compete with myoglobin for the uptake of oxygen, thereby reducing the depth of oxymyoglobin during blooming (Klont et al., 1998). Work by Hwang et al. (2010) showed that increasing oxidative fibres decrease colour stability making red muscles more prone to rapid discolouration during *post mortem* storage than white muscles. McKenna, Mies, Baird, Pfeiffer, Ellebracht and Savell (2005) identified the *m. longissimus lumborum*, *m. longissimus thoracis*, *m. semitendinosus*, *m. tensor fasciae latae* as muscles of high colour

stability, whilst the *m. psoas major*, *m. adducter*, *m. infraspinatus* and *m. supraspinatus* were considered to be of low colour stability. According to the classification by Kirchofer, Calkins and Gwartney (2002) the *m. longissimus dorsi*, *m. semitendinosus*, and *m. tensor fasciae antebrachii* are white muscles, the *m. supraspinatus* is an intermediate muscle and *m. infraspinatus* is a red muscle. In that regard, work by McKenna et al. (2005) supports the theory that white muscles are considered to be of high colour stability and red muscles are of low colour stability.

Muscle fibre composition has been shown to be an important determinant of meat tenderness (Hwang et al., 2010). For example, muscles containing predominantly red fibres have been reported to be more susceptible to cold shortening than those with predominantly white fibres (Smulders, Marsh, Swartz, Russell & Hoenecke, 1990). This is because white fibres are more equipped for glycolytic metabolism and they have an efficient calcium recapture system than red fibres (Klont et al., 1998). Calcium promotes muscle contraction and the uptake of calcium is regulated by the sarcoplasm reticulum which is not well developed in red muscles. (Cornforth, Pearson, & Merkel, 1980). A review by Ouali (1990) indicated that the rate of proteolytic degradation is faster in white muscles than in red muscles. This is related to the fact that red muscle fibres have thicker Z-lines, which are less susceptible to proteolytic degradation (Maltin, Balcerzak, Tilley & Delday, 2003). Increasing the proportion of white fibres may therefore be beneficial in improving meat tenderness especially in muscles exhibiting slow proteolytic degradation.

2.4.1.4 Implication of muscle fibre composition on sampling for goat meat quality evaluation

In species such as cattle, there are indications that the *m. longissimus* and *semimembranosus* are of similar type (Kirchofer et al., 2002). However, a study by Argüello,

Castro, Capote and Solomon (2005) showed that there may be variation in muscle fibre composition between *m. longissimus* and *m. semimembranosus* of goats. Therefore any interpretations based on one of these muscles should not be extended to the other. It is therefore important to characterise fibre composition of various goat muscles. This information is valuable in interpreting results from biochemical analysis and meat quality evaluation of these muscles.

2.4.2 The biochemistry underlying the conversion of muscle to meat

2.4.2.1 Development of rigor mortis

A series of physical and biochemical changes are initiated in the muscle when blood circulation stops after exsanguination. Muscle energy metabolism shifts from aerobic to anaerobic once oxygen bound by myoglobin is fully depleted (Pösö & Puolanne, 2005). Initially, the muscle is maintained in a relaxed state by ATP generated from the phosphorolysis of creatine phosphate and the conversion of two adenosine diphosphate into adenosine monophosphate and ATP (Fig. 2.2).

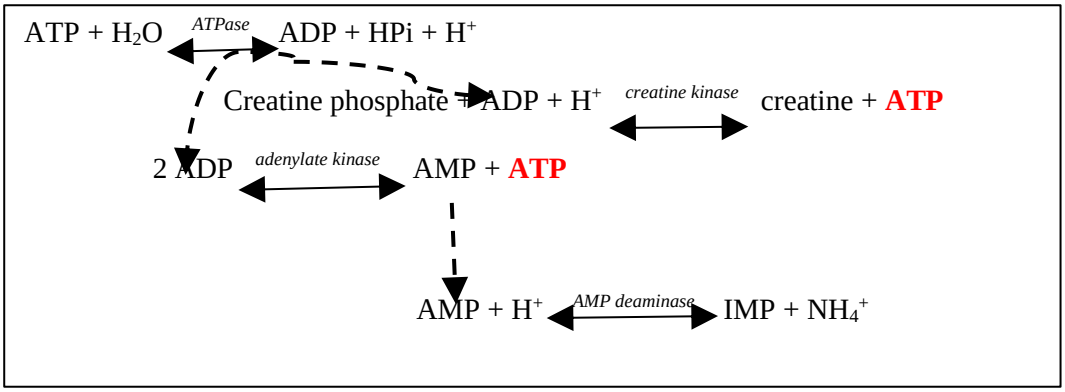


Figure 2.2 ATP production from *creatine kinase* and *adenylate kinase* catalysed reactions. Adapted from Scheffler, Park and Gerrard (2011).

Glycogenolysis and glycolysis proceed once creatine phosphate has been reduced to approximately 25 - 30% of its rest levels (Scheffler et al., 2011). The ATP generated by anaerobic glycolysis is quickly depleted in an attempt to maintain the muscles in a relaxed state. When ATP concentration drops to 25 – 60% of its rest levels, myosin heads start to bind actin filaments, signifying the onset of *rigor mortis* (Honikel, Roncalès & Hamm 1983). Permanent actomyosin bonds are formed at extremely low levels or in the absence of ATP and the muscles become stiff (Honikel et al., 1983). After full *rigor mortis* has developed, the muscles lose their stiffness in the resolution phase and the carcass is ready for fabrication (Partmann, 1963).

2.4.2.2 Biochemical processes during the conversion of muscle to meat

During *post mortem* glycolysis, glycogen is converted to lactic acid through a sequence of biochemical steps outlined in Fig. 2.3. As glycolysis proceeds, the accumulation of lactic acid and associated hydrogen ions, gradually lower muscle pH from neutral to an ultimate pH (pH_u) of 5.3-5.7 (Briskey & Wismer-Pedersen, 1961). Glycolysis stops when all glycogen reserves have been used up or inactivation of glycolytic enzymes by low pH (Scopes, 1974).

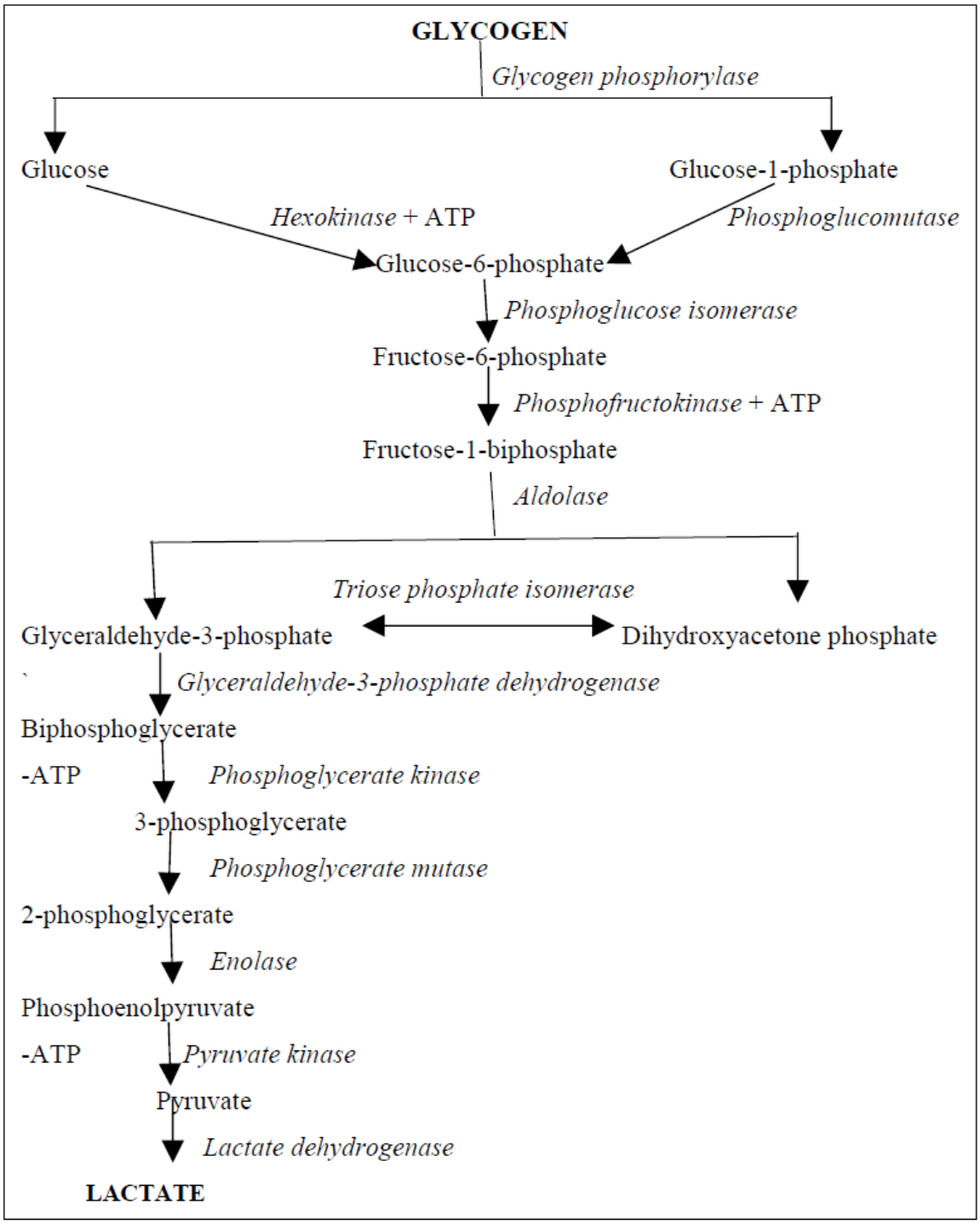


Figure 2.3 A simplified diagram of *post mortem* glycolysis. Glycolytic enzymes are shown in italics. Adapted from Scheffler and Gerrard (2007).

2.4.2.3 Regulation of post mortem glycolysis

It has been postulated that different enzymes may be rate-limiting at different times during the conversion of muscle to meat (Scheffler & Gerrard, 2007). In an attempt to elucidate the development of pork quality, Hammelman, Bowker, Grant, Forrest, Schinckel and Gerrard (2003) observed that the concentration of glucose-6-phosphate decreased during the first hour *post mortem* and later rebounded to levels equal to or higher than the initial. These researchers concluded that *glycogen phosphorylase* may be rate-limiting in the early stages of *post mortem* glycolysis. *Glycogen phosphorylase* is an enzyme which catalyses the degradation of glycogen into glucose-1-phosphate. *Phosphoglucomutas*e isomerises the formed glucose-1-phosphate into glucose-6-phosphate, which then proceeds through glycolysis (Fig. 2.3). The early *post mortem* decrease in glucose-6-phosphate concentration is an indication of decreased *glycogen phosphorylase* activity due to an imbalance between glycogenolysis and glycolysis (Scheffler & Gerrard, 2007). Loss of enzyme inhibition due glycogen breakdown cause the later rebound of glucose-6-phosphate (Hammelman et al., 2003).

Work by Hammelman et al. (2003) also supports *phosphofructokinase* as a rate limiting enzyme in the later stages of glycolysis. This is due to the fact that glycolysis may stop even in the presence of glycolytic metabolites (England, Matarneh, Scheffler, Wachet & Gerrard, 2014). *Phosphofructokinase* is an enzyme which requires ATP to convert fructose-6-phosphate into fructose 1.6 biphosphate. Kastenschmidt, Hoekstra and Briskey (1968) demonstrated that ATP levels decreased dramatically over *post mortem* time. Thus the activity of *phosphofructokinase* is hindered by the lowered amounts of ATP as glycolysis proceeds.

2.4.2.4 Glycolytic potential

Glycolytic potential (GP), estimates glycogen content and the potential of lactic acid formation in muscles (Maribo, Støier & Jørgensen, 1999b). Glycolytic potential includes the

main intermediates from glycogenolysis and glycolysis and it is calculated using the formula proposed by Monin and Sellier (1985) as follows:

GP = 2 (glycogen + glucose + glucose-6-phosphate) + lactate

Glycolytic potential accurately predicts pH_u and is a strong indicator of whether carcasses will yield normal or DFD meat (Young et al., 2004). According to Wulf, Emnett, Leheska and Moeller (2002) the critical threshold of GP is 100 µmol/g, below which, results in high pH_u. Similarly, Simela, Webb and Frylinck (2004b) reported GP values above 100 µmol/g for goat meat with normal pH, whilst high pH meat had an average GP value of 87 µmol/g.

2.4.3 Kinetics of pH and temperature decline

2.4.3.1 Rate and extent of pH decline

Both the rate and extent of *post mortem* glycolysis are known to influence the development of key meat quality attributes (Scheffler et al., 2011). As previously mentioned, pH should gradually decrease from neutral to a pH_u of 5.3 - 5.7 (Briskey & Wismer-Pedersen, 1961). Rapid glycolytic rate (pH value at 1 hour *post mortem* less than 6.0) leading to low pH while temperature is still high denatures sarcoplasmic and myofibrillar proteins and produces pale, soft and exudative (PSE) meat (Scheffler & Gerrard, 2007). This phenomenon is common in porcine muscle. On the other hand, slow glycolytic rate (pH value at 3 hours *post mortem* higher than 6.3) leading to high pH_u, above 6.0 results in dark meat and in extreme cases, dark firm dry meat (DFD) meat (Simela et al., 2004a).

The extent of *post mortem* glycolysis is reflected by the pH_u attained when glycolysis stops. Table 2.2 shows some pH_u values reported for goat muscles. High ultimate pH_u is indicative of *ante mortem* stress and could result in low quality meat in terms of colour, water holding capacity and tenderness (Lawrie & Ledward, 2006). In beef, meat with desirable eating quality has an pH_u of ~5.5 and muscles with pH_u values higher than 5.8 usually are classified

as being DFD (Tarrant & Sherington, 1980). The pH_u for desirable chevon quality has not been established, but Simela et al. (2004a) reported a tendency towards DFD condition for chevon with an pH_u higher than 6.

Table 2.2 Some ultimate pH values reported for muscles of various goat breeds

Breed and sex type	Muscle	Mean or range of pH_u	References
Black male goats	LD	5.53 - 5.61	Abdullah and Musallam (2007)
Majorera male kids	SM	5.58 - 5.73	Argüello et al. (2005)
	TB	5.49 - 5.82	
	LD	5.59 - 5.73	
Bucks of various genotypes	LD	5.76 - 5.93	Dhanda et al. (2003)
Batina males	LD	5.75	Kadim et al. (2003)
	BF	6.10	
	ST	6.08	
	SM	5.83	
Dhofari males	LD	5.56	
	BF	5.76	
	ST	5.76	
	SM	5.57	
Jabal Khaddar males	LD	5.64	
	BF	5.93	
	ST	5.99	
	SM	5.72	
Alpine does	LD	6.02	Kouakou, Gelaye, Kannan, Pringle and Amoah (2005)
Spanish male kids	LD	5.45 - 5.73	Marichal et al. (2003)
	TB	5.59 - 5.80	
	SM	5.49 - 5.64	
Castrated feral goats	LT	5.8 - 6.3	Pratiwi, Murray and Taylor (2007)
Castrated Small East African	GB	5.59 - 6.49	Safari et al. (2011)
South African indigenous goats	SM	5.74 - 6.10	Simela et al. (2004a)
Nebrodi male kids	LD	5.6	Todaro, Corrao, Alicata, Schinelli, Giaccone and Priolo (2004)
Castrated Criollo Neuquino	LD	5.62	Zimerman, Grigioni, Taddeo and Domingo (2011)

Abbreviations: LD–*Longissimus dorsi*; BF– *Biceps femoris*; ST–*Semitendinosus*; SM–*Semimembranosus*; TB–*Triceps brachii*; GB– *Gluteobiceps*

The extent of *post mortem* glycolysis depends on muscle glycogen content at slaughter. In bovine muscles, at least 40 - 45 µmol/g of glycogen is required for the normal acidification of meat (Immonen, Ruusunen & Puolanne, 2000). The critical threshold value for pre-slaughter glycogen levels in goat muscle has not been established. In a study with indigenous goats of South Africa, Simela et al. (2004b) reported glycogen concentrations between 14.4 µmol/g and 42.2 µmol/g for the *m. longissimus thoracis* samples collected at 15 minutes *post mortem*. In other studies, glycogen concentrations has high as 55 µmol/g have been reported for goat muscles sampled at 15 minutes *post mortem* (Kannan, Kouakou, Terrill & Gelaye, 2003). Low muscle glycogen limits the acidification of meat resulting in high pH and in extreme cases DFD meat.

As implied by the term, DFD meat is characterised by dark coloured meat with a firm texture and dry appearance. The muscle appears dark because it has high intracellular water which reflects less light (MacDougall, 1986). In addition, the surviving activity of the cytochrome enzymes, which is greater at high pH_u, use up oxygen available on the meat's surface, allowing deoxymyoglobin to dominate and the meat remains dark even after blooming (Kadim, Mahgoub, Al-Kindi, Al-Marzooqi & Al-Saqri, 2006). High pH_u is also associated with less denaturation of myoglobin which would facilitate a higher level aerobic metabolism at the surface of the meat. The meat appears dry because the water is tightly bound with the muscle and there is little exudation of fluid (Egbert & Cornforth, 1986). The DFD meat is undesirable in the meat industry because of its poor organoleptic and storage properties (Newton & Gill, 1980).

Chronic *ante mortem* stress has been implicated as the main cause of glycogen depletion and consequently high pH meat (Ferguson & Warner, 2008).Various factors during transportation of animals from the farm to the abattoir, such as loading and unloading, duration

of transportation social disruption, novelty of environment and personnel and conditions of lairage are known to cause inevitable *ante mortem* stress (Sanz, Verde, Sáez & Sañudo, 1996; Kadim et al., 2006). The effect of *ante mortem* stress on meat quality is profound if the animal is slaughtered before replenishing its muscle glycogen reserves. In South Africa, animals slaughtered under commercial conditions are kept in lairage overnight to allow them to rest and recover from the effects of transportation. According to Kannan, Terrill, Kouakou, Gazal, Gelaye, Amoah and Samake (2000) goats should be kept in lairage with access to feed in order to minimise *ante mortem* stress which may occur due to feed withdrawal.

Goats are generally prone to *ante mortem* stress as evidenced by high muscle pH values prevalent in literature (Dhanda et al., 2003; Kadim et al., 2006; Pratiwi et al., 2007). It is not clear why goats are so susceptible to *ante mortem* stress, but it could be related to their nervous or excitable nature (Webb et al., 2005). However, high pH is not intrinsic of goats as some breeds are reported to have normal or close to normal pH values (Kadim et al., 2003; Marichal et al., 2003; Abdullah & Musallam, 2007).

2.4.3.2 Muscle pH and temperature combinations at the onset of rigor mortis

In South Africa, carcasses of livestock slaughtered under commercial conditions are rapidly chilled to prevent proliferation of microbial organisms. The most common chilling method involves transferring carcasses to a chamber at 0 - 4 °C air temperature, immediately after the dressing procedure (Strydom, Frylinck & Smith, 2005). However, this chilling procedure can affect the ultimate quality of goat meat. As previously mentioned (§2.3.3), goat carcasses are prone to cold shortening and subsequent muscle toughening during normal chilling conditions (Webb, 2005).

Earlier studies have shown that the combination of muscle pH and temperature at the onset of *rigor mortis* is crucial for optimal meat tenderness (Hannula & Puolanne, 2004).

Classic work by Locker and Hagyard (1963) demonstrated that minimum shortening occurs when pre *rigor* muscles are held at temperatures between 14 °C and 19 °C, until the onset of *rigor mortis* (pH ~6). On the other hand cold shortening occurs when muscles are rapidly chilled to temperature below 10 °C before the onset of *rigor mortis* (Pearson & Young, 1989). At such low temperatures, the capacity of the sarcoplasmic reticulum to recapture calcium ions is low (Cornforth et al., 1980). Increased cellular calcium activates the calcium depended *myosin ATPase* which hydrolyses ATP and provides energy for muscle contraction (Thompson, Perry, Daly, Gardner, Johnston & Pethick, 2006). Thus the term "shortening" refers to short sarcomeres of highly contracted muscles. Another form of shortening, heat shortening, occurs when muscles enter into *rigor mortis* at temperatures above 35 °C (Thompson, 2002).

The known effects of pH/temperature combinations at the onset of *rigor mortis* has led to the development of the pH/temperature window, implemented by Meat Standards Australia in their beef and sheep carcass grading system to identify carcasses at risk of heat or cold shortening (Thompson, 2002; Pearce, van de Ven, Mudford, Warner, Hocking-Edwards, Jacob, Pethick & Hopkins, 2010). In order to avoid the heat or cold shortening window, carcass pH should drop from a pH greater than 6 to less than 6 whilst temperature is dropping from 35 °C to 12 °C (Fig. 2.4). A similar concept could be implemented as a determinant of goat meat tenderness, although this has not been examined.

.

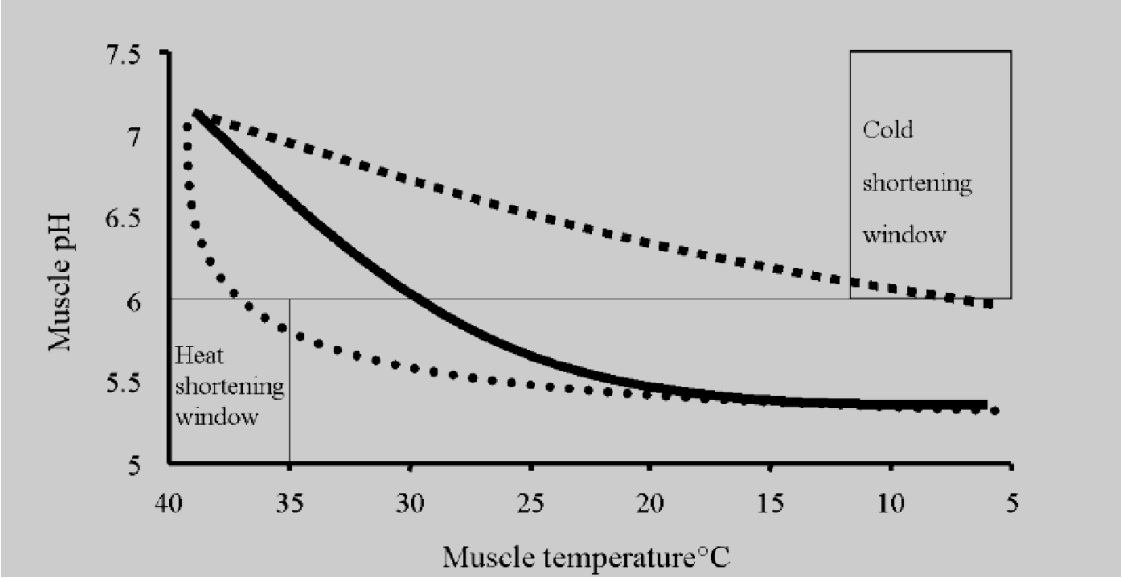


Figure 2.4 The pH/temperature window used by Meat Standards Australia (MSA) to optimise the decline in pH in relation to muscle temperature in beef and sheep carcasses. The solid line represents an optimal rate of decline, the dashed line a cold shortening and the dotted line a heat shortening scenario. Adapted from Thompson (2002).

The extent of sarcomere shortening and muscle toughening can be reduced by several mechanisms. One such way is by delaying the chilling of carcasses. Delayed chilling is defined as a process of keeping intact carcasses out of the chill room for some period of time (Savell Mueller & Baird, 2005). In that way, carcasses are slowly chilled until the onset of *rigor mortis*. At elevated temperatures (above 10 - 15 °C) the sarcoplasmic reticulum can recapture the released calcium ions and muscles enter into *rigor mortis* in a relaxed state, resulting in optimal meat tenderness (Cornforth et al., 1980). In a study to determine the effect of chilling rate on meat quality of suckling lambs, Fernández and Vieira (2012) reported that lamb carcasses held at 12 °C for 7 hours and then chilled at 2 °C had longer sarcomeres and had better organoleptic properties than carcasses which were conventionally chilled. Thus delayed chilling of carcasses would be a simpler and cheaper alternative of avoiding the deleterious effects of rapidly chilling carcasses. In practice, delayed chilling may not be the best way of minimising the risk

of cold shortening. Most abattoirs have temperature set at 0 - 4 °C to prevent proliferation of micro-organisms. In such situations, delaying the chilling of carcass may disrupt the flow of abattoir processes and may compromise food safety.

Another way of preventing cold shortening during chilling is suspending carcasses in such a way that muscles are restrained from shortening. Hostetler, Link, Landmann and Fitzhugh (1972) evaluated different alternatives of carcass suspension including the traditional vertical suspension by the Achilles tendon. These researchers found that suspending carcasses from the *obturator foramen* with thoracic and pelvic limbs free was the most beneficial way of improving sarcomere length and ultimate meat tenderness.

Above all, electrical stimulation has been used widely to improve meat quality in many species including goats (Savell et al., 1977). Electrical stimulation involves passing an electrical current through the carcass causing the muscles to contract. Muscle contraction during electrical stimulation accelerates the pH rate decline (Fig. 2.5) so that carcasses can be rapidly chilled without the risk of cold shortening. Early depletion of ATP ensures that muscles enter into *rigor mortis* in a relaxed state, resulting in improved meat tenderness.

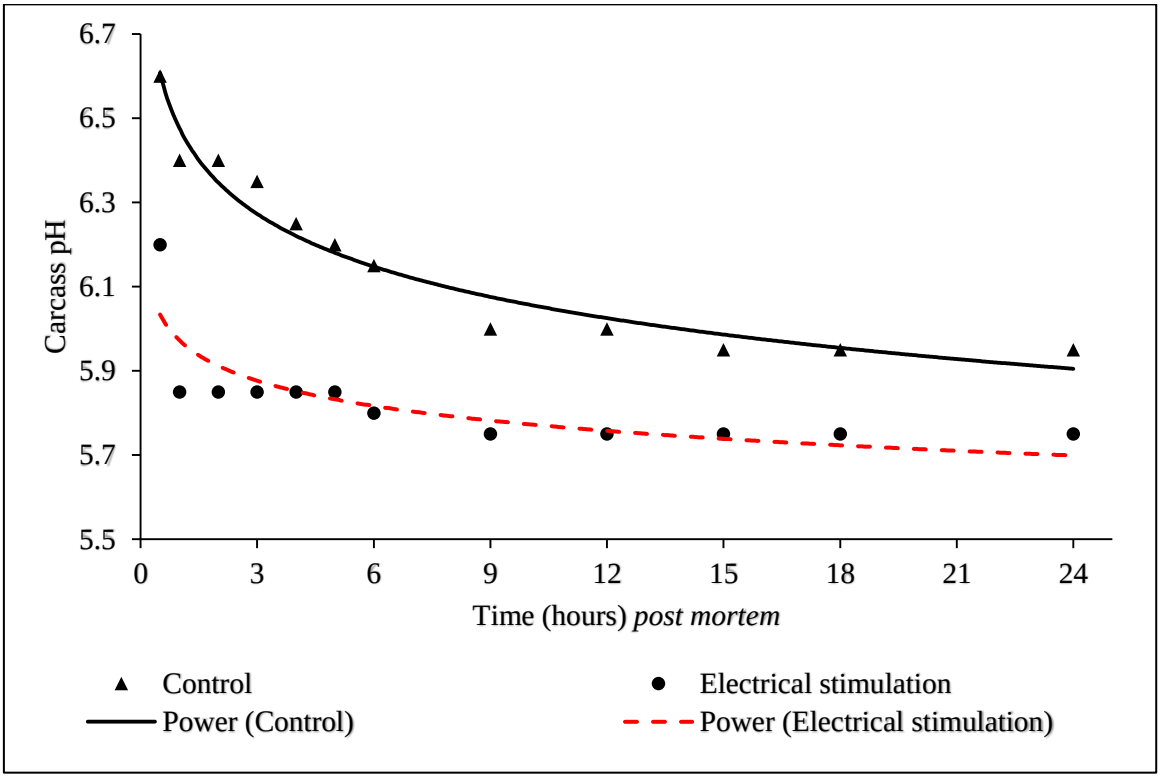


Figure 2.5 The effect of *post mortem* electrical stimulation on the rate of pH decline in *m. longissimus* of goats. Adapted from Gadiyaram et al. (2008).

The actual mechanism by which electrical stimulation improves goat meat tenderness is still debatable. Biswas, Das, Banerjee and Sharma (2007) found that the electrically stimulated *m. longissimus dorsi* of Black Bengal goats had longer sarcomeres than the non-stimulated muscle. These researchers suggested that meat tenderness was as a result of the combined effects of tender stretching and prevention of cold shortening caused by electrical stimulation. King et al. (2004) found that both high and low voltage electrical stimulation improved tenderness of goat *m. gluteobiceps* with no effects on sarcomere lengths. Gadiyaram et al. (2008) reported that samples of the *m. longissimus dorsi* from electrically stimulated goat carcasses had shorter sarcomeres but were more tender than corresponding samples from non-stimulated carcasses. The findings of Biswas et al. (2007) support the notion that electrical stimulation improves meat tenderness by counteracting the effects of cold shortening. On the

other hand, the results of King et al. (2004) and Gadiyaram et al. (2008) seem to agree with other researchers who have suggested that electrical stimulation improves meat tenderness by disrupting the myofibrillar structure and/or accelerating the rate of proteolysis (Maribo, Ertbjerg, Andersson, Barton-Gade & Møller, 1999a; Savell, Dutson, Smith & Carpenter, 1978).

2.5 Objective properties of goat meat

The quality of meat depends on the user's perception and is usually defined by indices such as pH, colour, tenderness, flavour, juiciness, nutritive value and wholesomeness (Webb et al., 2005). This section discusses the quality attributes related to visual appearance (colour and water holding capacity) and palatability (juiciness and tenderness) of goat meat. These quality attributes are considered as key factors that determine acceptability and continued interest in the product (Maltin et al., 1997).

2.5.1 Water and moisture loss

Fresh meat contains about 75% water which is held mostly within the structure of the myofibril (Apple & Yancey, 2013). Water is driven out of the myofibrillar system to spaces between fibre bundles by *rigor* shortening and myofibrillar shrinkage (Lawrie & Ledward, 2006). When the meat is cut, water will drain from the extracellular space to the surface if capillary forces do not retain it (Honikel, 1998). Water loss in meat occurs in three main ways. Firstly water is lost as drip from cut surfaces of fresh meat during storage. If the meat is frozen, more water losses occur upon thawing. Lastly moisture is lost as evaporative or drip losses during cooking. The moisture that remains in the meat after cooking determines the meat's juiciness (Bouton, Ford, Harris & Ratcliff, 1975).

2.5.1.1 Water loss in fresh meat

Water holding capacity (WHC), is defined as the ability of meat to retain water during the application of external forces and /or processing (Hamm, 1975). Factors that influence the ability of meat to retain its natural water have been previously reviewed (Huff-Lonergan & Lonergan, 2005; Pearce, Rosenvold, Andersen & Hopkins, 2011).

Both the rate and extent of glycolysis are known to have a profound effect on the WHC of a muscle. For example accelerated glycolytic rates have been reported to increase drip losses of fresh meat (Ryu & Kim, 2005). Similarly Biswas et al. (1997) reported that electrical stimulation hastened *post mortem* glycolysis and consequently decreased the WHC of goat meat. On the other hand, slow glycolytic rates leading to high pH_u, are associated with high WHC (Kauffman, Eikelenboom, van der Wal, Engel & Zaar, 1986). Bouton, Harris and Shorthose (1971) demonstrated that the WHC of meat decreased with decrease in pH_u. The WHC of muscle is at its lowest when muscle pH reaches the iso-electric point of 5.0 to 5.5 (Gault, 1985). At this iso-electric point, equal positive and negative charges of contractile proteins cause the charged portions of the proteins to attract thereby reducing the amount of water that can be attracted to the myofibrillar proteins (Apple & Yancey, 2013).

Most of the water is held by capillary forces arising from the arrangement of thick and thin filaments within the myofibrils (Huff-Lonergan & Lonergan, 2005). The formation of cross bridges between thick and thin filaments as the muscle goes into *rigor* reduces the space for water to reside (Offer & Trinick, 1983). This decline in filament spacing may force sarcoplasmic fluid from between myofilaments to the extramyofibrillar space (Lawrie & Ledward, 2006). This observation may explain why shorter sarcomeres are associated with high drip losses (Honikel, Kim, Hamm & Roncales, 1986). In goat muscles, the relationship between sarcomere length and drip loss has not been established, but the study of Kadim et al.

(2006) showed that muscles with longer sarcomeres tend to have lower expressible fluid that those with shorter sarcomeres.

2.5.1.2 Thawing losses of goat meat

Thawing is known to exacerbate water loss in meat probably due to the disruption of the muscle fibre structure as well as modification and/or denaturation of proteins (Leygonie, Britz & Hoffman, 2012). There is limited information on thawing losses of goat meat, but Schnöfeldt, Naudé, Bok, van Heerden, Sowden and Boshoff (1993b) reported thawing losses of less than 1% in *m. longissimus thoracis et lumborum* and *semimembranosus* of Angora and Boer goats. These authors aged the meat samples for seven days prior to freezing which could have improved the WHC (Kristensen & Purslow, 2001) and minimised the thawing losses.

2.5.1.3 Cooking losses of goat meat

Meat's juiciness is the moisture sensation of the cooked product and it is influenced by WHC and cooking loss of the meat (Schönfeldt et al., 1993a). The method, time and temperature of cooking can have an effect on cooking losses and on the subsequent eating quality of meat (Pearce et al., 2011). High temperatures used in cooking meat denature proteins and cause structural changes which lower the WHC of meat, leading to cooking losses (Honikel, 1998). Cooking losses as high as 30% have been reported for goat meat (Babiker, El Khider & Shafie, 1990; Abdullah & Musallam, 2007; Lee, Kouakou & Kannan, 2008b). Goat muscles have low intramuscular fat content, hence they tend to have low drip losses and high evaporative losses during cooking (Casey, 1992). High evaporative losses are undesirable as they reduce the size and juiciness of the meat.

2.5.2 Surface myoglobin pigments

Colour of meat depends on the meat's light scattering properties as well as the concentration and chemical state of myoglobin (Brewer, 2004). Three main chemical forms of myoglobin namely, oxymyoglobin, deoxymyoglobin and metmyoglobin give fresh meat its characteristic colour (Cornforth, 1994). These myoglobin redox forms are formed by oxygenation, reduction and oxidation reactions as outlined in Fig. 2.6. A review by Mancini and Hunt (2005) discusses in detail the interconversion of these myoglobin forms on the surface of fresh meat.

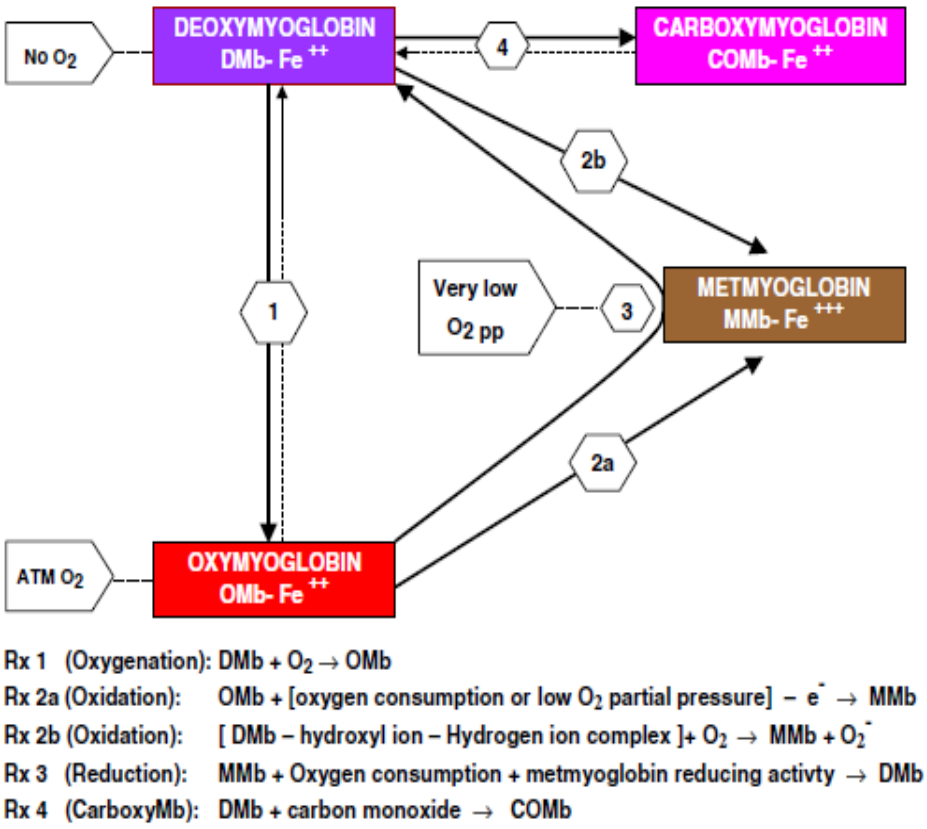


Figure 2.6 Interconversion of myoglobin redox forms on the surface of meat. Adapted from Mancini and Hunt (2005).

Briefly, deoxymyoglobin is the purplish pigment, associated with freshly cut meat. On exposure to oxygen (blooming), myoglobin is converted to oxymyoglobin giving meat its characteristic bright red colour. In the presence of oxygen, oxymyoglobin is slowly oxidised to an undesirable brownish pigment, metmyoglobin. Accumulation of metmyoglobin is the basis for meat discolouration (Mancini & Hunt, 2005). Earlier studies in beef have shown that considerable consumer rejection occurs at metmyoglobin as low as 20% (Hood & Riordan, 1973).

Very few studies have been conducted to quantify surface myoglobin pigments of goat meat, despite the importance of these pigments in determining meat colour. Kannan, Kouakou, and Gelaye (2001) studied colour changes of chevon during refrigerated storage. These researchers reported that metmyoglobin formation reached maximum levels within 4 to 8 days of storage. The results of Kannan et al. (2001) agree with Kadim et al. (2003) who reported that ageing goat meat for 4 to 6 days may have a negative influence on meat colour. According to Kannan et al. (2014) goat meat is relatively high in PUFAs which could make the meat more susceptible to both lipid and myoglobin oxidation.

2.5.3 Instrumental colour of goat meat

Meat colour is an important characteristic by which the consumers judge the quality and acceptability of meat (Bekhit & Faustman, 2005). Bright red meat is the usual preference and consumers often discriminate against meat which does not meet their expectations. The characteristic colour of goat meat has not been established, but there are perceptions that goat meat is darker than other types of red meat. In a study to compare the quality of goat meat to lamb, Babiker et al. (1990) found that the subjective colour scores were not significantly different between goat meat and lamb. This may suggest that the colour of goat meat compares well to that of lamb and consumers may not perceive the difference.

2.5.3.1 Evaluation of the quality goat meat

In many studies, goat meat colour is evaluated using the *Commission Internationale de L'eclairage* (CIE) system. This system defines meat colour in terms of lightness (L*), redness (a*), yellowness (b*), saturation (Chroma) and vividness (hue angle). The L* values range from 0 (black) to 100 (white), the a* values scale from + 60 (red) to - 60 (green), and the b* values span from + 60 (yellow) to - 60 (blue) (Young, Priolo, Simmons & West, 1999). The a* and b* values can be used to calculate Chroma $(a^{*2} + b^{*2})^{1/2}$ and hue angle [(arctangent b*/a*)] (AMSA, 2012). The L* value (lightness) is a useful indicator of DFD meat whilst the a* value (redness) is useful in evaluating the extent of meat discolouration due to myoglobin oxidation (Mancini & Hunt, 2005). Instrumental colour values (CIE L*, a*, b*) previously reported for various goat breeds are presented in Table 2.3.

Table 2.3 Instrumental colour values CIE (L*, a*, b*) reported for various goat breeds

Breed	Muscle	Variables	Colour values			Conditions	Reference
			L*	a*	b*		
Batina	LD		40.7	23.2	4.70	The colour readings were taken at 24 hours *post mortem.* Freshly cut muscle samples were allowed to bloom for 60 minutes at 1 - 3 °C.	Kadim et al. (2003)
	SM		38.2	24.9	4.84		
	BF		42.9	24.4	4.03		
	ST		42.4	24.3	4.58		
Dhofari	LD		40.1	23.6	4.84		
	SM		40.4	24.0	5.66		
	BF		43.9	24.2	4.36		
	ST		41.9	24.3	4.71		
Jabal Khadar	LD		42.1	23.5	5.76		
	SM		40.1	25.3	5.34		
	BF		42.2	24.9	4.15		
	ST		42.4	24.6	4.73		
South African indigenous goats	SM		38.6	13.8	9.60	The colour readings were taken at 24 hours *post mortem.* Freshly cut muscle samples were wrapped in an oxygen permeable polythene film and allowed to bloom for 3 hours at 2 - 4 °C with light.	Simela et al. (2004a)
Castrated Feral goats	LT	20 kg	46.8	19.6	4.71	The colour readings were taken at 24 hours *post mortem.* Freshly cut muscle samples allowed to bloom for 30 minutes.	Pratiwi et al. (2007
		30 kg	44.3	25.3	3.1		
		40 kg	41.8	23.0	3.6		
		50 kg	43.2	23.9	1.8		
		60 kg	42.6	23.1	1.6		
Spanish	LD	ES	40.8	11.3	11.3	The colour readings were taken at 24 hours *post mortem.* Freshly cut muscle samples were bloomed for 40 minutes at 2 - 4 °C with light.	Gadiyaram et al. (2008)
		NS	39.9	10.9	11.1		
Crossbreeds	LD	ES	40.1	10.8	10.7		
		NS	39.5	10.5	10.1		

Abbreviations: BF - *Biceps femoris*; LD - *Longissimus dorsi*; LT - *Longissimus thoracis*; SM - *Semimembranosus*; ST - *Semitendinosus*
ES - Electrical stimulation; NS - Non-stimulated

2.5.3.2 Factors affecting the colour goat meat

The research findings on various intrinsic and extrinsic factors that affect colour of goat meat are summarised in Table 2.4.

Table 2.4 Research findings on various intrinsic and extrinsic factors that affect goat meat colour

Factor	Summary of major finding(s)	Reference
Species	Goat meat had a darker red colour than lamb /mutton.	Sen et al. (2004)
Genotype	Genotype had a significant influence on meat colour (subjective colour scores; chroma meter-L*, a*, b*, hue angle and fibre optic probe values).	Dhanda et al. (2003)
Age	L* values decreased with increase in animal age.	Pratiwi et al. (2007)
Muscle type	There were colour variations between muscles with TB being more red than the LD or SM.	Kannan et al. (2001)
Ambient temperature	The PM of goats slaughtered in hot season (35 °C) had lower L*, a*, b* values than that of goats slaughtered at in cool season (21 °C).	Kadim et al. (2008)
Ante mortem stress	Meat samples of transport stressed goats were significantly darker (lower L*) and more red (higher a*) than those of non-stressed goats.	Kadim et al. (2006)
Rate and extent of *post mortem* glycolysis	Carcasses with pH_u less than 5.8 had a bright red colour, while carcasses exhibiting slow glycolytic rates and high pH_u had lower L* values with a tendency towards the DFD condition.	Simela et al. (2004a)
Electrical stimulation	Medium voltage (100 V) electrical stimulation improved goat meat colour.	Cetin and Topcu (2009)
Ageing	The LD, SM, ST and BF aged for 6 days had significantly lower L* values than muscles aged for 1 day.	Kadim et al. (2003)

Abbreviations: SM - *Semimembranosus*; TB - *Triceps Brachii*; LD - *Longissimus dorsi*; ST - *Semitendinosus*; BF - *Biceps femoris*; PM - *Psoas major*
DFD - Dark firm dry

2.5.4 Tenderness of goat meat

Tenderness is rated the most important eating quality of meat by consumers (Troy & Kerry, 2010). Previous studies have indicated that goat meat is less tender than lamb/mutton (Table 2.5). The degree of tenderness depends on the collagen content and solubility, the extent of sarcomere shortening during *rigor* development and/or the extent of myofibrillar protein degradation during *post mortem* ageing (Koohmaraie & Geesink, 2006).

Table 2.5 Tenderness ratings for sheep and goat meat, reported in literature

Source	Ratings		Hedonic scale† (Point)
	Sheep	Goat	
Smith, Pike, and Carpenter (1974)	6.8	5.3	8
Savell et al. (1977)	6.0	3.5	8
Babiker et al. (1990)	3.1	2.8	4
Griffin et al. (1992)	5.7	4.2	8
Schönfeldt et al. (1993b)	4.8	2.4	6
Sen et al. (2004)	4.3	3.4	5

† The hedonic scale points range from lowest (dislike extremely) to highest (like extremely).

2.5.4.1 Collagen content and solubility

Collagen content and solubility are the two basic properties that determine the background toughness of meat (Torrescano, Sánchez-Escalante, Giménez, Roncalés & Beltrán, 2003). These properties vary with *ante mortem* factors such as species, breed, sex, age, function of muscle, level of nutrition and exercise or training (Lawrie & Ledward, 2006). A study by Schönfeldt et al. (1993a) indicated that there are differences in collagen content and solubility, between goat breeds, which could affect the overall meat tenderness. These researchers found that the *m. longissimus thoracis et lumborum* of Angora goats had lower collagen content and more soluble collagen and thus it had higher tenderness ratings than the corresponding muscle of Boer goats. A study by Marichal et al. (2003) involving Spanish goats indicated that there

are inter-muscular variation in collagen content and solubility, with the *m. longissimus* having higher collagen solubility and tenderness ratings than the *m. semimembranosus*.

Collagen content does not change much during growth, but the solubility collagen decreases with age as more intermolecular crosslinks of collagen are formed (Nishimura, 2010). For example, Schönfeldt et al. (1993a) reported that meat from young Boer and Angora goats of less than one year had more soluble collagen content and had better tenderness ratings than meat from older goats.

2.5.4.2 Extent of sarcomere shortening during rigor development

The extent of sarcomere shortening during the *rigor* development is known to have an effect on meat tenderness (Hopkins, Toohey, Lamb, Kerr, van de Ven & Refshauge, 2011). Muscles with longer sarcomeres tend to be more tender than those with shorter sarcomeres (Kerth, Cain, Jackson, Ramsey & Miller, 1999). Wheeler, Shackelford and Koohmaraie (2000) suggested that if sarcomere lengths could be extended to at least 2.0 µm, the meat would be tender regardless of its collagen content and proteolysis. The aforementioned sarcomere length /tenderness relationship is not always universal. Smulders et al. (1990) reported high, negative correlations between sarcomere length and shear force values in both aged and unaged muscles where pH values at 3 hours *post mortem* were greater than 6.3, but, no relationship was observed between sarcomere length and tenderness of muscles where pH values at 3 hours *post mortem* were less than 6.3. These researchers concluded that "tenderness is highly dependent on shortening in slow glycolysing muscles and completely independent in more rapid pH decline". Veiseth, Shackelford, Wheeler and Koohmaraie (2004) suggested that sarcomere length is strongly correlated to meat tenderness only when sarcomeres are shorter than 2 µm.

2.5.4.3 Myofibrillar protein degradation

Proteolytic activity during ageing is known to improve meat tenderness. The mechanism by which ageing improves meat tenderness is discussed in many reviews (Takahashi, 2006; Kemp, Sensky, Bardsley, Buttery & Parr, 2010). In goats, the results of Kadim et al. (2003) indicated that ageing for 6 days can significantly improve meat tenderness. Other studies seem to suggest that the effects of ageing on goat meat quality are minimal. For instance, Gadiyaram et al. (2008) indicated that there may be no added benefits in ageing electrically stimulated goat meat. Kannan et al. (2014) pointed out that significant improvements in goat meat quality occur within the first 4 hours of ageing, thereafter the improvements are insignificant. Research on the effects of ageing on goat meat tenderness may not be of practical importance since goat carcasses are small and are usually consumed within a short space of time (Simela & Merkel, 2008).

2.5.4.4 Instrumental texture of goat meat

The Warner Bratzler shear force (WBSF) test is one of the method used for evaluating instrumental texture of goat meat (Savell et al., 1977; Dhanda, Taylor, Murray & McCosker, 1999b; Zimerman et al., 2011). This test measures the force required to shear a core of cooked meat, in that way, mimicking the force produced during biting and chewing of the meat (Honikel, 1998). Table 2.6 shows WBSF values reported in literature for various goat breeds.

Table 2.6 Warner Bratzler shear force values reported for various goat breeds

Breed/ genotype	Muscle	Carcass handling	Cooking method	Shear force	Reference
Desert goats	SM	Chilled for 24 hours at 4 °C	Meat samples were wrapped in aluminium foil and oven roasted at 175 to 180 °C	4.0 kg	Babiker et al. (1990)
Spanish and cross breeds	LM	ES (580 V for 120 sec); chilled for 24 hours at 2 °C	Meat samples were cooked in a convection oven to an internal temperature of 71 °C	3.0 kg	Gadiyaram et al. (2008)
		Chilled for 24 hours at 2 °C		4.6 kg	
		ES (580 V for 120 sec); chilled for 24 hours at 2 °C and aged for 96 hours		3.0 kg	
		Chilled for 24 hours at 2 °C, aged for 96 hours		3.8 kg	
Nubian×Florida	SM	Chilled at 0 - 2 °C for 24 hours	Meat samples were broiled to an internal temperature of 70 °C	7.2 kg	Johnson, McGowan, Nurse and Anous (1995)
	BF			6.3 kg	
	ST			4.1 kg	
	AD			6.1 kg	
	LD			5.7 kg	
Spanish ×Florida	SM			7.6 kg	
	BF			6.1 kg	
	ST			3.6 kg	
	AD			7.0 kg	
	LD			6.2 kg	

Table 2.6 Cont…

Breed/ genotype	Muscle	Carcass handling	Cooking method	Shear force	Reference
Florida	SM BF ST AD LD	Chilled at 0 - 2 °C for 24 hours	Meat samples were broiled to an internal temperature of 70 °C	6.3 kg 5.7 kg 3.8 kg 6.7 kg	Johnson McGowan, Nurse and Anous (1995)
Boer × Spanish crossbreeds	LM	Chilled at 2 °C for 24 hours	Meat samples were cooked in a convection oven to an internal temperature of 71 °C	3.79 kg	Lee et al. (2008b).
Australian Feral	LT TB VS	Chilled at 2 °C	Meat samples were cooked in a water bath at 85 °C to for 45 minutes	73.4 N 52.2 N 54.5 N	Pratiwi et al. (2007)
South African indigenous	SM	Chilled for 24 hours, at ~ 4 °C Chilled for 24 hours, at ~ 4 °C, aged for 96 hours	Meat samples were boiled in a water bath to an internal temperature of 75 °C	74.8 N 66.9 N	Simela et al. (2004a)
Boer Cashmere Crossbreed	LTL SM LTL SM LTL SM	ES (100 V); chilled at 4 °C for 20 hours	Meat samples were cooked to an internal temperature of 71 ± 1.5 °C by heating each side for 2.5 minutes on an electric hot plate set at 170 °C	 9.1 kg 3.7 kg 5.4 kg 3.8 kg 8.8 kg	Swan, Esguerra and Farouk (1998)

Abbreviations: BF - *Biceps femoris*; GM - *Gluteus medius*; LM - *Longissimus*; LD - *Longissimus dorsi*; AD - *Adductor*; LTL - *Longissimus thoracis et lumborum*; SM - *Semimembranosus*; ST - *Semitendinosus*; TB - *Triceps* group; VS - *Vastus* group
ES - Electrical stimulation

2.6 Summary

Chevon could become the staple meat of the world attributable to the increasing demand for lean and nutritious products. Paradoxically, the leanness of goat carcasses allows rapid dissipation of heat in the early *post mortem* phase leading to cold shortening and subsequent muscle toughening (Smith et al., 1978; Webb et al., 2005; Kannan et al., 2006; Santos et al., 2008; Mushi et al., 2009; Kadim & Mahgoub, 2012; Kannan et al., 2014). Therefore, there is a critical need for research on strategies that maximises the conversion of muscle to meat to enhance the quality of goat meat. This entails a better understanding of the mechanisms underlying the development of goat meat quality.

This chapter reviewed literature on carcass, muscle and meat quality of goats. Abundant literature is available on carcass yield of goats (Mahgoub & Lu, 1998; Simela et al., 2011; Gokdal, 2013). However, very few studies link carcass and/or muscle characteristics to the ultimate quality of goat meat (Van Niekerk & Casey, 1988; Arguello et al., 2005). In addition, published information on fibre characteristics and energy metabolism in goat muscles is very scarce. This information is crucial in understanding the mechanisms controlling the development of goat meat quality and provides basis for further improve the quality of goat meat.

Appropriate *ante- peri* and *post mortem* handling procedures, coupled with good genetics, nutrition and management practises can guarantee the desired goat meat quality (Goetsch et al., 2011). This study investigated slaughter conditions that would enhance the conversion of muscle to meat and the resultant meat quality of two South African goat breeds. The knowledge generated from this study provides an insight on breeds, carcass treatments or a combination of these factors that could be utilised for better chevon quality.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Management of the experimental animals

This project was approved by the Animal Ethics Committee of the University of Pretoria (ref no. EC072 - 13). A flock of newly weaned male kids from established populations of South African indigenous and Boer goats (n = 20 goats per breed; weighing between 14 kg and 20 kg) were purchased from a group of farmers in Bronkhorstspruit, Gauteng, South Africa. The goats were transported over a distance of 57 km to Hatfield experimental farm of the University of Pretoria, Gauteng, South Africa. On arrival at the experimental farm, the goats were vaccinated against pasteurella and clostridial infections, dewormed against major internal parasites and spray dipped against external parasites. The goats were kept in separate pens according to breed but they were treated in the same way during the rearing phase.

The goats were kept on a commercial diet of Meadow game pellets formulated to provide 110 g/kg DM crude protein, 3.68% non-protein nitrogen, 25 g/kg DM crude fat, 110 g/kg DM crude fibre, 6 g/kg DM calcium and 2.5 g/kg DM phosphorus. The pellets were provided at 3% of live weight per animal per day to meet the nutritional requirements of the goats. Lucerne hay and clean water were available *ad libitum*. On adaptation to the diet and the environment, the goat kids were castrated using Burdizzo clamps. Routine weighing was done every second week to monitor growth. The goats were reared for approximately 200 days to attain a marketable weight of between 30 kg and 40 kg.

3.2 Slaughter, carcass treatment and sampling procedures

Ten (10) goats per breed were randomly selected from the twenty available goats. All the goats selected for slaughter had no permanent incisors. Animals with milk teeth are designated A-age class in the current South African Red Meat Carcass Classification System (RSA Government notice no. R55, 2015). A day prior to slaughter, the goats were weighed and transported over a distance of 26 km to the abattoir of Agricultural Research Council - Animal Production Institute (ARC - API) at Irene, Gauteng, South Africa. The goats were kept in lairage overnight, with Lucerne hay and water available *ad libitum* in order to minimise *ante mortem* stress which may occur due to feed withdrawal.

At slaughter, the goats were electrically stunned by applying 220 V across the head at the base of the ears for 5 seconds. Immediately after stunning, the goats were exsanguinated by severing the neck and the jugular veins. Within 5 minutes of slaughter, samples of the *m. longissimus dorsi* (LD) and *m. semimembranosus* (SM) each weighing approximately 10 g, were immediately placed in small plastic bags, vacuum sealed, snap frozen in liquid nitrogen and immediately placed in the -80 °C Ultra Low Temperature Freezer (NEW ECO Snijders, -80 °C Ultra Low Temperature Freezer Volume 711 l (VF720-86), United Scientific, Cape Town, South Africa) for determination of muscle fibre type.

The goat carcasses were dressed by removing the skin, head (between the occipital and first cervical vertebrae), fore-feet (at the carpal-metacarpal joint), hind feet (at the tarsal-metatarsal joint) and viscera (Colomer-Rocher, Morand-Fehr & Kirton, 1987). After evisceration, the carcasses were weighed to determine hot carcass weight (HCW). The goat carcasses were split into left and right sides along the vertebral column using a saw. Within 15 minutes of slaughter, the left sides of the carcasses were electrically stimulated for 30 seconds

(400 V peak, 5 ms pulses at 15 pulses per second; Tender Pulse, High Voltage Stimulation Power Supply, Manufactured by AIS Enterprises, Brisbane, Australia). One probe of the electrical stimulator was placed on the shin and the other was placed on the neck of the carcass half. The right sides of the carcasses were held at 10 - 15 °C for 6 hours and then chilled at 0 – 4 °C until 24 hours (delayed chilling treatment). The carcass sides were not randomly allocated to treatment to avoid possible treatment error. Furthermore, the left and right sides of carcasses are considered to be relatively similar (Carroll & O'Carroll, 1964).

The Red Meat Research Development South Africa (RMRDSA) funded the earlier research "Slaughter conditions and chevon quality", but did not support this follow up study. Therefore we had to minimise the number of replicates and treatments and test the most essential factors for practical application. The results reported by Simela (2005) were used for to plot the curves for the conventional treatment.

Muscle pH and temperature readings were taken between the fourth and fifth lumbar vertebra and close to the posterior end of the SM. The pH and temperature readings were taken by inserting a portable pH meter (Eutech Instruments, CyberScan pH 11) into the muscle to a depth of about 1.5 cm. The readings were taken at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*. Samples of both the LD and SM, each weighing approximately 5 g were taken from the same anatomical position as pH/temperature readings, at 15 minutes, 3 hours and 24 hours *post mortem*. Immediately after cutting, the samples were snap frozen in liquid nitrogen and stored at -80 °C, for determination of muscle metabolite concentrations. To prevent desiccation of samples during -80 °C storage, the meat samples were immediately placed in small plastic bags, vacuum sealed and snap frozen in liquid nitrogen and immediately placed in the -80 °C Ultra Low Temperature Freezer (NEW ECO Snijders, -80 °C Ultra Low

Temperature Freezer Volume 711 l (VF720-86), United Scientific, Cape Town, South Africa). All snap frozen samples were handled the same way to eliminate experimental error.

At 24 hours *post mortem*, both carcass sides were weighed to determine cold carcass weight (CCW). Dressing percentages (DP) and chilling losses of goat carcasses were calculated according to the formulas used by Simela et al. (2011) as follows:

$$\text{Dressing percentage} = \frac{\text{CCW}}{\text{Live weight}} \times 100$$

$$\text{Chilling loss (\%)} = \frac{\text{HCW} - \text{CCW}}{\text{HCW}} \times 100$$

The LD and SM were dissected from both carcass sides, at 24 hours *post mortem*. Fresh meat samples, each weighing approximately 50 g were kept at 0 - 4 °C for determination of sarcomere lengths, water holding capacity (WHC), instrumental colour values (CIE L*, a*, b*, Chroma and hue angle) and surface myoglobin redox forms (deoxymyoglobin, oxymyoglobin and metmyoglobin). The LD and SM samples each weighing approximately 200 g were vacuum packed and kept frozen at -20 °C, for determination of thawing losses, evaporative losses, drip losses, cooking losses and WBSF values. The vacuum bag thickness used was 70 microns of various sizes. The vacuum packer: A Boss twin-chamber vacuum machine type: Titan-X 630; no 080842; id no 063-Z3-0DN-0-4-0-00 (Miestertech Z3000). Vacuum pump 100m3/h, vacuumed at 99% at 1°C.

3.3 Laboratory analyses

3.3.1 Muscle fibre characteristics

Cross sections of 12 µm were cut in a cryostat (NEW ECO Snijders, -80 °C Ultra Low Temperature Freezer Volume 711 l (VF720-86), United Scientific, Cape Town, South Africa) from frozen samples of both the LD and SM. The cross sections were mounted on a slide, covered with a cover slip and stained for *succinate dehydrogenase* (SDH) activity using nitroblue tetrozolium (Pearse, 1968). The prepared slides were viewed under an Olympus B340 microscope system attached to CC12 video camera (Olympus, Tokyo, Japan), under 100 × magnification. Muscle fibre types were categorised as red, intermediate and white (Fig. 3.1), according to the *nomenclature* of Gauthier (1969). Cross sectional areas (CSA) and percentages of muscle fibre types were analysed using the Analysis Life Sciences software (Soft Imaging Systems Gmbh, Münster, Germany).

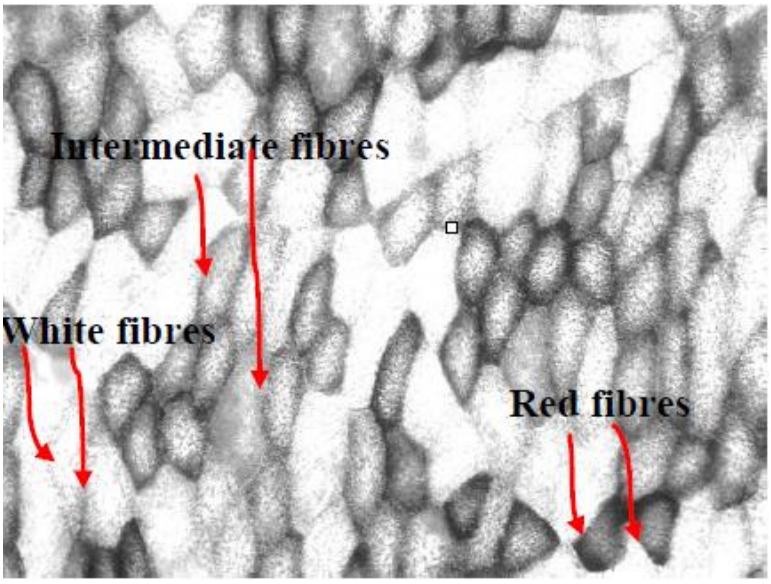


Figure 3.1 Cross sections of the m. longissimus dorsi showing red, intermediate and white muscle fibre types. Viewed under 100 × magnification.

3.3.2 Muscle metabolic status

The concentration of creatine phosphate, glycogen, glucose, glucose-6-phosphate, ATP and lactate in both the LD and SM samples were determined using enzyme analytical methods. Perchloric acid muscle extraction was done using a modified method by Dalrymple and Hamm (1973). Briefly, a frozen muscle sample of 2 - 3 g was homogenized using an Ultra Turrax T5 blender (Janke and Kunkel IKA$^{@}$ -Labortechnik), in 10 ml of 0.6 N perchloric acid. The homogenate was centrifuged (10 000 RPM) for 15 minutes at 4 °C. A part (0.1 ml) of the supernatant from the extract was used for determination of muscle glycogen and glucose using the *amyloglycosidase* method (Keppler & Decker, 1974).

The remaining supernatant was neutralised to a methyl orange end point with a few drops of 5.4 N potassium hydroxide. The resulting potassium perchlorate was precipitated out for 20 minutes and decanted through a filter paper (Whatman 4). Lactate content in the supernatant was determined using the *lactate dehydrogenase* method (Gutmann & Wahlefeld, 1974). Creatine phosphate, ATP and glucose-6-phosphate were determined using the *creatine kinase*, *hexokinase* and *glucose-6-phosphate dehydrogenase* method (Lamprecht, Stein, Heinz & Weisser, 1974).

The metabolite concentrations were used to calculate glycolytic potential (GP) using Monin and Sellier (1985) formula:

GP (µmol/g) = 2 (glycogen + glucose + glucose-6-phosphate) + lactate.

3.3.3 Water holding capacity

Water holding capacity of both LD and SM samples was determined using the filter paper press method as described by Strydom et al. (2005). Briefly, a 400 - 500 mg meat sample was

placed on a filter paper (Whatman 4), contained between two Perspex plates. Constant pressure was applied using a hand operated screw for 5 minutes (Carver Laboratory Press Model C, 1 metric ton for 60 seconds; Carver, Inc., Wabash, USA). The borders of meat and fluid expressed were marked out and their areas were measured using a video image analyser (Olympus, Tokyo, Japan), according to Irie, Izumo and Mohri (1996). Water holding capacity was expressed as a ratio of meat area to fluid area.

3.3.4 Thawing and cooking losses

Frozen meat samples of both the LD and SM, weighing approximately 200 g were thawed at 0 - 4 °C for 24 hours. The thawed meat samples were broiled in an oven (Mielé, model H217, Mielé & Cie, Gütersloh, Germany) pre-set at 190 °C to an internal temperature of 75 °C. Thawing loss was expressed as a percentage of pre-thawed weight and cooking loss was expressed as a percentage of pre-cooked weight (Molette, Rémignon & Babilé, 2003).

3.3.5 Instrumental colour and surface myoglobin redox forms

Fresh meat samples weighing approximately 20 g were cut from both the LD and SM. The meat samples of 15 mm thickness were allowed to bloom for 1 hour at ± 4 °C before reading the colour values. A Konica-Minolta 600d spectrophotometer with the SpectraMagic NX Pro software package was used to read instrumental colour values (CIE L*, a*, b*, Chroma and hue angle). The spectrophotometer configuration was: illuminant D65, observer angle 10°, measurement aperture 8 mm. Measurements were taken excluding the spectral component, after calibration using the included white reference. Three readings were taken from each sample and the mean values were used for statistical analysis.

Surface myoglobin redox forms (deoxymyoglobin, oxymyoglobin and metmyoglobin), were calculated according to Krzywicki (1979). The described Konica-Minolta 600d spectrophotometer was used to record the meat spectra from 400 nm to 730 nm, at 10 nm intervals. The surface myoglobin redox forms were calculated at isobestic points 473 nm, 525 nm, 572 nm (obtained by linear interpolation) and 730 nm.

3.3.6 Sarcomere lengths

Samples of both the LD and SM were prepared according to Hegarty and Naudé (1970). Briefly, muscle samples weighing approximately 5 g were homogenised in approximately 15 ml distilled water (Dreyer, Van Rensburg, Naudé, Gouws & Stiemie, 1979), using an Ultra-Turrax blender at low speed until all individual fibres were separated. A few drops of the homogenate were mounted on a slide and covered with a cover slip. The slides were viewed under an Olympus B340 microscope system attached to CC12 video camera (Olympus, Tokyo, Japan) at 31 000 × magnification. Analysis Life Sciences software package (Soft Imaging Systems Gmbh, Münster, Germany) was used to process the data. Fifty sarcomeres were measured per sample and their mean lengths were used for statistical analysis.

3.3.7 Warner Bratzler shear force values

The cooked meat samples of both the LD and SM were cooled at 16 °C for 2 hours to an internal temperature of 19 °C. From each sample, six cores with a diameter of 12.5 mm were removed parallel to the direction of muscle fibres. The cores were sheared across the fibres, using a Warner Bratzler shear device mounted on a Universal Instron apparatus (Model 4301, Instron Ltd, Buckinghamshire, UK: crosshead speed = 200mm/min, one shear in the centre of

each core). The toughness of meat was measured as the average peak force (kg), required to shear through the six cores per sample.

3.4 Statistical analyses

The two main factors were breed (indigenous *vs.* Boer goats) and carcass treatment (electrical stimulation *vs.* delayed chilling). The effects of these main factors and their interaction (if applicable) on muscle or meat characteristics were tested on two goat muscles (the LD and SM). The overall means and their standard errors were presented, if the main factor had no significant effect. All statistical analyses were conducted using IBM SPSS version 23.0 (SPSS, 2015).

3.4.1 Carcass characteristics

The effect of breed on LW, HCW, CCW, DP and chilling losses was analysed by General Linear Model (GLM) using one-way multivariate analyses of variance (MANOVA). Means were compared using least significant difference procedure and differences were considered significant at $P < 0.05$.

3.4.2 Histochemical properties

The effect of breed on fibre cross sectional area and percentages in both the LD and SM was analysed as described in §3.4.1.

3.4.3 Biochemical properties

The concentration creatine phosphate, glycogen, glucose, glucose-6-phoshate, ATP, lactate and the calculated GP for both the LD and SM was analysed by GLM procedure using

a two-way MANOVA. The model used included the fixed effects of breed, carcass treatment and their first order interactions. *Post mortem* metabolic changes were analysed as repeated measurements. Significances between means were assessed using the least-significant-differences procedure and differences were considered significant at $P < 0.05$. Paired samples *t*-test procedure was used for comparison of means if F-tests on the interaction effect were significant. The same test (paired samples *t*-test procedure) was used to compare the LD and SM samples and differences were considered significant at $P < 0.05$.

3.4.4 Muscle pH and temperature decline

Data on pH and temperature decline for both the LD and SM was analysed as described in §3.4.3.

3.4.5 Objective properties

Data on WHC, thawing losses, evaporative losses, drip losses, total cooking losses, surface myoglobin redox forms (deoxy-, oxy- and metmyoglobin), instrumental colour values (L*, a*, b*, Chroma and hue angle), sarcomere lengths and WBSF values for both the LD and SM was analysed as described in §3.4.3, but as single observations.

3.4.6 Correlation analysis

Pearson's correlation coefficients were calculated to determine the relationships between carcass, muscle and meat quality parameters. The bivariate correlation analysis was performed with a two-tailed test of significance.

CHAPTER 4

4 RESULTS

Aspects of the results reported in this chapter were published as a research article in Small Ruminant Research:

Pophiwa, P., Webb, E.C., & Frylinck, L. (2016). Meat quality characteristics of two South African goat breeds after applying electrical stimulation or delayed chilling of carcasses. *Small Ruminant Research*, *145*, 107-114.

4.1 Live weight and carcass characteristics of indigenous and Boer goats

Live weight and carcass characteristics are not only related to meat yield, but they have an implication on meat quality. There is abundant literature on carcass and meat yield of goats (Dhanda, Taylor, McCosker & Murray, 1999a Simela, Ndlovu & Sibanda, 1999; Gökdal, 2013). However, very few studies link carcass characteristics to the biochemical and physical processes during the conversion of muscle to meat and the resultant meat quality. Therefore studying selected animal and carcass characteristics could be useful in predicting both meat yield and meat quality in the early stages of meat production. This section describes live weight and carcass characteristics of indigenous and Boer goats that were used for this study.

Least square mean for live weight and selected carcass characteristics of indigenous and Boer goats are presented in Table 4.1.

Table 4.1 Least square means ($\bar{x}$ ± SEM) for the effect of breed on live weight, hot carcass weight, cold carcass weight, dressing percentage and chilling loss of goats

Characteristic	Breed		*P*-value
	Indigenous goats	Boer goats	
Live weight (kg)	33.7^{a} ± 0.37	39.8^{b} ± 1.05	0.0001
Hot carcass weight (kg)	16.7^{a} ± 0.27	19.9^{b} ± 0.54	0.0001
Cold carcass weight (kg)	16.0^{a} ± 0.25	18.9^{b} ± 0.52	0.0001
Dressing percentage	47.4 ± 0.54	47.5 ± 0.57	0.91
Chilling loss (%)	4.03^{a} ± 0.12	4.81^{b} ± 0.19	0.002

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

At slaughter, Boer goats were 6.1 kg heavier (P <0.001) and their chilled carcasses were 2.9 kg heavier (P <0.001) than those of indigenous goats (Table 4.1). There were no breed differences (P >0.05) in the dressing percentages of the goats, with an average value of 47.5 ± 0.55%. Chilling losses were higher (P <0.01) in carcasses of Boer goats than in carcasses of indigenous goats (4.81 ± 0.12% *vs.* 4.03 ± 0.19%).

4.2 Muscle fibre characteristics of indigenous and Boer goats

One of the intrinsic factors that influence the development of meat quality is the muscle fibre composition (Karlsson et al., 1999). Despite their importance in controlling the biochemical process during the conversion of muscle to meat, very little is known regarding the fibre characteristics of goat muscles. This section describes fibre characteristics in goat muscles. This information is valuable in interpreting results from biochemical analysis and meat quality evaluation in subsequent sections.

4.2.1 The effect of breed on fibre cross sectional areas

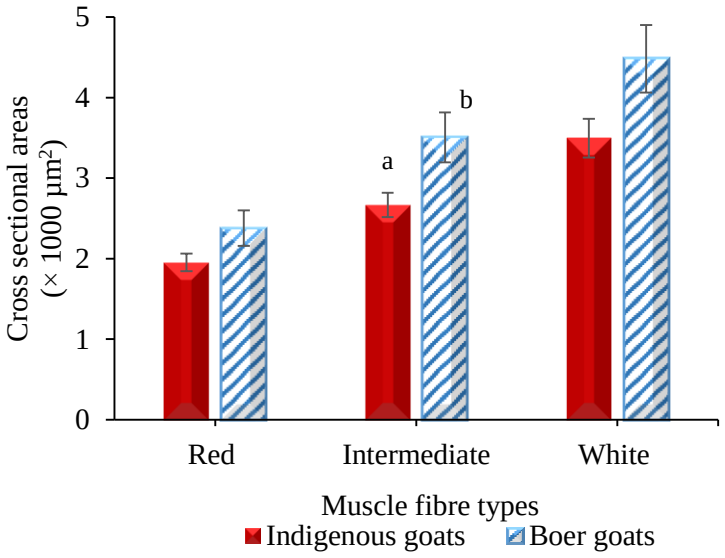
The effect of breed on fibre cross sectional areas (CSA) in LD and SM samples of indigenous and Boer goats are presented in Table 4.2 and Fig. 4.1A & B.

Table 4.2 *P*-values of the effect of breed on cross sectional areas of different fibre types in *m. longissimus dorsi* and *m. semimembranosus* of goats

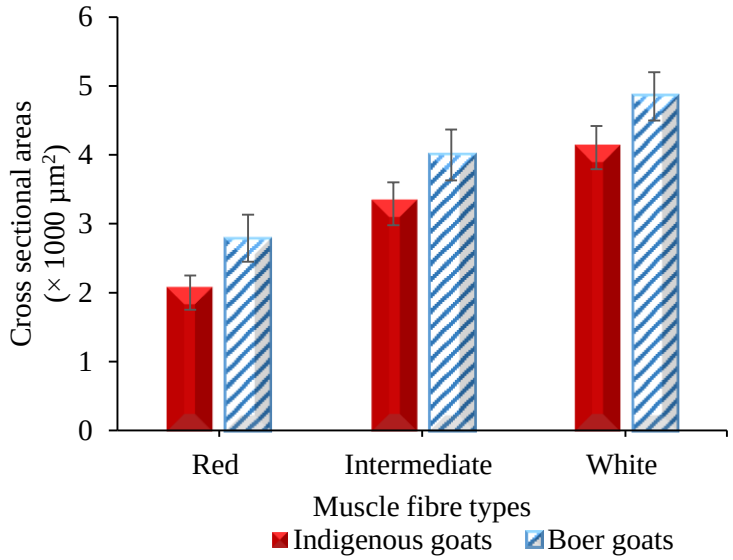
Muscle	Fibre type	*P*-values
Longissimus dorsi	Red	0.10
	Intermediate	0.02
	White	0.06
Semimembranosus	Red	0.08
	Intermediate	0.16
	White	0.13

In LD samples, breed had no effect (P >0.05) on CSA of red or white fibres (Table 4.2). However, the intermediate fibres in LD samples of indigenous goats had smaller (P <0.05) CSA than corresponding samples of Boer goats (2667 ± 145 µm^2 *vs*. 3506 ± 307 µm^2; Fig 4.1A). An overview of the results (Fig 4.1A) showed that red fibres had the smallest CSA, intermediate fibres were of intermediate size and white fibres had the largest CSA, with average values of 2166 ± 484 µm^2, 3087 ± 690 µm^2 and 3989 ± 892 µm^2, respectively.

In SM samples, all the fibre CSA were not different (P >0.05) between the two goat breeds (Table 4.2). The average CSA of red, intermediate and white fibres in SM samples were 2443 ± 546 µm^2, 3671 ± 821 µm^2 and 4496 ± 1005 µm^2, respectively (Fig. 4.1B)



A.



B.

Figure 4.1 Fibre cross sectional areas (µm^2) in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats. Vertical bars indicate standard error of means. Means with different letters a, b were different (P <0.05)

4.2.2 The effect of breed on fibre percentage

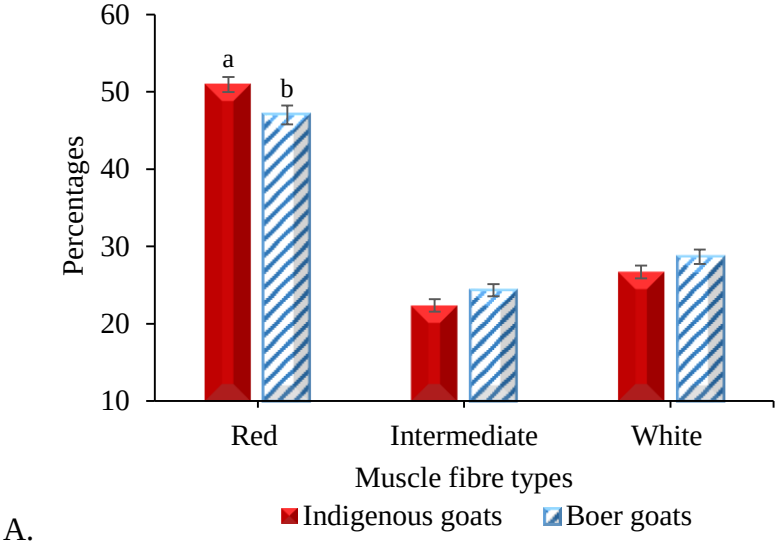
The effect of breed on fibre percentage in LD and SM samples of indigenous and Boer goats are presented in Tables 4.3 and Figs. 4.2A & B.

Table 4.3 *P*-values of the effect of breed on percentages of different fibre types in *m. longissimus dorsi* and *m. semimembranosus* of goats

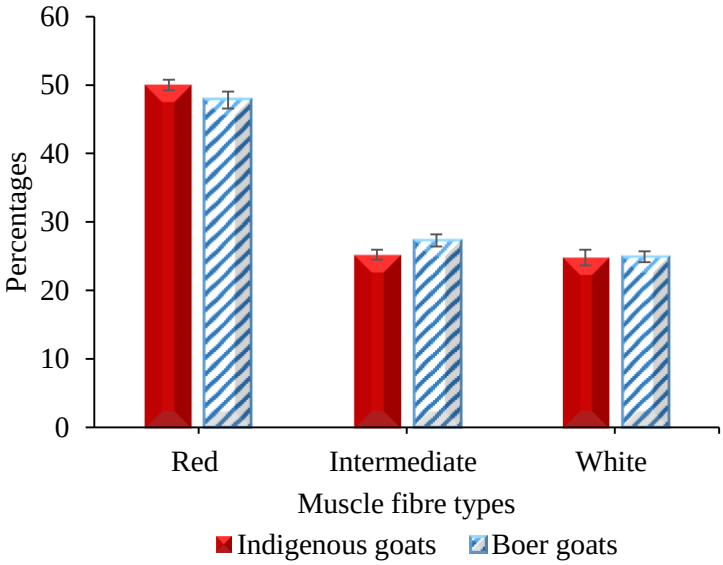
Muscle	Fibre type	*P*-value
Longissimus dorsi	Red	0.02
	Intermediate	0.09
	White	0.13
Semimembranosus	Red	0.15
	Intermediate	0.08
	White	0.95

There were no breed differences (P >0.05) in the percentages of intermediate or white fibres (Table 4.3). However, the LD samples of indigenous goats had a higher (P <0.05) percentage of red fibres than the corresponding samples of Boer goats (50.9 ± 0.98% *vs.* 47 ± 1.22%; Fig. 4.2A). The average percentages of red, intermediate and white fibres in LD samples were 49 ± 10.9%, 23 ± 5.22% and 28 ± 6.19%, respectively.

In SM samples, there were no breed differences (P >0.05) in fibre percentages with average values of 49 ± 10.9%, 26 ± 5.87% and 25 ± 5.55% for red, intermediate and white, respectively (Table 4.3 and Fig 4.2B).



A.



B.

Figure 4.2 Fibre percentages in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats. Vertical bars indicate standard error of means. Means with different letters a, b were different (P <0.05)

4.2.3 Comparison of the *m. longissimus dorsi* and the *m. semimembranosus*

Fibre characteristics in LD and SM samples were compared and the results are presented in Table 4.4. The SM samples had larger (P <0.05) CSA of intermediate fibres than the LD

samples (3671 ± 230 µm^2 *vs.* 3087 ± 192 µm^2). However, the CSA of red or white fibres were not different (P >0.05) between the two muscles (Table 4.4). Regarding fibre percentage, the SM samples had a higher percentage of intermediate fibres (26.2 ± 0.61% *vs.* 23.4 ± 0.59%, P <0.01) and a lower percentage of white fibres (24.8 ± 0.68% *vs.* 27.7 ± 0.65%, P <0.01) than the LD samples, whereas the percentage of red fibres was not different (P >0.05) between the two muscles (Table 4.4).

Table 4.4 Comparison of fibre characteristics ($\bar{x}$ ± SEM) in *m. longissimus dorsi* and *m. semimembranosus* of goats

Variable	Muscle		*P*-value
	Longissimus dorsi	*Semimembranosus*	
Fibre cross sectional area (µm^2)			
Red	2166 ± 127	2443 ± 202	0.23
Intermediate	3087^a ± 192	3671^b ± 230	0.045
White	3989 ± 262	4496 ± 235	0.14
Fibre percentage			
Red	49.0 ± 0.89	48.9 ± 0.75	0.97
Intermediate	23.4^a ± 0.59	26.2^b ± 0.61	0.001
White	27.7^a ± 0.65	24.8^b ± 0.68	0.004

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

4.3 Biochemical changes in *post mortem* muscles of indigenous and Boer goats

It was highlighted (§2.4.2) that very few studies, if any, have attempted to investigate the biochemical and physical changes taking place during the conversion of muscle to meat in goats. This is despite the fact that these changes are crucial in determining the ultimate quality of meat (Scheffler & Gerrard, 2007). This section describes the *post mortem* changes in the

concentration of creatine phosphate, glycogen, glucose, glucose-6-phosphate, ATP, lactate and the calculated glycolytic potential in goat muscles that were used to evaluate chevon quality in subsequent sections. This information provides an insight on the biochemistry underlying the development of goat meat quality in slaughter conditions set for this study.

4.3.1 The effects of breed, carcass treatment and their interaction on the concentration of muscle creatine phosphate

The effects of breed on the concentration of creatine phosphate in LD and SM samples of goats are presented in Table 4.5.

Table 4.5 Least square means ($\bar{x}$ ± SEM) for the effect of breed on creatine phosphate concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Breed		*P*-value
		Indigenous goats	Boer goats	
Longissimus dorsi	15 minutes	3.16 ± 0.27	3.31 ± 0.30	0.69
	3 hours	2.34 ± 0.10	2.46 ± 0.10	0.44
	24 hours	1.81^{a} ± 0.12	2.16^{b} ± 0.09	0.03
Semimembranosus	15 minutes	2.95 ± 0.26	3.30 ± 0.27	0.35
	3 hours	2.11^{a} ± 0.14	2.54^{b} ± 0.11	0.03
	24 hours	1.63^{a} ± 0.08	1.95^{b} ± 0.10	0.01

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

There were no breed differences (P >0.05) in LD creatine phosphate concentration at 15 minutes or 3 hours *post mortem*, with average values of 3.23 ± 0.20 µmol/g and 2.40 ± 0.07 µmol/g, respectively (Table 4.5). At 24 hours *post mortem*, the LD samples of indigenous goats

had 16% lower (P <0.05) creatine phosphate content than corresponding samples of Boer goats (1.81 ± 0.12 µmol/g *vs.* 2.16 ± 0.09 µmol/g).

On average, the concentration of creatine phosphate in SM samples at 15 minutes *post mortem* was 3.13 ± 0.19 µmol/g with no significant difference (P >0.05) between the two goat breeds (Table 4.5). However, at 3 hours *post mortem*, the SM samples of indigenous goats had 17% lower (P <0.05) creatine phosphate concentration than SM samples of Boer goats (2.11 ± 0.14 µmol/g *vs.* 2.54 ± 0.11 µmol/g). The tendency for lower (P <0.01) creatine phosphate content in SM samples of indigenous goats (1.63 ± 0.08 µmol/g) compared to those of Boer goats (1.95 ± 0.10 µmol/g) was also significant at 24 hours *post mortem* (Table 4.5).

The effects of carcass treatment the concentration of creatine phosphate in LD and SM samples of goats are presented in Table 4.6

Table 4.6 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on creatine phosphate concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	2.80^{a} ± 0.11	3.67^{b} ± 0.36	0.03
	3 hours	2.30 ± 0.10	2.50 ± 0.10	0.15
	24 hours	1.95 ± 0.11	2.02 ± 0.12	0.63
Semimembranosus	15 minutes	2.94 ± 0.21	3.31 ± 0.31	0.33
	3 hours	2.34 ± 0.12	2.30 ± 0.15	0.84
	24 hours	1.98^{a} ± 0.10	1.60^{b} ± 0.08	0.003

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

Initially (at 15 minutes *post mortem*), the LD samples of electrical stimulation treatment had 24% lower (P <0.05) creatine phosphate concentration than the corresponding samples of

delayed chilling treatment (Table 4.6). The LD creatine phosphate content decreased to 2.40 ± 0.07 µmol/g, and 1.98 ± 0.08 µmol/g at 3 hours and 24 hours *post mortem* respectively, with no significant differences (P >0.05) between the two carcass treatments at both sampling times.

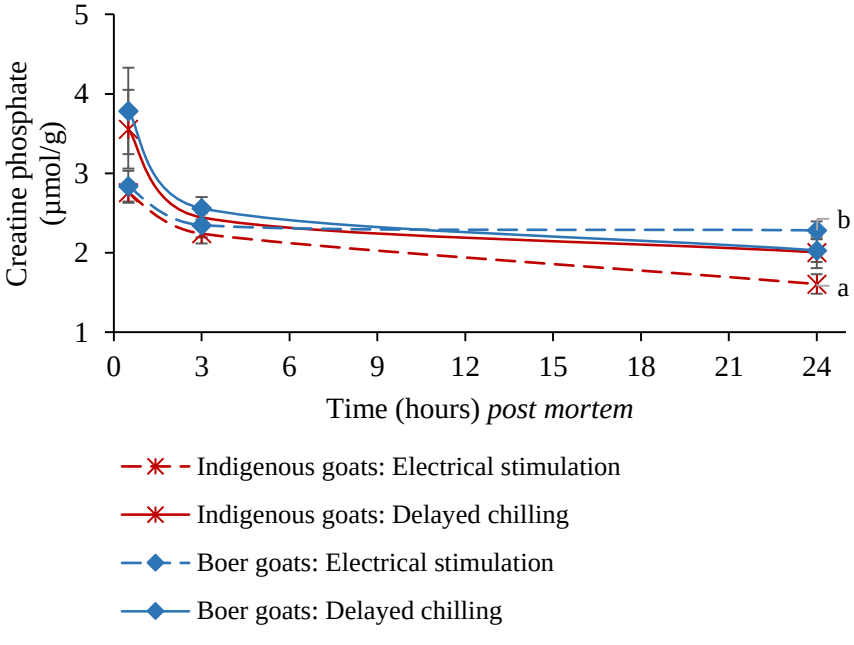
The concentration of SM creatine phosphate decreased from 3.13 ± 0.19 µmol/g at 15 minutes *post mortem* to 3.30 ± 1.21 µmol/g at 3 hours *post mortem*, with no significant difference (P >0.05) between the two treatments (Table 4.6). At 24 hours *post mortem*, the SM samples of electrical stimulation treatment had 18% higher (P <0.01) creatine phosphate content than corresponding samples of delayed chilling treatment (1.60 ± 0.08 µmol/g).

The interaction effect of breed and carcass treatment on the concentration of creatine phosphate in LD and SM samples of goats are presented in Table 4.7 and Fig. 4.3A & B.

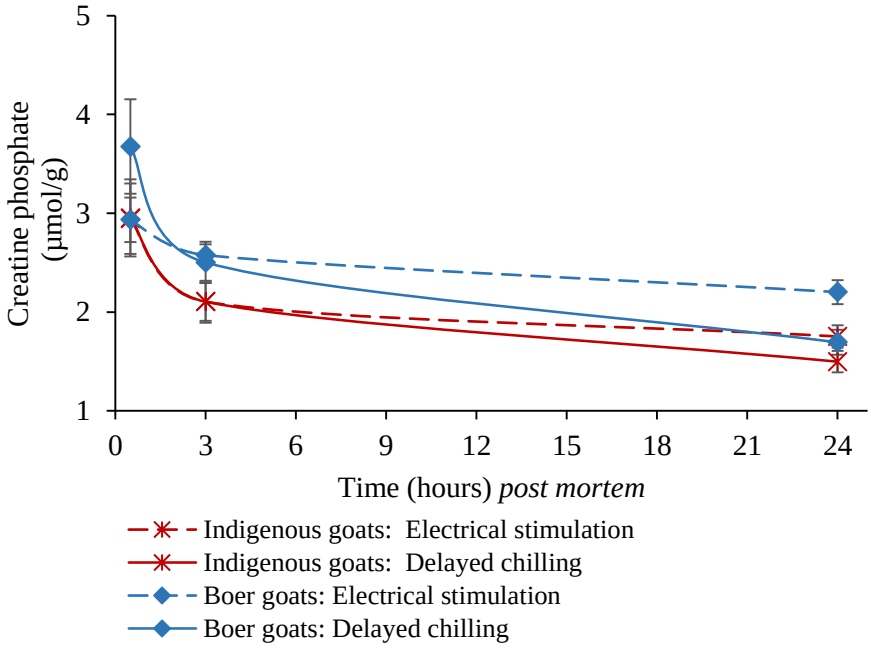
Table 4.7 *P*-values of the interaction effect between breed and carcass treatment on creatine phosphate concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	30 minutes	0.85
	3 hours	0.98
	24 hours	**0.04**
Semimembranosus	30 minutes	0.33
	3 hours	0.84
	24 hours	0.29

Significant (P <0.05) interaction effect are in indicated in bold



A.



B.

Figure 4.3 Creatine phosphate concentration (µmol/g), at 15 minutes, 3 hours and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means. Means within the different letters a, b were different (P <0.05).

The interaction effect of breed and carcass treatment on LD creatine phosphate concentration was significant (P <0.05) only at 24 hours *post mortem* (Table 4.7). In electrical stimulation treatment, the concentration of creatine phosphate in LD samples of Boer goats was 30% higher (P <0.05) than in corresponding samples of indigenous goats (1.61 ± 0.12 µmol/g). On the other hand, breed had no effect (P <0.05) on LD creatine phosphate content in delayed chilling treatment, with an average value of 1.81 ± 0.12 µmol/g (Fig. 4.3A). In SM samples, interaction effect of breed and carcass treatment on creatine phosphate concentration was not significant (P >0.05) at any sampling time (Table 4.7 and Fig 4.3B).

4.3.2 The effects of breed, carcass treatment and their interaction on the concentration of muscle glycogen

The effects of breed on the concentration of glycogen in LD and SM samples of goats are presented in Table 4.8.

Table 4.8 Overall means ($\bar{x}$ ± SEM) for glycogen concentration (µmol glycosyl units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	$\bar{X}$ ± SEM
Longissimus dorsi	15 minutes	19.3 ± 0.92
	3 hours	11.5 ± 0.75
	24 hours	4.23 ± 0.43
Semimembranosus	15 minutes	20.9 ± 1.00
	3 hours	12.0 ± 0.85
	24 hours	2.95 ± 0.26

Breed had no effect (P >0.05) on muscle (both LD and SM) glycogen content at any sampling time (Table 4.8). Overall, the LD glycogen concentration decreased by 78% from

initial levels of 19.3 ± 0.96 µmol/g to 4.23 ± 0.44 µmol/g, at 24 hours *post mortem*. A similar pattern of change was observed in SM samples with overall glycogen levels decreasing by 86% from 20.9 ± 1.00 µmol/g to 2.95 ± 0.26 µmol/g, over *post mortem* time (Table 4.8).

The effects of carcass treatment on the concentration of glycogen in LD and SM samples of goats are presented in Table 4.9.

Table 4.9 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on glycogen concentration (µmol glycosyl units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	17.0^{a} ± 1.25	21.6^{b} ± 1.29	0.02
	3 hours	8.5^{a} ± 1.13	14.5^{b} ± 1.05	0.0001
	24 hours	4.74 ± 0.70	3.72 ± 0.54	0.25
Semimembranosus	15 minutes	21.0 ± 1.39	20.9 ± 1.48	0.96
	3 hours	11.5 ± 1.14	12.6 ± 1.26	0.54
	24 hours	3.10 ± 0.41	2.80 ± 0.33	0.42

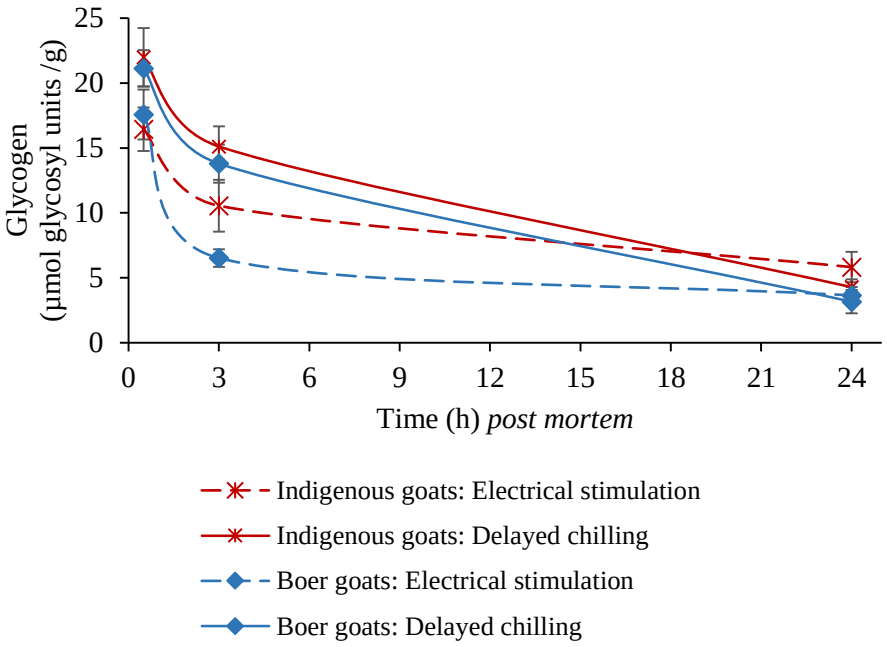
Means within the same row with different superscripts $^{a, b}$ were different (P <0.05)

Initially (at 15 minutes *post mortem*) glycogen concentration were 21% lower (P <0.05) in LD samples of electrical stimulation treatment (17.0 ± 1.25 µmol/g) than in corresponding samples of delayed chilling treatment (Table 4.9). The tendency for lower (P <0.001) LD glycogen concentration in electrical stimulation treatment (8.28 ± 1.13 µmol/g) compared to delayed chilling treatment (14.5 ± 1.05 µmol/g) continued to 3 hours *post mortem*. At 24 hours *post mortem*, the difference in LD glycogen concentration between the two treatments was not significant (P >0.05), with an average value of 4.23 ± 0.44 µmol/g (Table 4.9).

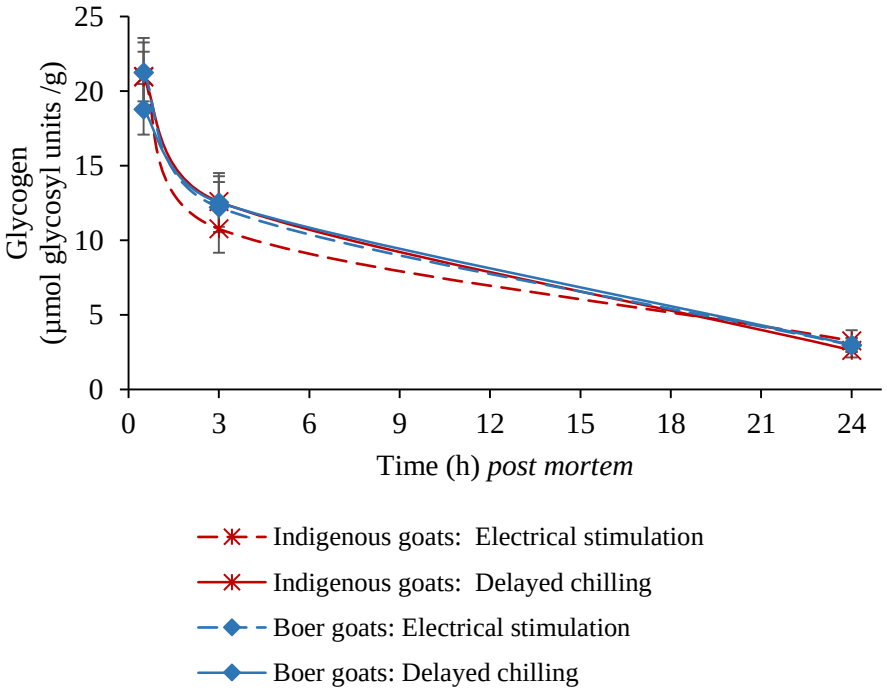
The interaction effect of breed and carcass treatment on muscle (both LD and SM) glycogen content were not significant at any sampling time (Table 4.10 and Figs. 4.4A & B).

Table 4.10 *P*-values of the effect of the interaction between breed and carcass treatment on glycogen concentration (µmol glycosyl units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.59
	3 hours	0.37
	24 hours	0.54
Semimembranosus	15 minutes	0.25
	3 hours	0.67
	24 hours	0.55



A.



B.

Figure 4.4 Glycogen concentration (µmol glycosyl units /g), at 15 minutes, 3 hours and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.3.3 The effects of breed, carcass treatment and their interaction on the concentration of muscle glucose

The effect of breed on the concentration of glucose in LD and SM samples of goats are presented in Table 4.11.

Table 4.11 Least square means ($\bar{x}$ ± SEM) for the effect of breed on glucose concentration (µmol/g) in *m. longissimus dorsi* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	$\bar{X}$ ± SEM
Longissimus dorsi	15 minutes	1.58 ± 0.11
	3 hours	2.22 ± 0.11
	24 hours	3.39 ± 0.10
Semimembranosus	15 minutes	1.63 ± 0.16
	3 hours	1.97 ± 0.09
	24 hours	2.77 ± 0.09

There were no breed differences (P >0.05) in muscle (both LD and SM) glucose concentration, at any sampling time. Overall, the glucose concentration in LD samples doubled from 1.58 ± 0.11 µmol/g to 3.39 ± 0.10 µmol/g, over *post mortem* time (Table 4.11). In SM samples, glucose concentration increased by about 70% from 1.63 ± 0.16 µmol/g to 2.77 ± 0.09 µmol/g, over *post mortem* time (Table 4.11).

The effects of carcass treatment on the concentration of glucose in LD and SM of goats are presented in Table 4.12. There were no differences (P >0.05) between the two treatments in LD glucose content at 15 minutes or at 3 hours *post mortem*, with average values of 1.58 ± 0.11 µmol/g and 2.22 ± 0.11 µmol/g, respectively. At 24 hours *post mortem*, glucose concentration was 21% higher (P <0.001) in LD samples of electrical stimulation treatment

(3.79 ± 0.13 µmol/g) than in corresponding samples of delayed chilling treatment (2.99 ± 0.14 µmol/g).

Differences in SM glucose concentration between the two treatments was observed at 15 minutes *post mortem* when glucose concentration was 58% higher (P <0.05) in electrical stimulation treatment than in corresponding samples of delayed chilling treatment (1.26 ± 0.07 µmol/g; Table 4.12). As *post mortem* time progressed, the SM glucose levels were not different (P >0.05) between the two treatments with average values of 2.22 ± 0.11 µmol/g and 2.77 ± 0.99 µmol/g, at 3 hours and 24 hours *post mortem* (Table 4.12).

Table 4.12 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on glucose concentration (µmol/g) in *m. longissimus dorsi* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

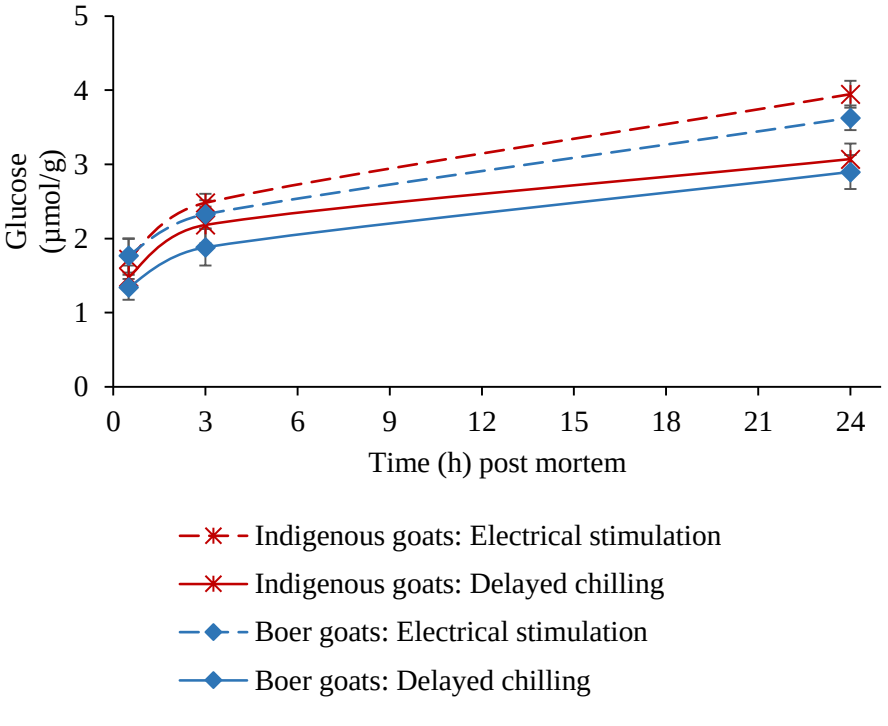
Muscle	Time *post mortem*	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	1.75 ± 0.17	1.41 ± 0.11	0.12
	3 hours	2.40 ± 0.11	2.03 ± 0.17	0.08
	24 hours	3.79[a] ± 0.13	2.99[b] ± 0.14	0.0001
Semimembranosus	15 minutes	1.99[a] ± 0.30	1.26[b] ± 0.07	0.03
	3 hours	2.06 ± 0.15	1.88 ± 0.11	0.36
	24 hours	2.84 ± 0.13	2.70 ± 0.11	0.58

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

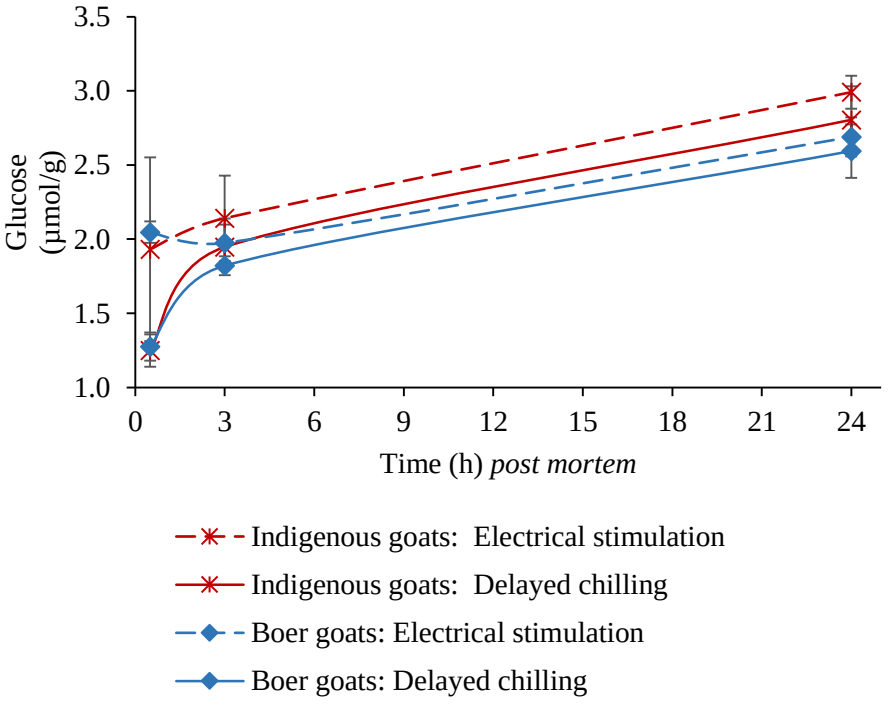
The interaction effect of breed and carcass treatment on muscle (both LD and SM) glucose content were not significant at any sampling time (Table 4.13 and Figs. 4.5A & B).

Table 4.13 *P*-values of the effect of the interaction between breed and carcass treatment on glucose concentration (µmol units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.66
	3 hours	0.73
	24 hours	0.72
Semimembranosus	15 minutes	0.89
	3 hours	0.91
	24 hours	0.79



A.



B.

Figure 4.5 Glucose concentration (µmol/g), at 15 minutes, 3 hours and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.3.4 The effects of breed, carcass treatment and their interaction on the concentration of muscle glucose-6-phosphate

Overall means for the effect of breed on the concentration of glucose-6-phosphate in LD and SM samples of goats are presented in Table 4.14.

Table 4.14 Overall means ($\bar{x}$ ± SEM) for the effect of breed on glucose-6-phosphate concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	$\bar{X}$ ± SEM
Longissimus dorsi	15 minutes	0.74 ± 0.08
	3 hours	0.66 ± 0.07
	24 hours	4.14 ± 0.28
Semimembranosus	15 minutes	0.73 ± 0.07
	3 hours	0.61 ± 0.10
	24 hours	3.42 ± 0.31

There were no breed differences (P >0.05) in muscle (both LD and SM) glucose-6-phosphate concentration, at any sampling time (Table 4.14). On average, the concentration of muscle glucose-6-phosphate was ~0.7 µmol/g, at 15 minutes *post mortem*. The concentration of glucose-6-phosphate decreased by 11% in LD samples and by 16% in SM within the first 3 hours *post mortem*, before increasing to levels at least 4 times higher than initial, at 24 hours *post mortem* (Table 4.14).

The effects of carcass treatment the concentration of glucose-6-phosphate LD and SM samples of goats are presented in Table 4.15. In LD samples, the average glucose-6-phosphate concentration at 15 minutes *post mortem* was 0.66 ± 0.06 µmol/g, with no significant differences between the two carcass treatments (Table 4.15). At 3 hours *post mortem*, the

concentration of glucose-6-phosphate was 3.6 times higher (P <0.001) in electrically stimulated LD samples than in corresponding samples of delayed chilling treatment (0.38 ± 0.07 µmol/g). The concentration of LD glucose-6-phosphate increased to 3.39 ± 0.12 µmol/g, at 24 hours *post mortem* with no significant differences between the two carcass treatments (Table 4.15).

The concentration of glucose-6-phosphate in SM samples was not affected by carcass treatment, at any sampling time (Table 4.15). The average values for SM glucose-6-phosphate concentration were 0.73 ± 0.07 µmol/g, 0.61 ± 0.10 µmol/g and 3.42 ± 0.31 µmol/g, at 15 minutes, 3 hours and 24 hours *post mortem*, respectively.

Table 4.15 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on glucose-6-phosphate (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	0.73 ± 0.10	0.59 ± 0.08	0.27
	3 hours	1.10[a] ± 0.16	0.38[b] ± 0.07	0.0001
	24 hours	4.49 ± 0.42	3.78 ± 0.41	0.22
Semimembranosus	15 minutes	0.80 ± 0.09	0.65 ± 0.10	0.26
	3 hours	0.68 ± 0.12	0.54 ± 0.15	0.50
	24 hours	3.06 ± 0.39	3.78 ± 0.47	0.26

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

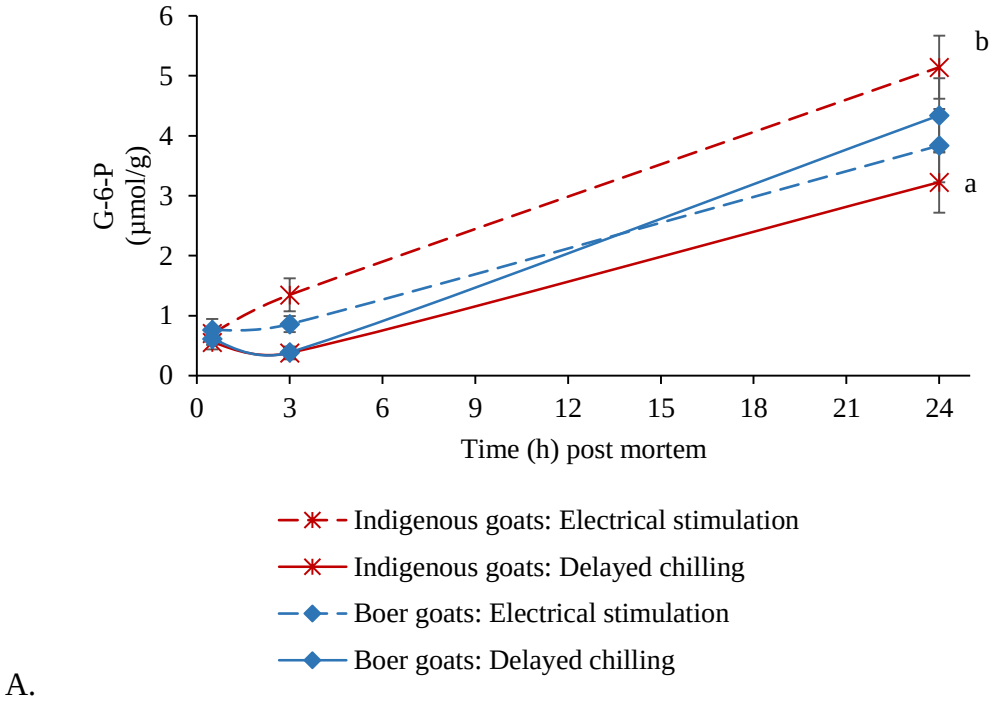
The interaction effect of breed and carcass treatment on the concentration of glucose-6-phosphate in LD and SM samples of goats are presented in Table 4.16 and Fig. 4.6A & B. The interaction effect of breed and carcass treatment was significant 24 hours *post mortem*, with electrically stimulated LD samples of indigenous goats showing 37% higher (P <0.05) glucose-

6-phosphate content than corresponding samples of delayed chilling treatment (3.23 ± 0.51 µmol/g) (Table 4.16 and Fig. 4.6A). On the other hand, the differences in glucose-6-phosphate concentration between the two carcass treatments were not significant (P >0.05) in LD samples of Boer goats. In SM samples, the interaction effect of breed and carcass treatment on glucose-6-phosphate was not significant at any sampling time (Table 4.16 and Fig 4.6B).

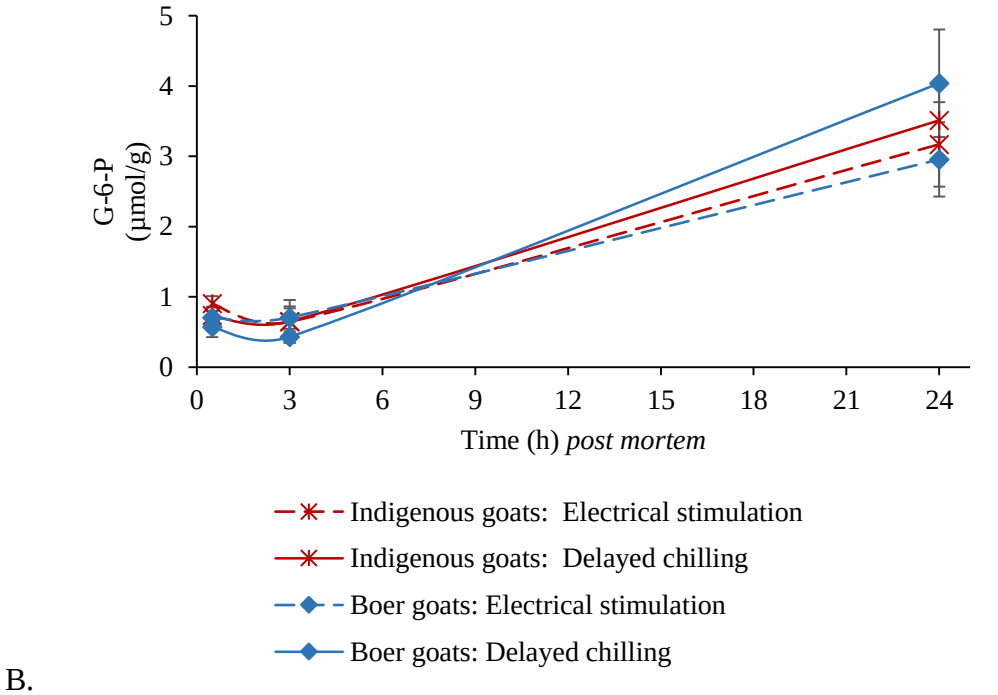
Table 4.16 *P*-values of the effect of the interaction between breed and carcass treatment on glucose-6-phosphate concentration (µmol units/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.06
	3 hours	0.14
	24 hours	**0.04**
Semimembranosus	15 minutes	0.89
	3 hours	0.49
	24 hours	0.56

Significant interactions between breed and carcass treatment are shown in **bold**



A.



B.

Figure 4.6 Glucose-6-phosphate (G-6-P) concentration (µmol/g), at 15 minutes, 3 hours and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after applying electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means. Means within the different letters a, b were different (P <0.05).

4.3.5 The effects of breed, carcass treatment and their interaction on the concentration of muscle ATP

The effects of breed on the concentration of ATP in LD and SM samples of goats are presented in Table 4.17.

Table 4.17 Least square means ($\bar{x}$ ± SEM) for the effect of breed on ATP concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Breed		*P*-values
		Indigenous goats	Boer goats	
Longissimus dorsi	15 minutes	7.29 ± 0.25	6.89 ± 0.21	0.24
	3 hours	5.74 ± 0.35	5.36 ± 0.27	0.28
	24 hours	2.85 ± 0.16	3.05 ± 0.15	0.37
Semimembranosus	15 minutes	7.58 ± 0.30	7.04 ± 0.26	0.18
	3 hours	6.04 ± 0.30	6.23 ± 0.26	0.64
	24 hours	2.44^{a} ± 0.12	3.05^{b} ± 0.15	0.002

Means within the same row with different superscripts [a, b] were different (*P* <0.05).

There were no breed differences (*P* >0.05) in ATP concentration of LD samples, at any sampling time (Table 4.17). The average values for ATP concentration in LD samples were 7.09 ± 0.17 µmol/g, 5.55 ± 0.22 µmol/g and 2.95 ± 0.11 µmol/g, at 15 minutes, 3 hours and 24 hours *post mortem*, respectively.

In SM samples, breed had no effect (*P* >0.05) on ATP concentration at 15 minutes (7.31 ± 0.20 µmol/g) or at 3 hours *post mortem* (6.13 ± 0.19 µmol/g), but at 24 hours *post mortem*, the SM samples of indigenous goats had 20% lower (*P* <0.01) ATP content than the corresponding samples of Boer goats (2.44 ± 0.12 µmol/g *vs.* 3.05 ± 0.15 µmol/g) (Table 4.17).

The effects of carcass treatment the concentration of ATP in LD and SM samples of goats are presented in Table 4.18.

Table 4.18 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on ATP concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass treatment		*P*-values
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	6.72^{a} ± 0.25	7.46^{b} ± 0.21	0.03
	3 hours	4.68^{a} ± 0.21	6.41^{b} ± 0.28	0.0001
	24 hours	2.95 ± 0.70	2.94 ± 0.54	0.97
Semimembranosus	15 minutes	7.55 ± 0.31	7.07 ± 0.25	0.23
	3 hours	5.91 ± 0.30	6.36 ± 0.24	0.26
	24 hours	2.97^{a} ± 0.16	2.52^{b} ± 0.13	0.02

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

In comparison to delayed chilling treatment, electrically stimulated LD samples had 10% lower (P <0.05) ATP concentration, at 15 minutes *post mortem* (6.72 ± 0.25 µmol/g *vs.* 7.46 ± 0.21 µmol/g). The tendency for lower (P <0.001) ATP concentration in electrical stimulation treatment (4.68 ± 0.21 µmol/g) compared to delayed chilling treatment (6.41 ± 0.28 µmol/g) continued to 3 hours *post mortem* (Table 4.18). The difference in ATP concentration between the two carcass treatments was not significant 24 hours *post mortem*, with an average value of 2.95 ± 0.11 µmol/g.

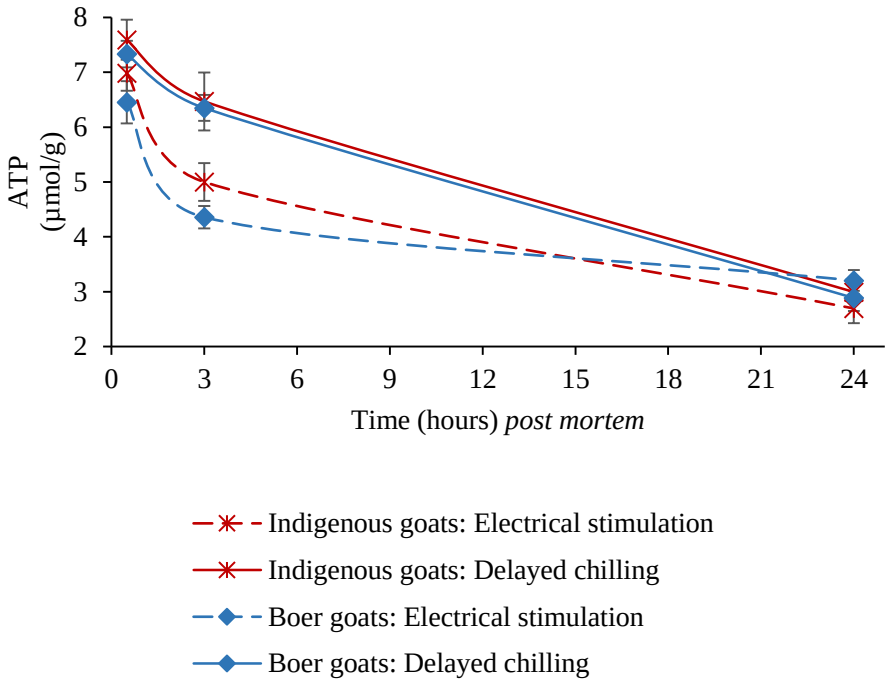
The ATP content in SM samples did not differ significantly between the two carcass treatments at 15 minutes (7.31 ± 0.20 µmol/g) or at 3 hours *post mortem* (6.13 ± 0.19 µmol/g) hours *post mortem*. However, at 24 hours *post mortem*, electrically stimulated SM samples had

~15% higher (P <0.05) ATP concentration than matching samples of delayed chilling treatment (2.97 ± 0.16 µmol/g *vs.* 2.52 ± 0.13 µmol/g) (Table 4.18).

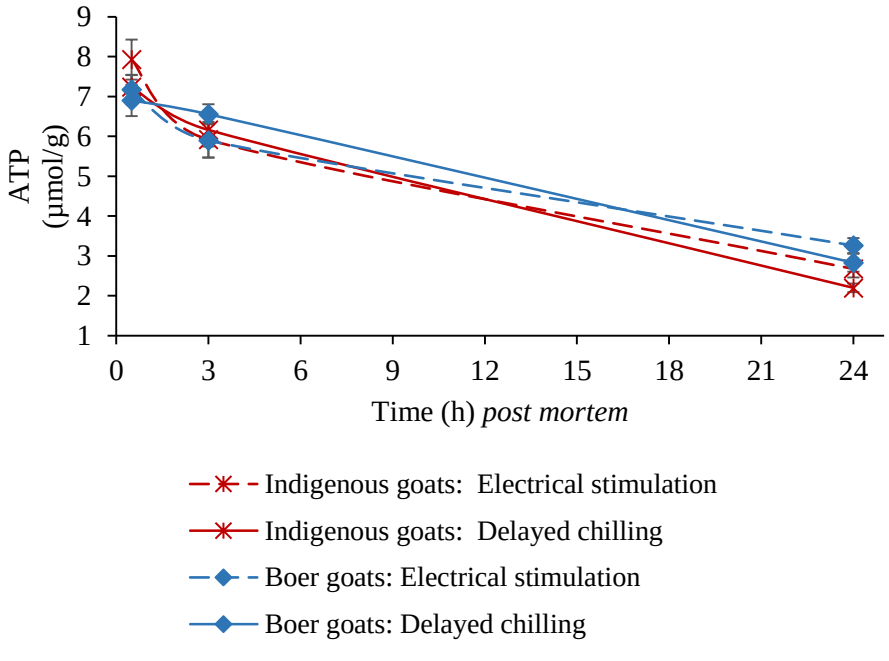
The interaction effect of breed and carcass treatment on muscle (both LD and SM) ATP content were not significant at any sampling time (Table 4.19 and Figs 4.7A & B).

Table 4.19 *P*-values of the effect of the interaction between breed and carcass treatment on ATP concentration (µmol units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.69
	3 hours	0.46
	24 hours	0.17
Semimembranosus	15 minutes	0.60
	3 hours	0.60
	24 hours	0.91



A.



B.

Figure 4.7 ATP concentration (µmol/g) measured at 15 minutes, 3 and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.3.6 The effects of breed, carcass treatment and their interaction on the concentration of muscle lactate

The effects of breed on the concentration of lactate in LD and SM samples of goats are presented in Table 4.20.

Table 4.20 Least square means ($\bar{x}$ ± SEM) for the effect of breed on lactate concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	$\bar{X}$ ± SEM
Longissimus dorsi	15 minutes	36.0 ± 1.13
	3 hours	47.7 ± 1.65
	24 hours	73.2 ± 1.82
Semimembranosus	15 minutes	35.0 ± 1.43
	3 hours	45.7 ± 1.44
	24 hours	76.5 ± 1.87

There were no breed differences (P >0.05) in muscle (both LD and SM) lactate concentration, at any sampling time. In LD samples, the average lactate concentrations were 36 ± 1.13 µmol/g, 47.7 ± 1.65 µmol/g and 73.2 ± 1.82 µmol/g, at 15 minutes, 3 hours and 24 hours *post mortem*, respectively (Table 4.20). The SM samples had average concentrations of 35 ± 1.43 µmol/g, 45.7 ± 1.44 µmol/g and 76.5 ± 1.87 µmol/g, at 15 minutes, 3 hours and 24 hours *post mortem*, respectively (Table 4.20).

The effects of carcass treatment the concentration of lactate in LD and SM of goats are presented in Table 4.21.

Table 4.21 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on lactate concentration (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass treatment		*P*-values
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	43.6^{a} ± 1.37	28.4^{b} ± 1.73	0.0001
	3 hours	54.1^{a} ± 1.97	41.3^{b} ± 2.59	0.0001
	24 hours	74.3 ± 2.75	72.2 ± 2.41	0.57
Semimembranosus	15 minutes	40.0^{a} ± 1.72	30.0^{b} ± 1.67	0.0001
	3 hours	50.7^{a} ± 1.88	40.8^{b} ± 1.55	0.0001
	24 hours	74.3 ± 1.89	78.6 ± 3.20	0.26

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

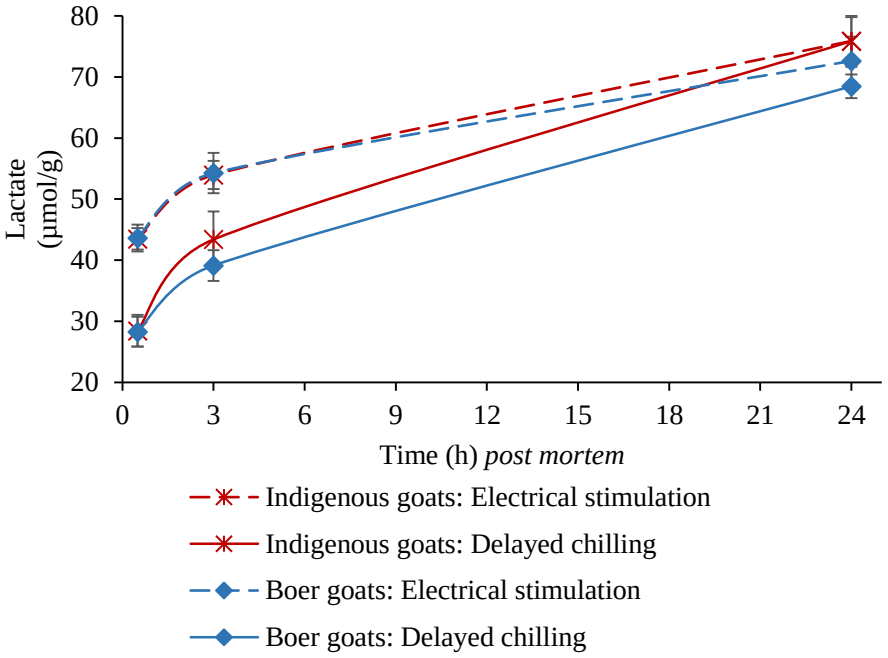
The LD samples of electrical stimulation treatment had 53% higher (P <0.001) lactate concentration than corresponding samples of delayed chilling treatment (43.6 ± 1.37 µmol/g *vs.* 28.4 ± 1.73 µmol/g), at 15 minutes *post mortem* (Table 4.21). The tendency for higher (P <0.001) lactate concentration in LD samples of electrical stimulation treatment compared to those of delayed chilling treatment continued to 3 hours *post mortem* (54.1 ± 1.99 µmol/g *vs.* 41.3 ± 2.59 µmol/g). At 24 hours *post mortem*, the LD lactate levels were not different (P >0.05) between the two treatments, with an average value of 76.5 ± 1.87 µmol/g.

Similar to the trend described for the LD samples, electrically stimulated SM samples had higher (P <0.001) lactate content than corresponding samples of delayed chilling treatment, at 15 minutes (40.0 ± 1.72 µmol/g. *vs.* 30.0 ± 1.67 µmol/g) and 3 hours *post mortem* (50.7 ± 1.88 µmol/g *vs.* 40.8 ± 1.55 µmol/g). At 24 hours *post mortem*, there were no differences (P >0.05) between the two carcass treatments in SM lactate content, with an average concentration of 76.5 ± 1.87 µmol/g (Table 4.21).

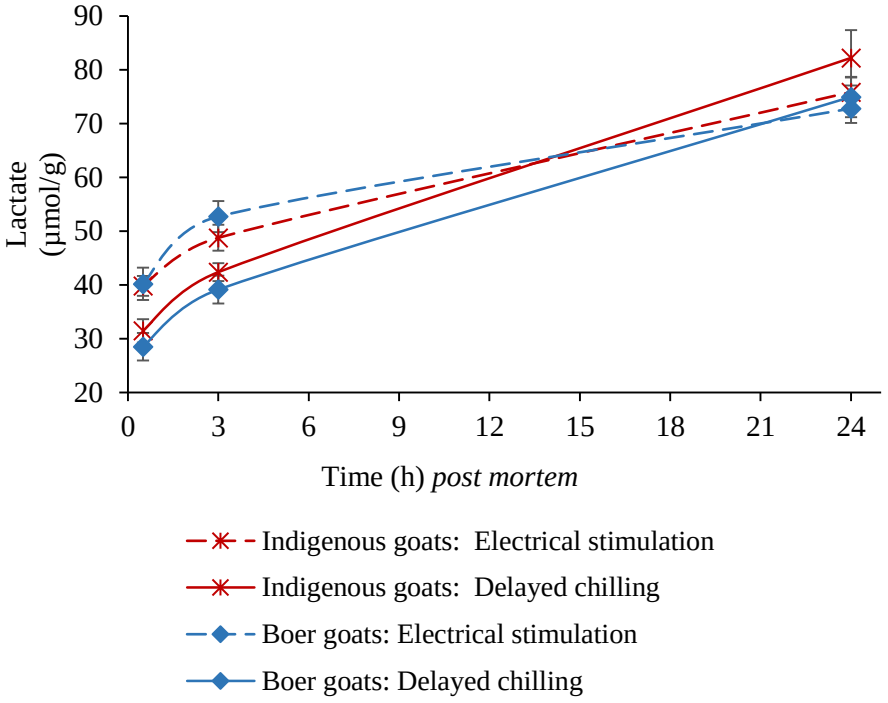
The interaction effect of breed and carcass treatment on muscle (LD and SM) were not significant at any sampling time (Table 4.22 and Fig 4.8A & B).

Table 4.22 *P*-values of the effect of the interaction between breed and carcass treatment on lactate concentration (µmol units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	30 minutes	0.95
	3 hours	0.49
	24 hours	0.57
Semimembranosus	30 minutes	0.50
	3 hours	0.15
	24 hours	0.58



A.



B.

Figure 4.8 Lactate concentration (µmol/g), measured at 15 minutes, 3 hours and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.3.7 The effects of breed, carcass treatment and their interaction on the calculated glycolytic potential

The effect of breed on the calculated glycolytic potential in LD and SM samples of goats are presented in Table 4.23.

Table 4.23 Least square means ($\bar{x}$ ± SEM) for the effect of breed on calculated glycolytic potential (µmol/g) of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Breed		*P*-values
		Indigenous goats	Boer goats	
Longissimus dorsi	15 minutes	78.9 ± 2.97	79.2 ± 2.96	0.95
	3 hours	80.7[a] ± 2.29	72.5[b] ± 1.74	0.007
	24 hours	101[a] ± 3.22	92.1[b] ± 2.63	0.03
Semimembranosus	15 minutes	84.3 ± 3.56	78.8 ± 3.76	0.26
	3 hours	74.0 ± 2.95	75.9 ± 3.38	0.66
	24 hours	96.9 ± 3.76	92.6 ± 2.87	0.38

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

Initially (at 15 minutes), the GP values of LD samples were not different (P >0.05) between the two goat breeds, with an average value of 79 ± 2.07 µmol/g. However, at 3 hours *post mortem*, the LD samples of indigenous goats showed higher (P <0.01) GP values than corresponding samples of Boer goats (80.7 ± 2.29 µmol/g *vs.* 72.5 ± 1.74 µmol/g). The tendency for higher (P <0.05) GP values in LD samples of indigenous goats compared to those of Boer goats was also observed at 24 hours *post mortem* (101 ± 3.22 µmol/g *vs.* 92.1 ± 2.63 µmol/g; Table 4.23).

There were no breed differences (P >0.05; Table 4.23) in GP values of SM samples, with average values of 81.6 ± 2.59 µmol/g, 75 ± 2.22 µmol/g and 94.7 ± 2.36 µmol/g at 15 minutes, 3 hours and 24 hours, respectively.

The effects of carcass treatment on the calculated GP in LD and SM samples goats are presented in Table 4.24.

Table 4.24 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on calculated glycolytic potential (µmol/g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem.*

Muscle	Time *post mortem*	Carcass treatment		*P*-values
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	82.5 ± 3.14	75.5 ± 2.54	0.10
	3 hours	78.2 ± 2.18	75.0 ± 2.25	0.28
	24 hours	100 ± 3.25	93.1 ± 2.78	0.09
Semimembranosus	15 minutes	87.6^{a} ± 3.11	75.6^{b} ± 3.77	0.02
	3 hours	79.2 ± 3.06	70.7 ± 3.00	0.06
	24 hours	92.3 ± 2.71	97.1 ± 3.86	0.32

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

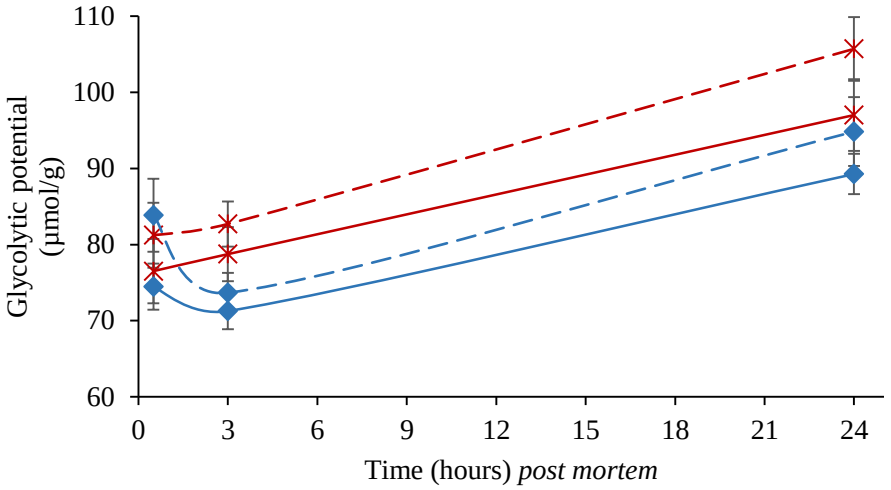
The GP values of LD samples were not different (P >0.05; Table 4.24) between the two treatments, with average values of 79 ± 2.07 µmol/g, 76.6 ± 1.57 µmol/g and 96.7 ± 2.18 µmol/g at 15 minutes, 3 hours and 24 hours, respectively.

In SM samples, the GP values were higher (P <0.05) in electrical stimulation treatment than delayed chilling treatment, at 15 minutes *post mortem* (87.6 ± 3.11 µmol/g *vs.* 75.6 ± 3.77 µmol/g; Table 4.24). However, the GP values of SM samples were not significantly different (P >0.05) between the two treatments at 3 hours (75 ± 2.22 µmol/g) or at 24 hours (94.7 ± 2.36 µmol/g) *post mortem.*

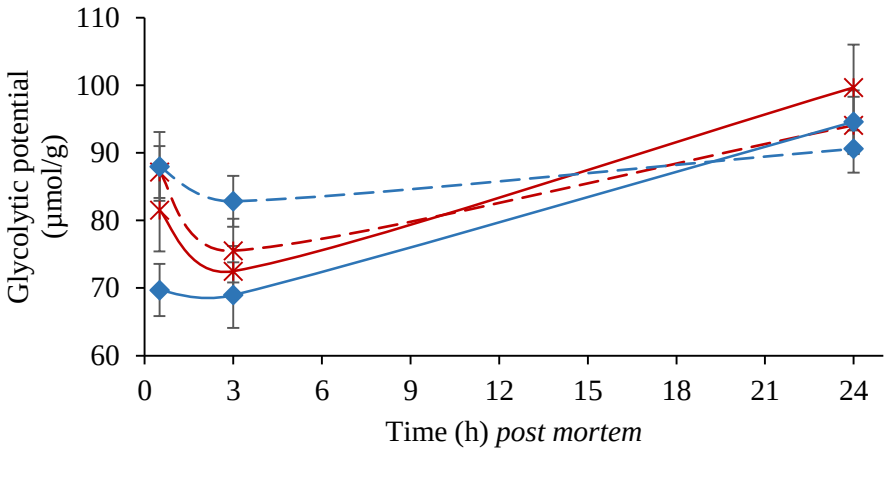
The interaction effect of breed and carcass treatment on muscle (both LD and SM) calculated GP were not significant at any sampling time (Table 4.25 and Figs 4.9A & B).

Table 4.25 *P*-values of the effect of the interaction between breed and carcass treatment on calculated glycolytic potential (µmol units /g) in *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 3 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.58
	3 hours	0.79
	24 hours	0.71
Semimembranosus	15 minutes	0.20
	3 hours	0.22
	24 hours	0.87



A.



B.

Figure 4.9 Glycolytic potential (µmol/g), calculated at 15 minutes, 3 hours and 24 hours *post mortem* in (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.3.8 Comparison of the *m. longissimus dorsi* and the *m. semimembranosus*

The concentration of biochemical parameters in LD and SM samples were compared and the results are presented in Table 4.26.

Table 4.26 Comparison of biochemical parameters ($\bar{x}$ ± SEM) in *m. longissimus dorsi* and *m. semimembranosus* of goats

Variable	Time *post mortem*	Muscle		*P*-value
		Longissimus dorsi	*Semimembranosus*	
Creatine phosphate	15 minutes	3.23 ± 0.20	3.13 ± 0.19	0.69
	3 hours	2.40 ± 0.07	2.32 ± 0.10	0.51
	24 hours	1.98[a] ± 0.08	1.77[b] ± 0.07	0.04
Glycogen	15 minutes	19.3 ± 0.96	20.9 ± 1.00	0.23
	3 hours	11.5 ± 0.90	12.0 ± 0.85	0.65
	24 hours	4.23[a] ± 0.44	2.96[b] ± 0.26	0.01
Glucose	15 minutes	1.58 ± 0.11	1.63 ± 0.16	0.81
	3 hours	2.22 ± 0.11	1.97 ± 0.09	0.08
	24 hours	3.39[a] ± 0.12	2.77[b] ± 0.09	0.0001
Glucose-6-phosphate	15 minutes	0.66 ± 0.06	0.73 ± 0.07	0.45
	3 hours	0.74 ± 0.10	0.61 ± 0.10	0.30
	24 hours	4.14 ± 0.30	3.42 ± 0.31	0.09
ATP	15 minutes	7.09 ± 0.17	7.31 ± 0.20	0.40
	3 hours	5.55[a] ± 0.22	6.13[b] ± 0.19	0.03
	24 hours	2.95 ± 0.11	2.74 ± 0.11	0.16
Lactate	15 minutes	36.0 ± 1.63	35.0 ± 1.43	0.56
	3 hours	47.7 ± 1.90	45.7 ± 1.44	0.35
	24 hours	73.2 ± 1.81	76.5 ± 1.87	0.22
Glycolytic potential	15 minutes	79.0 ± 2.07	81.6 ±2.59	0.42
	3 hours	76.6 ± 1.57	75.0 ±2.22	0.53
	24 hours	96.7 ± 2.18	94.7 ±2.36	0.53

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

Immediately after slaughter (15 minutes), the concentration of creatine phosphate (3.17± 0.14 µmol/g) was not different (P >0.05) between the LD and SM samples and the tendency continued to 3 hours *post mortem* (2.36 ± 0.06 µmol/g). However, at 24 hours *post mortem*, the LD samples had 10% higher (P <0.05) creatine phosphate concentration than SM samples (1.98 ± 0.08 µmol/g *vs.* 1.77 ± 0.07 µmol/g) (Table 4.26).

Glycogen levels were not different (P >0.05) between the LD and SM samples at 15 minutes (20.1 ± 0.69 glycosyl units /g) or at 3 hours *post mortem* (11.8 ± 0.69 glycosyl units /g). At 24 hours *post mortem* the LD samples had 30% higher glycogen levels than the SM samples (4.23 ± 0.44 glycosyl units /g *vs.* 2.96 ± 0.26 glycosyl units /g) (Table 4.26).

Glucose levels were not different (P >0.05) between the LD and SM samples at 15 minutes (1.60 ± 0.10 µmol/g) or at 3 hours *post mortem* (2.09 ± 0.07 µmol/g). Differences between LD and SM glucose content were only significant at 24 hours *post mortem*, with LD samples showing 18% higher (P <0.05) glucose levels than SM samples (3.39 ± 0.12 µmol/g *vs.* 2.77 ± 0.09 µmol/g) (Table 4.26).

There were no differences (P >0.05) between LD and SM glucose-6-phosphate concentration at any sampling time, with average values of 0.69 ± 0.05 µmol/g, 0.67 ± 0.07 µmol/g and 3.78 ± 0.22 µmol/g at 15 minutes, 3 hours and 24 hours, respectively (Table 4.26).

Immediately after slaughter (15 minutes), the concentration of ATP was not different (P >0.05) between the LD and SM samples (7.20 ± 0.13 µmol/g), but at 3 hours *post mortem*, the LD samples had 9.6% lower (P <0.05) ATP content than the SM samples (5.54 ± 0.22 µmol/g vs. 6.13 ± 0.19 µmol/g). At 24 hours *post mortem*, the concentration of ATP between the SM and LD was not different (P >0.05), with an average value of 2.84 ± 0.08 µmol/g (Table 4.26).

There were no differences (P >0.05) between LD and SM lactate content with average values of 35.5 ± 1.08 µmol/g, 46.7 ± 1.19 µmol/g and 74.8 ± 1.31 µmol/g at 15 minutes, 3 hours and 24 hours, respectively. Similarly, GP values of LD and SM were not different (P >0.05) at any sampling time, with average values of 80.3 ± 1.65 µmol/g, 75.8 ± 1.35 µmol/g and 95.7 ± 1.60 µmol/g at 15 minutes, 3 hours and 24 hours, respectively (Table 4.26).

4.4 Kinetics of pH and temperature decline

It is known that controlling the rate of pH and temperature decline prior to the onset of *rigor mortis* is crucial for improved meat quality (Hannula & Puolanne, 2004). In this study, the rates of pH and temperature decline were monitored in carcasses of the indigenous and Boer goats under electrical stimulation or delayed chilling conditions. The purpose was to investigate the slaughter conditions that would improve the conversion of muscle to meat in goats.

4.4.1 The effects of breed, carcass treatment and their interaction on muscle pH values.

The effect of breed on pH values of the LD and SM of goats are presented in Table 4.27. There were no breed differences (P >0.05) in LD pH at 15 minutes (6.35 ± 0.04) or at 1 hour *post mortem* (6.25 ± 0.04). However, at 3 hours *post mortem*, the LD of indigenous goats had a higher (P <0.05) pH than the LD of Boer goats (6.23 ± 0.06 *vs.* 6.10 ± 0.05). As *post mortem* time progressed, the LD pH values of the two goat breeds were not different (P >0.05), with average values of 5.99 ± 0.04 and 5.74 ± 0.02, at 6 hours and 24 hours *post mortem*, respectively (Table 4.27).

There were no breed differences (P >0.05) in SM pH values, at any sampling time (Table 4.27). The average SM pH values were 6.46 ± 0.04, 6.34 ± 0.03, 6.17 ± 0.03, 6.03 ± 0.04 and 5.75 ± 0.02, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*.

Table 4.27 Least square means ($\bar{x}$ ± SEM) for the effect of breed on pH values of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Breed		*P*-value
		Indigenous goats	Boer goats	
Longissimus dorsi	15 minutes	6.36 ± 0.06	6.34 ± 0.05	0.73
	1 hour	6.24 ± 0.07	6.26 ± 0.05	0.77
	3 hours	6.23^{a} ± 0.06	6.10^{b} ± 0.05	0.047
	6 hours	6.01± 0.06	5.97 ± 0.06	0.50
	24 hours	5.73 ± 0.02	5.74 ± 0.03	0.86
Semimembranosus	15 minutes	6.49 ± 0.05	6.42 ± 0.05	0.30
	1 hour	6.33 ± 0.05	6.35 ± 0.05	0.76
	3 hours	6.18 ± 0.06	6.15 ± 0.05	0.59
	6 hours	6.05 ± 0.05	6.00 ± 0.05	0.43
	24 hours	5.73 ± 0.02	5.76 ± 0.02	0.39

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

The effect of carcass treatment on pH values of the LD and SM of goats are presented in Table 4.28. Initially (at 15 minutes *post mortem*), there was an average pH difference (P <0.001) of 0.38 units between electrically stimulated LD (6.16 ± 0.04) and the corresponding muscle of delayed chilling treatment (6.54 ± 0.05). Electrical stimulation further hastened pH decline (P <0.001) causing an average difference of 0.36 units with delayed chilling treatment (6.43 ± 0.05), at one hour *post mortem* (Table 4.28). The tendency for lower (P <0.01) pH in electrically stimulated LD compared to their counterparts in delayed chilling treatment was also observed at 3 hours (6.01 ± 0.04 *vs.* 6.32 ± 0.05) and at 6 hours (5.84 ± 0.04 *vs.* 6.13 ±

0.06) *post mortem* (Table 4.28). The pH_u values were not different ($P > 0.05$) between the two treatments, with an average of 5.74 ± 0.02 (Table 4.28).

Table 4.28 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on pH values of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass Treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	6.16^a ± 0.03	6.54^b ± 0.04	0.0001
	1 hour	6.07^a ± 0.05	6.43^b ± 0.05	0.0001
	3 hours	6.01^a ± 0.04	6.32^b ± 0.05	0.0001
	6 hours	5.84^a ± 0.04	6.13^b ± 0.06	0.0001
	24 hours	5.72 ± 0.03	5.76 ± 0.03	0.29
Semimembranosus	15 minutes	6.34^a ± 0.04	6.57^b ± 0.05	0.0001
	1 hour	6.25^a ± 0.05	6.43^b ± 0.04	0.005
	3 hours	6.06^a ± 0.05	6.27^b ± 0.04	0.005
	6 hours	5.94^a ± 0.04	6.11^b ± 0.04	0.009
	24 hours	5.74 ± 0.03	5.76 ± 0.03	0.61

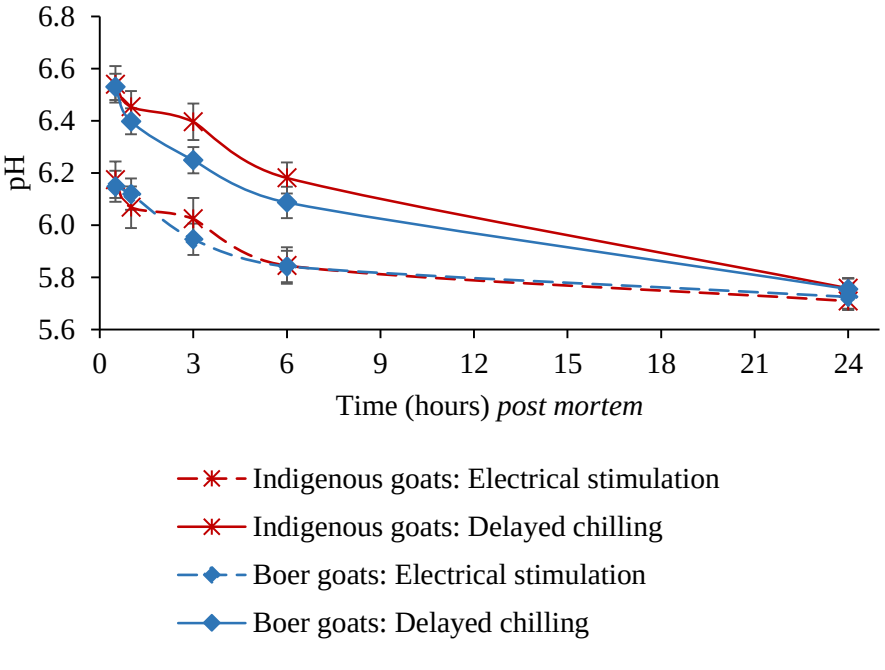
Means within the same row with different superscripts $^{a, b}$ were different ($P < 0.05$)

In SM samples, the average pH difference ($P < 0.001$) between electrical stimulation (6.34 ± 0.04) and delayed chilling treatment (6.57 ± 0.05), at 15 minutes *post mortem* was 0.23 units (Table 4.28). Electrical stimulation further caused an average pH difference ($P < 0.01$) of 0.18 units with delayed chilling treatment (6.43 ± 0.04), at one hour *post mortem* (Table 4.28). The tendency for lower ($P < 0.01$) pH in electrically stimulated SM compared to that of delayed chilling treatment was also observed at 3 hours (6.06 ± 0.05 *vs.* 6.27 ± 0.04) and at 6 hours (5.94 ± 0.04 *vs.* 6.11 ± 0.04) *post mortem*. The pH_u values were not different ($P > 0.05$) between the two treatments, with an average of 5.74 ± 0.02 (Table 4.28).

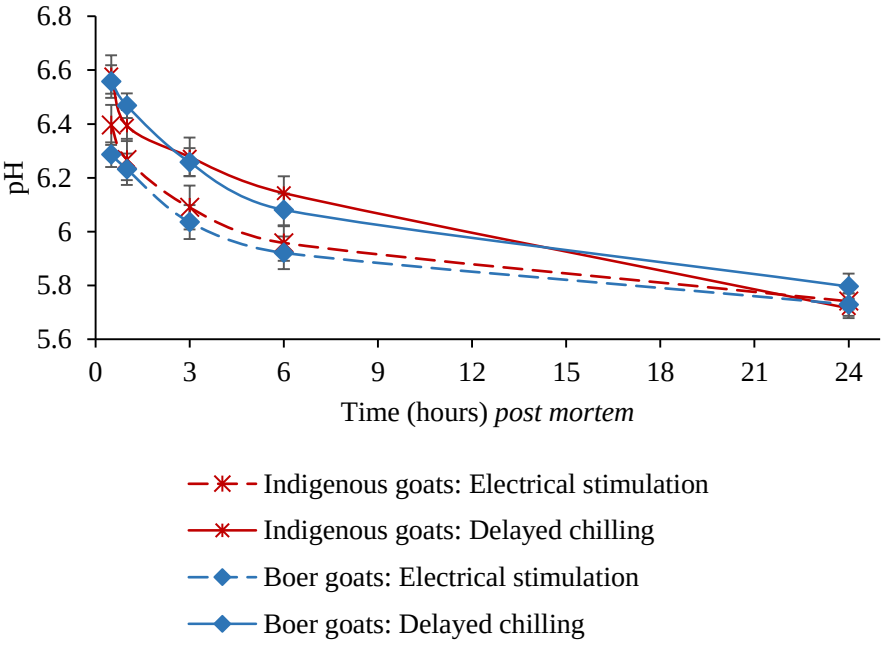
The interaction effect of breed and carcass treatment on muscle pH were not significant at any sampling time (Table 4.29 and Figs. 4.10A & B).

Table 4.29 *P*-values of the interaction effect of breed and carcass treatment on pH values of the *m. longissimus dorsi* and *m. semimembranosus*, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.88
	1 hour	0.27
	3 hours	0.86
	6 hours	0.53
	24 hours	0.80
Semimembranosus	15 minutes	0.52
	1 hour	0.37
	3 hours	0.80
	6 hours	0.84
	24 hours	0.25



A.



B.

Figure 4.10 Average pH-time profiles for the (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.4.2 The effects of breed, carcass treatment and their interaction on muscle temperature values

Overall means for the effect of breed on temperature values in LD and SM of goats are presented in Table 4.30. There were no breed differences (P >0.05) in muscle (both LD and SM) temperature values. The average LD temperature values were 36.8 ± 0.35 °C, 27.6 ± 0.50 °C, 16.0 ± 0.46 °C, 11.5 ± 0.51 °C and 6.14 ± 1.46 °C, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*, respectively (Table 4.30). The average SM temperature values were 37.3 ± 0.30 °C, 30.6 ± 0.56 °C, 18.1 ± 0.30 °C, 12.6 ± 0.37 °C and 4.49 ± 0.09 °C, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*, respectively (Table 4.30).

Table 4.30 Overall means ($\bar{x}$ ± SEM) for the effect of breed on temperature (°C) of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	$\bar{X}$ ± SEM
Longissimus dorsi	30 minutes	36.8 ± 0.35
	1 hour	27.6 ± 0.50
	3 hours	16.0 ± 0.46
	6 hours	11.5 ± 0.51
	24 hours	6.14 ±1.46
Semimembranosus	30 minutes	37.3 ± 0.30
	1 hour	30.6 ± 0.56
	3 hours	18.1 ± 0.30
	6 hours	12.6 ± 0.37
	24 hours	4.49 ± 0.09

The effect of carcass treatment on *post mortem* temperature values of the LD and SM of goats are presented in Table 4.31.

Table 4.31 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on temperature values (°C) of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	Carcass Treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	15 minutes	35.8[a] ± 0.56	37.9[b] ± 0.24	0.001
	1 hour	26.5[a] ± 0.80	28.6[b] ± 0.55	0.046
	3 hours	13.9[a] ± 0.43	18.1[b] ± 0.48	0.0001
	6 hours	8.48[a] ± 0.31	14.4[b] ± 0.18	0.0001
	24 hours	4.75 ± 0.91	4.54 ± 0.13	0.28
Semimembranosus	15 minutes	36.3[a] ± 0.39	38.4[b] ± 0.30	0.0001
	1 hour	30.1 ± 0.92	31.1 ± 0.65	0.36
	3 hours	16.9[a] ± 0.32	19.4[b] ± 0.31	0.0001
	6 hours	10.5[a] ± 0.23	14.8[b] ± 0.20	0.0001
	24 hours	4.61 ± 0.08	4.37 ± 0.16	0.17

Means within the same row with different superscripts [a, b] were different (P <0.05).

In LD samples, there was an average difference (P <0.01) of 2.3 °C between electrical stimulation treatment (35.8 ± 0.56 °C) and delayed chilling treatment (37.9 ± 0.24 ^{0}C), at 15 minutes *post mortem* (Table 4.31). Electrically stimulated LD continued to show lower (P temperature values than the corresponding muscle of delayed chilling treatment, at 1 hour (26.5 ± 0.80 °C *vs.* 28.6 ± 0.55 °C; P <0.05), 3 hours (13.9 ± 0.43 *vs.* 18.1 ± 0.48; P <0.001) and at 6 hours (8.48 ± 0.31 *vs.* 14.4 ± 0.18; P <0.001) *post mortem*. The temperature values were not different (P > 0.05) between the two treatments, at 24 hours *post mortem* with an average value of 6.14 ± 1.46 (Table 4.31).

In SM samples, there was an average difference (P <0.001) of 2.1 °C between electrical stimulation treatment (36.3 ± 0.39 °C) and delayed chilling treatment (38.4 ± 0.30 ^{0}C), at 15 minutes *post mortem* (Table 4.31). At 1 hour *post mortem*, the difference in SM temperature between electrical stimulation and delayed chilling treatment was not significant (P >0.05),

with an average value of 30.6 ± 0.56 °C. However, the SM of electrical stimulation treatment had lower (P <0.001) temperature values than the corresponding muscle of delayed chilling treatment, at 3 hours (16.9 ± 0.32 °C *vs.* 19.4 ± 0.31 °C) and at 6 hours (10.5 ± 0.23 °C *vs.* 14.8 ± 0.20 ^{0}C) *post mortem*. At 24 hours *post mortem*, the temperature values were not different between the two treatments (P > 0.05) with an average value of 4.49 ± 0.09 °C (Table 4.31).

The interaction effect of breed and carcass treatment on temperature values of the LD and SM of goats are presented in Tables 4.32 and Fig. 4.11A & B.

Table 4.32 *P*-values of the interaction effect of breed and carcass treatment on temperature values of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Muscle	Time *post mortem*	*P*-values
Longissimus dorsi	15 minutes	0.73
	1 hour	0.75
	3 hours	0.09
	6 hours	0.92
	24 hours	0.29
Semimembranosus	15 minutes	0.60
	1 hour	0.24
	3 hours	0.65
	6 hours	0.99
	24 hours	0.16

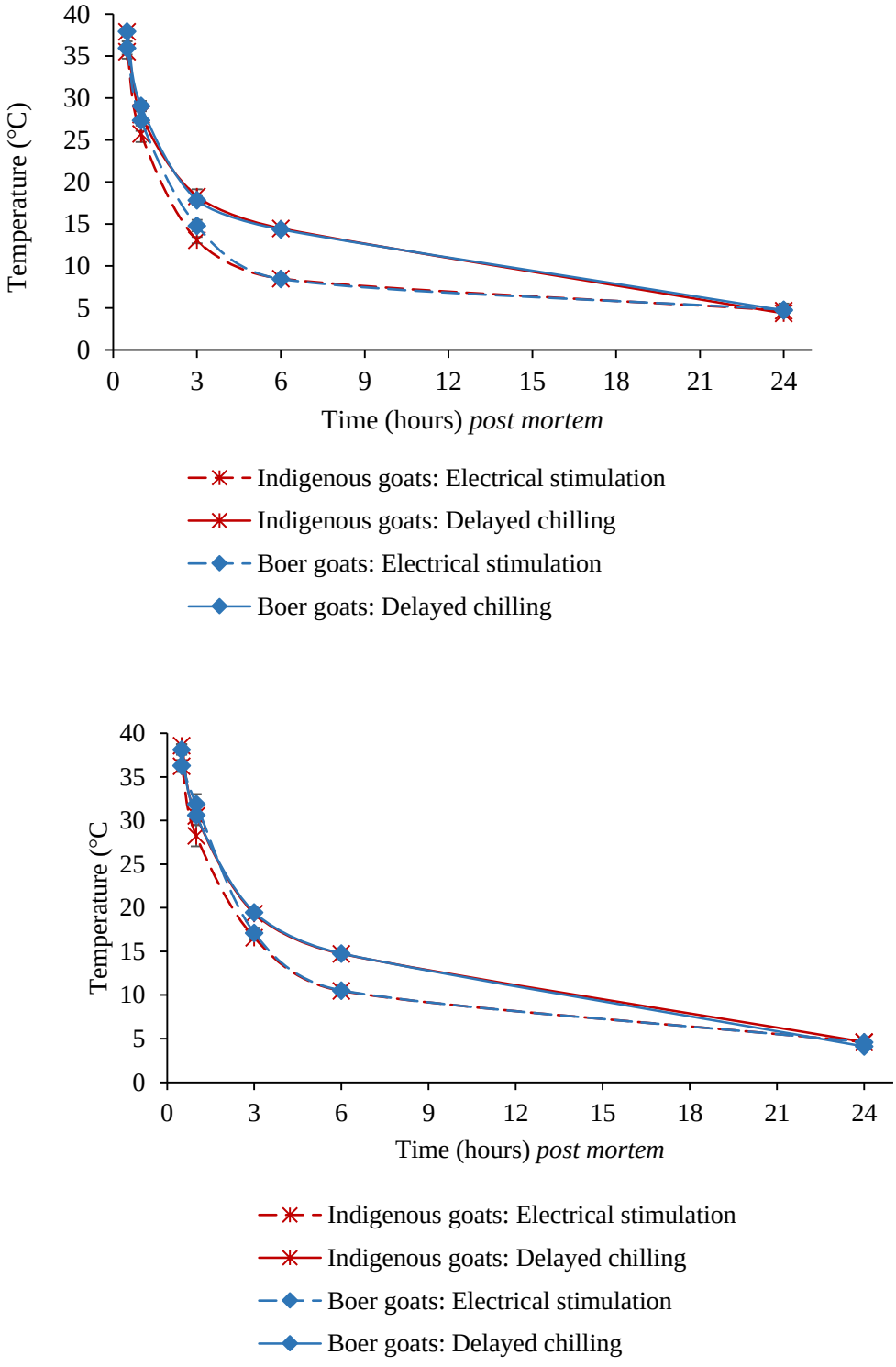


Figure 4.11 Average temperature-time profiles for the (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.

4.4.3 Comparison of pH and temperature values of the *m. longissimus dorsi* and the *m. semimembranosus* of goats

The pH and temperature values of the LD and SM were compared and the results are presented in Table 4.33.

Table 4.33 Comparison of pH and temperature values ($\bar{x}$ ± SEM) of the *m. longissimus dorsi* and *m. semimembranosus* of goats, at 15 minutes, 1 hour, 3 hours, 6 hours and 24 hours *post mortem*

Variable	Time *post mortem*	Muscle		*P*-value
		Longissimus dorsi	*Semimembranosus*	
pH	15 minutes	6.35^{a} ± 0.04	6.46^{b} ± 0.04	0.01
	1 hour	6.25^{a} ± 0.04	6.34^{b} ± 0.03	0.046
	3 hours	6.17 ± 0.03	6.17 ± 0.03	0.10
	6 hours	5.99 ± 0.04	6.03 ± 0.03	0.44
	24 hours	5.74 ± 0.02	5.75 ± 0.02	0.76
Temperature (°C)	15 minutes	36.8 ± 0.35	37.3 ± 0.30	0.24
	1 hour	27.6^{a} ± 0.50	30.6^{b} ± 0.51	0.0001
	3 hours	16.0^{a} ± 0.27	18.1^{b} ± 0.27	0.0001
	6 hours	11.5^{a} ± 0.17	12.6^{b} ± 0.17	0.0001
	24 hours	6.14 ± 1.03	4.49 ±1.03	0.26

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

Initially (15 minutes *post mortem*), the LD had lower (P <0.05) pH values (6.35 ± 0.04 *vs.* 6.46 ± 0.04) than the SM and the tendency continued to 1 hour *post mortem* (6.25 ± 0.04 *vs.* 6.34 ± 0.04, P <0.05). However, there were no differences (P >0.05) in pH values of the two muscles from 3 hours to 24 hours *post mortem* (Table 4.33). The average pH values were 6.17 ± 0.03, 6.01 ± 0.03 and 5.74 ± 0.01, at 3 hours 6 hours and 24 hours *post mortem*, respectively.

Initially (at 15 minutes *post mortem*), the LD and the SM had similar (P >0.05) temperature values, with an average of 37.1 ± 0.23 °C. However, from 1 hour to 6 hours *post mortem*, the LD temperature decreased faster (P <0.001) compared to that of the SM. The average temperature differences between the two muscles were 3 °C, 2.1 °C and 1.1 °C, at 1 hour, 3 hours and 6 hours *post mortem* (Table 4.33). At 24 hours *post mortem*, the temperature values of the two muscles were not different (P >0.05), with an average value of 5.31 ± 0.73 °C.

4.5 Objective properties of goat meat

Depending on the user's perception, indices such as pH, colour, tenderness, flavour, juiciness, nutritive value and wholesomeness are often used to describe the quality of meat (Webb et al., 2005). This section describes quality attributes related to visual appearance (colour and water holding capacity) and palatability (juiciness and tenderness) of goat meat. These quality attributes are considered as key factors that determine acceptability and continued interest in the product (Maltin et al., 1997).

4.5.1 The effects of breed, carcass treatment and their interactions on WHC, thawing losses, evaporative losses, drip losses and total cooking losses

The effect of breed on water holding capacity (WHC), thawing losses, evaporative losses, drip losses and total cooking losses of the LD and SM samples of goats are presented in Table 4.34.

Table 4.34 Least square means ($\bar{x}$ ± SEM) for the effect of breed on water holding capacity (WHC), thawing losses, evaporative losses, drip losses and total cooking losses of the *m. longissimus dorsi* and *m. semimembranosus* of goats.

Muscle	Variable	Breed		*P*-value
		Indigenous goats	Boer goats	
Longissimus dorsi	WHC	0.39 ± 0.01	0.39 ± 0.01	0.65
	Thawing losses (%)	2.59 ± 0.29	2.58 ± 0.24	0.98
	Evaporative losses (%)	18.4 ± 0.84	20.0 ± 0.80	0.16
	Drip losses (%)	0.24^{a} ± 0.08	0.54^{b} ± 0.09	0.03
	Total cooking losses (%)	18.6 ± 0.84	20.5 ± 0.87	0.10
Semimembranosus	WHC	0.36 ± 0.01	0.35 ± 0.01	0.53
	Thawing losses (%)	6.09 ± 0.32	5.72 ± 0.33	0.43
	Evaporative losses (%)	23.9 ± 0.93	24.0 ± 0.88	0.94
	Drip losses (%)	1.10 ± 0.30	0.99 ± 0.13	0.74
	Total cooking losses (%)	25.0 ± 1.07	25.0 ± 0.78	1.00

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

Most moisture parameters of LD samples were not different ($P > 0.05$) between the two goat breeds (Table 4.34). The only exception was drip loss, which was lower ($P < 0.05$) in LD samples of indigenous goats than in matching samples of Boer goats (0.24 ± 0.08% *vs.* 0.54 ± 0.09%). The average values for WHC, thawing losses, evaporative losses and total cooking losses in LD samples were 0.39 ± 0.01, 2.58 ± 0.19%, 19.2 ± 0.60% and 19.6 ± 0.62%, respectively.

Water holding capacity, thawing losses, evaporative losses, drip losses or total cooking losses of SM samples were not different ($P > 0.05$) between the two goat breeds (Tables 4.34). The average values for WHC, thawing losses, evaporative losses, drip losses and total cooking losses of SM samples were 0.36 ± 0.05, 5.91 ± 0.23%, 25.0 ± 0.67%, 1.04 ± 0.16% and 21.6 ± 0.50%, respectively.

The effect of carcass treatment on water holding capacity (WHC), thawing losses, evaporative losses, drip losses and total cooking losses of the LD and SM of goats are presented in Table 4.35. There were no differences (P >0.05) in WHC, thawing losses or drip losses between electrically stimulated LD samples and corresponding samples of delayed chilling treatment (Tables 4.35). However, evaporative losses and total cooking losses were higher (P <0.05) in LD samples of electrical stimulation treatment (20.5 ± 0.93% and 20.9 ± 0.97%, respectively) than in corresponding samples of delayed chilling treatment (17.9 ± 0.65% and 18.2 ± 0.65%, respectively). Water holding capacity, thawing losses, evaporative losses, drip losses or total cooking losses of SM samples were not different (P >0.05) between the treatments (Tables 4.35).

Table 4.35 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on water holding capacity (WHC), thawing losses, evaporative losses, drip losses and total cooking losses of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	WHC	0.39 ± 0.01	0.38 ± 0.01	0.53
	Thawing losses (%)	2.75 ± 0.20	2.41 ± 0.32	0.38
	Evaporative losses (%)	20.5^{a} ± 0.93	17.9^{b} ± 0.65	0.03
	Drip losses (%)	0.44 ± 0.10	0.34 ± 0.10	0.44
	Total cooking losses (%)	20.9^{a} ± 0.97	18.2^{b} ± 0.65	0.03
Semimembranosus	WHC	0.36 ± 0.01	0.35 ± 0.01	0.55
	Thawing losses (%)	5.80 ± 0.32	6.01 ± 0.33	0.67
	Evaporative losses (%)	24.0 ± 0.94	23.9 ± 0.77	0.93
	Drip losses (%)	0.78 ± 0.15	1.31 ± 0.23	0.10
	Total cooking losses (%)	24.8 ± 0.98	25.2 ± 0.94	0.77

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

The interaction effect of breed and carcass treatment on water holding capacity (WHC), thawing losses, evaporative loss, drip losses or total cooking losses of both the LD and SM of goats were not significant (Tables 4.36).

Table 4.36 *P*-values for the interaction effect of breed and carcass treatment on water holding capacity (WHC), thawing loss, evaporative loss, drip loss and total cooking losses of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	*P*-values
Longissimus dorsi	WHC	0.94
	Thawing losses (%)	0.83
	Evaporative losses (%)	0.54
	Drip losses (%)	0.36
	Total cooking losses (%)	0.65
Semimembranosus	WHC	0.42
	Thawing losses (%)	0.55
	Evaporative losses (%)	0.54
	Drip losses (%)	0.44
	Total cooking losses (%)	0.50

4.5.2 The effects of breed, carcass treatment and their interaction on surface myoglobin redox forms

The effect of breed on surface myoglobin redox forms of the LD and SM samples of goats are presented in Table 4.37. There were no breed differences (P >0.05) for any of the myoglobin redox forms (Table 4.37). On average the LD had 59.5 ± 1.27% deoxymyoglobin, 24.7 ± 0.96 %, oxymyoglobin and 15.8 ± 0.37% metmyoglobin. The SM had 57.7 ± 1.12% deoxymyoglobin, 23.7 ± 0.85% oxymyoglobin and 18.5 ± 0.32% metmyoglobin (Table 4.37).

Table 4.37 Least square means ($\bar{x}$ ± SEM) for the effect of breed on surface myoglobin redox forms (%) of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	$\bar{X}$ ± SEM
Longissimus dorsi	Deoxymyoglobin	59.5 ± 1.27
	Oxymyoglobin	24.7 ± 0.96
	Metmyoglobin	15.8 ± 0.37
Semimembranosus	Deoxymyoglobin	57.7 ± 1.12
	Oxymyoglobin	23.7 ± 0.85
	Metmyoglobin	18.5 ± 0.32

The effects of carcass treatment on surface myoglobin redox forms of LD and SM samples of goats are presented in Table 4.38. The LD samples of delayed chilling treatment had a lower (P <0.05) percentage of deoxymyoglobin (56.9 ± 1.64% *vs.* 62.1 ± 1.78%) and a higher (P <0.05) percentage of both oxymyoglobin (26.5 ± 1.24% *vs.* 22.9 ± 1.38%) and metmyoglobin (22.9 ± 1.38% vs. 15.0 ± 0.51%) than the corresponding samples of electrical stimulation treatment (Table 4.38). There were no differences (P >0.05) between electrical stimulation and delayed chilling treatment in myoglobin redox forms of SM samples (Table 4.38).

Table 4.38 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on surface myoglobin redox forms (%) of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Myoglobin redox forms	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	Deoxymyoglobin	62.1^{a} ± 1.78	56.9^{b} ± 1.64	0.04
	Oxymyoglobin	22.9^{a} ± 1.38	26.5^{b} ± 1.24	0.03
	Metmyoglobin	15.0^{a} ± 0.51	16.6^{b} ± 0.48	0.03
Semimembranosus	Deoxymyoglobin	56.6 ± 1.56	58.9 ± 1.61	0.33
	Oxymyoglobin	24.8 ± 1.16	22.6 ± 1.22	0.20
	Metmyoglobin	18.6 ± 0.49	18.5 ±0.44	0.97

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

The interaction effect of breed and carcass treatment was not significant (P >0.05) for any of the surface myoglobin redox forms (deoxy-, oxy- and metmyoglobin) in both the LD and SM of goats (Table 4.39).

Table 4.39 *P*-values for the interaction effect of breed and carcass treatment on surface myoglobin redox forms of the *m. longissimus dorsi* and *m. semimembranosus* of goats.

Muscle	Myoglobin pigments	*P*-value
Longissimus dorsi	Deoxymyoglobin	0.97
	Oxymyoglobin	0.95
	Metmyoglobin	0.75
Semimembranosus	Deoxymyoglobin	0.71
	Oxymyoglobin	0.67
	Metmyoglobin	0.86

4.5.3 The effects of breed, carcass treatment and their interaction on instrumental colour

The effect of breed on instrumental colour of the LD and SM samples of goats are presented in Table 4.40. There were no breed differences (P > 0.05) in any of the instrumental colour values (CIE L*, a*, b*, Chroma and Hue angle) of both the LD and SM samples (Table 4.40). The average values for L*, a*, b*, Chroma and Hue angle of LD samples were 39.2 ± 0.36, 17.4 ± 0.24, 11.9 ± 0.19, 21.1 ± 0.30 and 34.2 ± 0.21, respectively. The average colour values for SM samples were; L* = 36.1 ± 0.35, a*= 18.8 ± 0.21, b* = 12.3 ± 0.18, Chroma = 22.5 ± 0.26 and Hue angle = 33.2 ± 0.23.

Table 4.40 Least square means ($\bar{x}$ ± SEM) for the effect of breed on instrumental colour (CIE L*, a*, b*, Chroma and Hue angle) of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	$\bar{X}$ ± SEM
Longissimus dorsi	L*	39.2 ± 0.36
	a*	17.4 ± 0.24
	b*	11.9 ± 0.19
	Chroma	21.1 ± 0.30
	Hue angle	34.2 ± 0.21
Semimembranosus	L*	36.1 ± 0.35
	a*	18.8 ± 0.21
	b*	12.3 ± 0.18
	Chroma	22.5 ± 0.26
	Hue angle	33.2 ± 0.23

The effects of carcass treatment on instrumental colour of the LD and SM of goats are presented in Table 4.41. Electrically stimulated LD samples had lower (P <0.05) L* (38.4 ± 0.42 *vs.* 40.0 ± 0.52(P <0.05), a*(16.7 ± 0.26 vs 18.1 ± 0.35; P <0.01), b* (11.3 ± 0.23 *vs.* 12.5 ± 0.24; P <0.01) and Chroma (20.2 ± 0.33 *vs.* 22.0 ± 0.42 P <0.01) values than corresponding samples of delayed chilling treatment (Table 4.41). The hue angle values were not different (P >0.05) between the two treatments. There were no significant differences between the two treatments in instrumental colour values (CIE L*, a*, b*, Chroma and Hue angle) of SM samples (Table 4.41).

Table 4.41 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on instrumental colour (CIE L*, a*, b*, Chroma and Hue angle) of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	Carcass treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	L*	38.4[a] ± 0.42	40.0[b] ± 0.52	0.03
	a*	16.7[a] ± 0.26	18.1[b] ± 0.35	0.004
	b*	11.3[a] ± 0.23	12.5[b] ± 0.24	0.001
	Chroma	20.2[a] ± 0.33	22.0[b] ± 0.42	0.002
	Hue angle	33.9 ± 0.28	34.6 ± 0.29	0.09
Semimembranosus	L*	36.0 ± 0.50	36.3 ± 0.48	0.70
	a*	19.0 ± 0.28	18.6 ± 0.31	0.36
	b*	12.7 ± 0.25	12.0 ± 0.25	0.07
	Chroma	22.9 ± 0.35	22.2 ± 0.37	0.19
	Hue angle	33.6 ± 0.30	32.8 ± 0.31	0.07

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

The interaction effect of breed and carcass treatment were not significant for any instrumental colour value (CIE L*, a*, b*, Chroma and Hue angle) (Table 4.42).

Table 4.42 *P*-values for the interaction effect of breed and carcass treatment on instrumental colour values (CIE L*, a*, b*, Chroma and Hue angle) of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	*P*-values
Longissimus dorsi	L*	0.67
	a*	0.81
	b*	0.81
	Chroma	0.94
	Hue angle	0.43
Semimembranosus	L*	0.88
	a*	0.93
	b*	0.75
	Chroma	0.86
	Hue angle	0.65

Means within the same column with different superscripts $^{x, y}$ were different (P <0.05)

4.5.4 The effects of breed, carcass treatment and their interaction on sarcomere length and Warner-Bratzler shear force values

The effect of breed on sarcomere lengths and WBSF values of the LD and SM of goats are presented in Table 4.43. Breed was had no effect (P >0.05) on sarcomere lengths of both the LD and SM samples, with average values of 2.05 ± 0.02 µm and 2.06 ± 0.02 µm, respectively (Table 4.43). The WBSF values of LD samples were not different (P >0.05) between the two treatments, with an average of 4.28 ± 0.26 kg. On the other hand, WBSF values were 1.9 kg higher (P <0.01) in SM samples of indigenous goats than in corresponding samples of Boer goats (6.40 ± 0.48 kg) (Table 4.43).

Table 4.43 Least square means ($\bar{x}$ ± SEM) for the effect of breed on sarcomere lengths and Warner Bratzler shear force values of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	Breed		*P*-value
		Indigenous goats	Boer goats	
Longissimus dorsi	Sarcomere length (µm)	2.05 ± 0.02	2.04 ± 0.02	0.75
	WBSF value (kg)	4.28 ± 0.26	4.27 ± 0.15	0.99
Semimembranosus	Sarcomere length (µm)	2.03 ± 0.02	2.10 ± 0.03	0.08
	WBSF (kg)	8.27^{a} ± 0.42	6.40^{b} ± 0.48	0.001

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

The effects of carcass treatment on sarcomere lengths and WBSF values of the LD and SM of goats are presented in Table 4.44.

Table 4.44 Least square means ($\bar{x}$ ± SEM) for the effect of carcass treatment on sarcomere lengths and Warner Bratzler shear force values of the *m. longissimus dorsi* and *m. semimembranosus* of goats

Muscle	Variable	Carcass Treatment		*P*-value
		Electrical stimulation	Delayed chilling	
Longissimus dorsi	Sarcomere length (µm)	2.00^{a} ± 0.02	2.10^{b} ± 0.02	0.002
	WBSF (kg)	4.12 ± 0.18	4.43 ± 0.24	0.31
Semimembranosus	Sarcomere length (µm)	2.06 ± 0.02	2.07 ± 0.03	0.84
	WBSF (kg)	6.22^{a} ± 0.47	8.45^{b} ± 0.38	0.0001

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

The sarcomeres of electrically stimulated LD samples were 0.1 µm shorter (P <0.01) than those of corresponding samples in delayed chilling treatment (2.10 ± 0.02 µm). The WBSF values of LD samples were not different (P >0.05) between the two treatments, with an average value 4.28 ± 0.15 kg (Table 4.44).

Sarcomere lengths of SM samples were not different (P >0.05) between the two treatments, with an average value of 2.06 ± 0.02 µm (Table 4.44). However, electrical stimulation resulted in lower (P <0.001) WBSF than corresponding samples of delayed chilling treatment (6.22 ± 0.47 kg *vs.* 8.45 ± 0.38 kg).

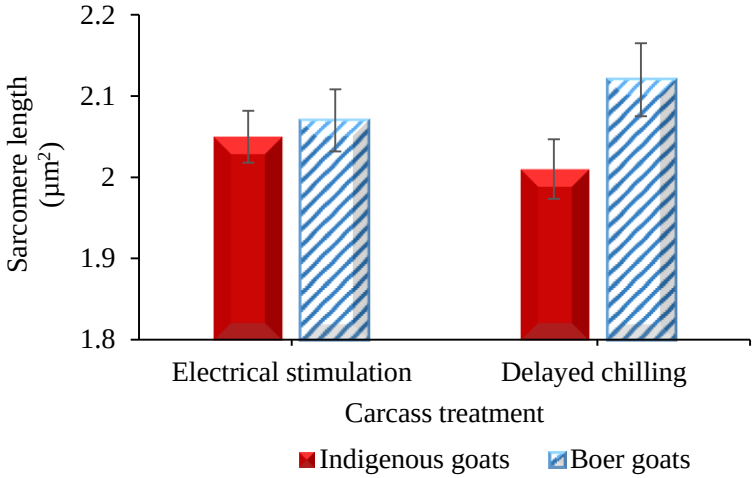
The interaction effect of breed and carcass treatment on sarcomere lengths and WBSF values of the LD and SM of goats are presented in Tables 4.45 and Fig. 4.12 & 4.13.The interaction effect of breed and carcass treatment on sarcomere lengths of both the LD and SM of goats was not significant (P >0.05) (Table 4.45 and Fig. 4.12).

The interaction effect of breed and carcass treatment on WBSF values was significant for SM samples (Fig. 4.13B). In Boer goats, the SM samples of electrical stimulation treatment had 3.3 kg lower (P <0.001) WBSF values than corresponding samples of delayed chilling treatment (8.08 ± 0.51 kg), whilst in indigenous goats, the difference of 1.1 kg in WBSF values between electrical stimulation (7.70 ± 0.59 kg) and delayed chilling (8.84 ± 0.57 kg) was not significant (Fig 4.13B).

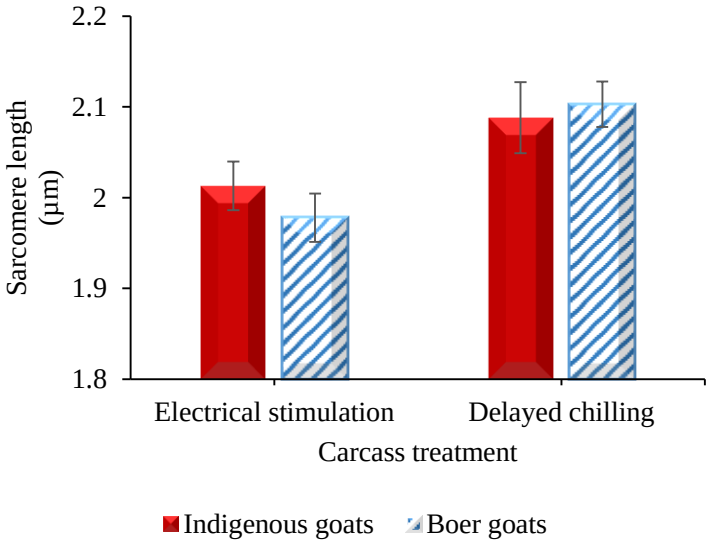
Table 4.45 *P*-values for the interaction of breed and carcass treatment on sarcomere lengths and Warner-Bratzler shear force values of the *m. longissimus dorsi* and *m. semimembranosus* of goats.

Muscle	Variable	*P*-values
Longissimus dorsi	Sarcomere length (µm)	0.41
	WBSF (kg)	0.53
Semimembranosus	Sarcomere length (µm)	0.27
	*WBSF (kg)	**0.04**

Significant interaction effect is indicated in bold

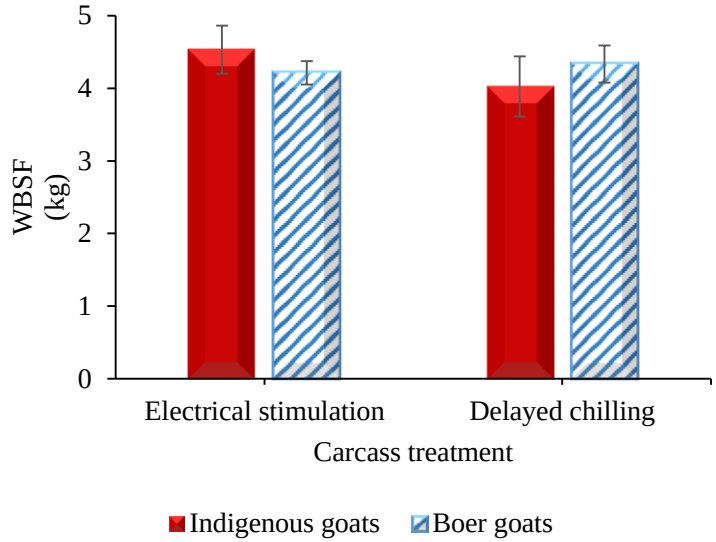


A.

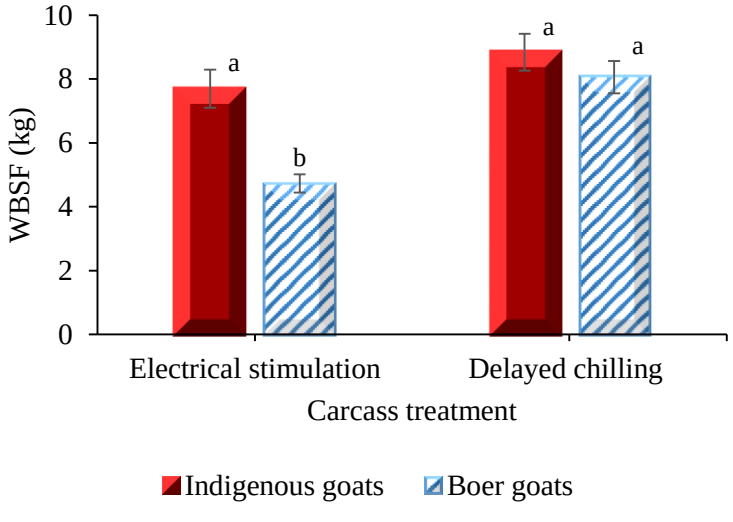


B.

Figure 4.12 Mean values for sarcomere lengths for the (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous goats and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means.



A.



B.

Figure 4.13 Mean values for Warner Bratzler shear force for the (A) *m. longissimus dorsi* and (B) *m. semimembranosus* of indigenous goats and Boer goats after electrical stimulation or delayed chilling of carcasses. Vertical bars indicate standard error of means. Means with different letters a, b were different (P <0.05).

4.5.5 Comparison of the *m. longissimus dorsi* and the *m. semimembranosus*

The objective properties of the LD and SM were compared and the results are presented in Table 4.46.

Table 4.46 Comparison of objective properties ($\bar{x}$ ± SEM) of *m. longissimus dorsi* and *m. semimembranosus* of goats

Variable	Muscle		*P*-value
	Longissimus dorsi	*Semimembranosus*	
WHC	0.39^{a} ± 0.01	0.36^{b} ± 0.01	0.03
Thawing losses (%)	2.58^{a} ± 0.19	5.91^{b} ± 0.23	0.0001
Drip loss (%)	0.39^{a} ± 0.07	1.04^{b} ± 0.16	0.0001
Evaporative loss (%)	19.2^{a} ± 0.60	24.0^{b} ± 0.60	0.0001
Total cooking loss (%)	19.6^{a} ± 0.62	25.0^{b} ± 0.67	0.0001
DMB (%)	59.5 ± 1.27	57.7 ± 1.12	0.31
OMB (%)	24.1 ± 0.96	23.1 ± 0.85	0.44
MMB (%)	15.8^{a} ± 0.37	18.5^{b} ± 0.32	0.0001
L*	43.9^{a} ± 0.31	40.6^{b} ± 0.32	0.0001
a*	17.4^{a} ± 0.24	18.8^{b} ± 0.21	0.0001
b*	4.75 ± 0.20	4.52 ± 0.18	0.37
Chroma	15.6^{a} ± 0.27	16.6^{b} ± 0.24	0.002
Hue angle	17.5^{a} ± 0.52	15.5^{b} ± 0.49	0.004
Sarcomere length (µm)	2.05 ± 0.02	2.06 ± 0.02	0.46
WBSF (kg)	4.28^{a} ± 0.15	7.33^{b} ± 0.35	0.0001

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

The LD samples had higher WHC (0.39 ± 0.01 *vs.* 0.36 ± 0.01; P <0.01), L* value (43.9 ± 0.31 *vs.*40.6 ± 0.32; P <0.001) and hue angle (17.5 ± 0.52 vs. 15.5 ± 0.49, P <0.01) than SM samples (Table 4.46). On the other hand, the SM had higher a* value (18.8 ± 0.24 vs. 17.4 ± 0.24, P <0.001), Chroma value (16.6 ± 0.24 vs. 15.6 ± 0.27, P <0.01), MMB (18.5 ± 0.21% vs. 15.8 ± 0.37%, P <0.001), thawing losses (5.91 ± 0.23% vs. 2.85 ± 0.19%; P <0.001), total cooking losses (25.0 ± 0.67% vs. 19.6 ± 0.62%, P <0.001) and WBSF values (7.33 ± 0.35 kg

vs. 4.28 ± 0.15 kg, *P* <0.001) than the LD samples (Table 4.46). There were no differences (*P* >0.05) in b* values, sarcomere lengths, DMB or OMB percentages of the two muscles, with average values of 4.63 ± 0.15, 2.05 ± 0.01 µm, 58.6 ± 0.84% and 24.2 ± 0.64%, respectively.

4.6 Correlations between carcass, muscle and meat quality characteristics

Carcass characteristics, histochemical and biochemical properties have an influence on the development of meat quality (Karlsson et al., 1998; Scheffler & Gerrard, 2007; Gokdal, 2013). However, very few studies have examined the relationship between carcass, muscle and meat characteristics of goats. This section links carcass characteristics, muscle histo- and biochemical properties to the ultimate quality of goat meat.

Correlations between carcass, muscle and meat quality parameters were determined in order to explain factors contributing to variation in meat quality traits for each muscle (Tables 4.47 to 4.50). Correlations of carcass traits, muscle fibre properties, biochemical properties as well as among muscle pH and temperature are provided in Appendix 1.

Table 4.47 Correlation-matrix showing correlation coefficients between live weight, carcass and muscle fibre characteristics with meat quality traits (pooled data for all the goats)

Parameter	Live weight	Cold carcass weight	Chilling loss	Fibre cross sectional areas			Fibre percentage		
				Red	Intermediate	White	Red	Intermediate	White
Longissimus dorsi									
Ultimate pH	**-0.32***	**-0.32***	0.07	-0.11	-0.08	-0.02	-0.10	0.03	0.11
Water holding capacity	**-0.36***	-0.21	-0.02	-0.02	-0.01	0.07	0.05	0.00	-0.07
Thawing loss	-0.24	-0.19	0.16	-0.26	-0.29	-0.24	0.08	-0.13	0.01
Total cooking loss	0.03	0.07	-0.16	0.30	**0.35***	0.31	-0.08	0.11	0.01
Drip loss	**0.37***	**0.35***	-0.23	**0.40****	**0.45****	**0.45****	-0.20	0.27	0.02
Evaporative loss	-0.01	0.03	-0.15	0.27	0.30	0.26	-0.06	0.08	0.00
Deoxymyoglobin	-0.21	-0.18	-0.10	-0.18	-0.09	-0.05	-0.13	-0.09	0.25
Oxymyoglobin	0.30	0.26	0.11	0.21	0.13	0.08	0.07	0.11	-0.19
Metmyoglobin	-0.07	-0.04	0.08	0.07	-0.01	-0.02	0.27	0.03	**-0.39***
L*	**0.31***	**0.33***	0.16	-0.21	-0.15	-0.25	0.15	-0.13	-0.09
a*	-0.04	0.00	0.13	0.17	0.08	0.05	0.22	0.00	-0.30
b*	0.31	**0.37***	0.25	0.04	0.04	-0.06	0.12	0.11	-0.27
Chroma	0.11	0.16	0.20	0.14	0.09	0.03	0.18	0.07	**-0.32***
Hue angle	**0.40***	**0.45****	0.24	-0.06	-0.04	-0.14	0.09	0.11	-0.22
Sarcomere length	-0.15	-0.10	0.29	0.02	-0.05	-0.10	0.07	0.20	-0.28
Shear force	**0.32***	**0.33***	**0.40****	-0.09	-0.02	-0.13	0.19	0.14	**-0.39***
Semimembranosus									
Ultimate pH	**-0.40****	-0.23	-0.15	**-0.49*****	**-0.55*****	**-0.47*****	-0.28	0.20	0.13
Water holding capacity	**-0.35***	-0.27	0.11	-0.16	-0.23	-0.30	0.03	-0.02	-0.01
Thawing loss	0.04	0.11	0.08	**-0.39***	**-0.35***	-0.31	-0.29	0.25	0.09
Cooking loss	-0.13	-0.13	0.19	0.14	0.07	0.06	-0.12	0.12	0.03
Drip loss	-0.04	-0.07	-0.15	0.10	0.19	0.30	0.16	0.18	**-0.34***
Evaporative loss	-0.13	-0.12	0.25	0.13	0.03	-0.02	-0.18	0.09	0.12
Deoxymyoglobin	**-0.44****	-0.30	-0.13	**-0.36***	**-0.41****	**-0.43****	0.08	0.02	-0.11
Oxymyoglobin	**0.44****	**0.33***	0.14	**0.33***	**0.38***	**0.42****	-0.10	-0.02	0.13
Metmyoglobin	**0.34***	0.15	0.07	**0.36***	**0.40****	**0.38***	-0.01	-0.04	0.05
L*	0.13	0.11	0.15	0.19	0.14	0.10	**-0.41****	-0.22	-0.25
a*	0.24	0.10	0.09	**0.36***	**0.46****	**0.53*****	-0.12	0.11	0.03
b*	0.31	**0.32***	0.16	0.12	0.20	**0.32***	-0.02	0.10	-0.06
Chroma	**0.36***	0.27	0.11	0.21	0.31	**0.42****	-0.12	0.15	0.00
Hue angle	0.25	0.31	0.18	0.06	0.13	0.24	0.03	0.06	-0.09
Sarcomere length	-0.17	-0.17	**0.43****	-0.03	-0.11	-0.14	**-0.38***	0.26	0.19
Shear force	-0.04	-0.06	0.09	-0.08	-0.01	-0.03	0.22	-0.07	-0.18

*P <0.05; **P <0.01; ***P <0.001

Table 4.48 Correlation-matrix showing correlation coefficients between glycolytic parameters and meat quality traits (pooled data for all the goats)

Parameter	Creatine phosphate			Glycogen			ATP			Lactate			Glycolytic potential		
	15 min	3 hours	24 hours	15 min	3 hours	24 hours	15 min	3 hours	24 hours	15 min	3 hours	24 hours	15 min	3 hours	24 hours
Longissimus dorsi															
Ultimate pH	0.06	0.09	0.29	-0.13	0.04	-0.23	0.06	0.16	0.09	0.15	0.00	0.23	-0.20	-0.01	-0.20
Water holding capacity	-0.16	0.02	0.18	-0.20	-0.07	-0.09	-0.22	-0.13	0.04	0.20	0.14	-0.07	-0.05	0.08	-0.21
Thawing loss	-0.05	0.11	0.09	-0.01	-0.09	0.30	-0.18	-0.27	-0.03	0.23	0.19	-0.11	0.18	0.17	-0.01
Cooking loss	-0.13	-0.03	0.23	-0.07	**-0.39***	-0.07	**-0.44****	**-0.39***	0.15	**0.33***	0.31	0.06	0.22	-0.05	0.05
Drip loss	0.20	0.08	0.11	0.07	-0.05	-0.12	-0.04	-0.16	0.12	0.02	-0.13	-0.12	0.09	-0.24	-0.04
Evaporative loss	-0.16	-0.04	0.24	-0.07	**-0.39***	-0.07	**-0.45****	**-0.38***	0.15	**0.34***	**0.33***	0.07	0.22	-0.02	0.04
Deoxymyoglobin	-0.20	-0.01	0.20	**-0.44****	-0.28	-0.04	**-0.31***	-0.13	0.07	0.17	0.30	-0.12	-0.28	0.08	-0.25
Oxymyoglobin	0.22	0.01	-0.18	**0.44****	0.24	0.02	**0.34***	0.16	-0.03	-0.17	-0.29	0.08	0.29	-0.10	0.21
Metmyoglobin	0.14	0.00	-0.24	**0.38***	**0.33***	0.07	0.20	0.05	-0.15	-0.14	-0.29	0.20	0.23	-0.02	0.29
L*	0.28	**0.32***	-0.18	-0.01	0.20	-0.16	**0.42****	**0.39***	-0.19	-0.31	-0.23	-0.10	-0.27	-0.08	-0.06
a*	0.01	-0.08	-0.06	**0.49****	**0.37***	0.11	0.14	0.09	0.08	-0.18	**-0.35***	0.15	0.31	-0.06	0.21
b*	0.23	0.23	-0.03	**0.53*****	**0.49****	0.00	**0.40***	**0.35***	0.06	**-0.39***	**-0.47****	-0.04	0.16	-0.08	0.06
Chroma	0.08	0.03	-0.04	**0.57*****	**0.45****	0.08	0.24	0.18	0.10	-0.27	**-0.43****	0.08	0.30	-0.06	0.16
Hue angle	0.31	**0.32***	-0.02	**0.44****	**0.47****	-0.03	**0.49****	**0.43****	0.04	**-0.44****	**-0.46****	-0.11	0.04	-0.08	-0.02
Sarcomere length	0.21	0.03	0.03	**0.33***	**0.35***	-0.12	**0.35***	**0.32***	-0.10	-0.23	-0.18	0.21	0.08	0.13	0.15
Shear force	**0.35***	0.12	-0.11	0.15	**0.32***	0.30	0.17	0.19	0.17	-0.30	**-0.37***	-0.08	-0.15	-0.15	0.03
Semimembranosus															
Ultimate pH	**0.35***	0.23	0.00	**-0.33***	0.13	0.02	0.23	0.22	0.05	-0.30	-0.31	-0.07	**-0.39***	**-0.34***	-0.11
Water holding capacity	0.28	0.30	0.16	0.05	0.01	0.03	**0.32***	0.23	0.10	-0.03	-0.08	-0.05	0.06	-0.09	-0.09
Thawing loss	0.08	-0.15	-0.22	-0.24	-0.29	-0.16	-0.15	-0.04	-0.03	-0.22	-0.14	-0.06	-0.31	**-0.32***	-0.07
Cooking loss	0.01	0.28	0.02	-0.04	0.20	0.03	0.14	0.30	0.14	0.09	-0.06	0.11	0.02	0.15	0.17
Drip loss	-0.16	-0.12	-0.08	-0.20	0.00	-0.10	-0.04	-0.06	-0.04	0.08	-0.06	0.05	-0.09	0.03	0.06
Evaporative loss	0.06	**0.34***	0.06	0.03	0.22	0.07	0.16	**0.34***	0.16	0.07	-0.05	0.11	0.05	0.16	0.17
Deoxymyoglobin	0.07	-0.21	-0.25	-0.28	-0.31	-0.28	0.12	0.09	-0.18	-0.11	-0.31	-0.17	-0.27	**-0.45****	**-0.32***
Oxymyoglobin	-0.03	0.21	0.25	0.23	0.29	0.29	-0.10	-0.10	0.19	0.09	0.29	0.13	0.23	**0.42****	0.29
Metmyoglobin	-0.16	0.17	0.19	**0.36***	0.30	0.19	-0.15	-0.05	0.12	0.15	0.30	0.24	0.33*	**0.46****	**0.35***
L*	-0.06	-0.12	-0.14	0.28	0.17	0.14	0.10	0.04	-0.11	0.01	0.10	0.03	0.23	0.19	0.05
a*	-0.22	0.07	0.28	0.11	0.21	0.16	-0.05	-0.15	0.20	0.28	**0.38***	0.13	0.26	**0.44****	0.25
b*	-0.09	0.07	0.20	0.14	0.19	0.29	0.01	-0.19	0.18	0.15	0.26	-0.01	0.23	**0.31***	0.11
Chroma	-0.18	0.04	0.26	0.08	0.13	0.20	-0.09	-0.27	0.22	0.22	0.30	-0.03	0.21	0.31	0.09
Hue angle	-0.02	0.06	0.13	0.12	0.18	0.31	0.04	-0.15	0.13	0.08	0.20	-0.01	0.17	0.27	0.11
Sarcomere length	0.00	0.08	-0.03	-0.11	0.13	-0.02	-0.02	0.18	0.17	0.00	-0.21	-0.12	-0.08	-0.06	-0.16
Shear force	0.11	-0.10	-0.31	0.06	0.04	-0.03	0.00	0.16	-0.16	**-0.38***	**-0.38***	0.07	-0.18	-0.22	0.09

*P <0.05; **P <0.01; ***P <0.001

Table 4.49 Correlation-matrix showing correlation coefficients between muscle pH and temperature with meat quality traits (pooled data for all the goats)

Parameter	pH					Temperature				
	15 minutes	1 hour	3 hours	6 hours	24 hours	15 minutes	1 hour	3 hours	6 hours	24 hours
Longissimus dorsi										
Ultimate pH	0.25	0.20	0.26	**0.55*** **	1.00	0.25	-0.16	-0.04	0.10	0.11
Water holding capacity	0.05	0.03	0.13	0.24	**0.45****	0.07	-0.25	-0.19	-0.22	0.15
Thawing loss	-0.15	-0.11	-0.16	0.00	-0.05	0.04	0.09	-0.13	-0.20	0.24
Total cooking loss	-0.15	**-0.31***	-0.30	**-0.46****	-0.25	**-0.33***	0.01	-0.16	-0.29	-0.16
Drip loss	0.00	-0.08	-0.23	**-0.46****	**-0.40***	-0.12	**0.34***	0.14	-0.04	-0.15
Evaporative loss	-0.15	-0.31	-0.27	**-0.42****	-0.21	**-0.33***	-0.04	-0.18	-0.29	-0.15
Deoxymyoglobin	-0.29	-0.16	-0.15	0.07	**0.39***	-0.09	**-0.36***	**-0.42****	**-0.40****	-0.08
Oxymyoglobin	0.26	0.16	0.11	-0.12	**-0.46****	0.06	**0.34***	**0.39***	**0.37***	0.09
Metmyoglobin	**0.31***	0.15	0.24	0.08	-0.15	0.14	**0.36***	**0.42****	**0.41****	0.03
L*	0.29	**0.41****	0.19	0.24	-0.11	0.13	0.10	0.08	0.21	-0.11
a*	**0.35***	0.12	0.29	0.02	-0.21	0.14	**0.36***	**0.57*****	**0.52*****	0.02
b*	**0.55*****	**0.36***	**0.43****	0.13	-0.17	0.04	**0.40****	**0.42****	**0.51*****	0.05
Chroma	**0.45****	0.21	**0.36***	0.05	-0.21	0.08	**0.40****	**0.54*****	**0.54*****	0.04
Hue angle	**0.56*****	**0.42****	**0.45****	0.18	-0.14	0.02	**0.34***	0.29	**0.45****	0.06
Sarcomere length	**0.56*****	**0.38***	0.28	**0.39***	**0.31***	0.29	0.09	**0.39***	**0.45****	0.06
Shear force	**0.36***	0.10	**0.33***	0.07	-0.07	-0.25	0.30	0.22	0.26	-0.04
Semimembranosus										
Ultimate pH	0.28	**0.31***	**0.37***	**0.39***	1.00	0.23	**0.32***	0.09	-0.07	-0.14
Water holding capacity	0.24	0.02	-0.09	0.26	**0.36***	0.14	0.15	-0.14	-0.23	0.01
Thawing loss	0.09	0.11	0.17	0.19	0.26	0.00	**0.38***	0.10	0.06	0.21
Total cooking loss	0.14	0.24	0.13	0.08	-0.16	-0.11	0.10	-0.03	-0.07	0.06
Drip loss	0.11	0.09	0.04	0.08	-0.18	0.24	0.16	**0.34***	0.26	-0.11
Evaporative loss	0.12	0.24	0.14	0.07	-0.14	-0.18	0.08	-0.12	-0.14	0.09
Deoxymyoglobin	0.19	0.28	0.11	0.26	**0.45****	0.14	0.17	0.23	0.06	0.17
Oxymyoglobin	-0.17	-0.26	-0.12	-0.29	**-0.39***	-0.13	-0.16	-0.23	-0.11	-0.16
Metmyoglobin	-0.21	-0.30	-0.06	-0.13	**-0.54****	-0.14	-0.19	-0.19	0.10	-0.17
L*	0.11	-0.12	-0.07	**-0.40***	**-0.33***	-0.25	**-0.35***	0.05	0.09	0.06
a*	**-0.44****	**-0.38***	-0.26	**-0.36***	**-0.46****	-0.06	-0.12	-0.18	-0.03	-0.23
b*	-0.18	-0.15	-0.17	**-0.52*****	-0.21	-0.14	-0.01	-0.13	-0.23	-0.03
Chroma	**-0.31***	-0.29	-0.25	**-0.47****	**-0.32***	0.00	0.03	-0.17	-0.15	-0.19
Hue angle	-0.09	-0.07	-0.10	**-0.48****	-0.12	-0.17	-0.02	-0.09	-0.23	0.06
Sarcomere length	0.09	0.12	0.10	-0.02	0.19	0.17	0.20	-0.17	-0.13	-0.18
Shear force	**0.33***	0.16	0.24	0.25	-0.13	0.16	0.10	**0.36***	**0.52*****	-0.21

*P <0.05; **P <0.01; ***P <0.001

Table 4.50 Correlation-matrix showing correlation coefficients between meat quality traits (pooled data for all the goats)

	1	2	3	3	4	6	7	8	9	10	11	12	13	14	15
Longissimus dorsi															
1 pH	1														
2 WHC	**0.45****														
3 Thaw loss	-0.05	0.26													
4 Cook loss	-0.25	0.02	0.13												
5 Drip loss	**-0.40***	-0.19	-0.13	**0.44****											
6 Evap. loss	-0.21	0.05	0.15	**0.99*****	**0.33***										
7 DMB	**0.39***	**0.42****	0.17	-0.06	**-0.48****	0.00									
8 OMD	**-0.46****	**-0.48****	-0.18	0.07	**0.52*****	0.02	**-0.98*****								
9 MMB	-0.15	-0.2	-0.13	0.00	0.28	-0.04	**-0.88*****	**0.78*****							
10 L*	-0.11	-0.28	-0.04	-0.24	-0.11	-0.25	-0.14	0.18	0.04						
11 a*	-0.21	-0.21	-0.21	-0.04	0.30	-0.07	**-0.82*****	**0.77*****	**0.82*****	-0.18					
12 b*	-0.17	**-0.34***	-0.25	-0.01	**0.33***	-0.05	**-0.75*****	**0.77*****	**0.57*****	**0.33***	**0.69*****				
13 Chroma	-0.21	-0.26	-0.24	-0.01	**0.34***	-0.05	**-0.82*****	**0.80*****	**0.74*****	-0.02	**0.94*****	**0.88*****			
14 Hue	-0.14	**-0.33***	-0.2	-0.03	0.27	-0.06	**-0.60*****	**0.64*****	**0.39***	**0.52*****	**0.45****	**0.95*****	**0.70*****		
15 SL	**0.34***	0.06	-0.12	-0.23	-0.12	-0.22	-0.31	0.28	**0.33***	0.12	**0.39***	**0.45****	**0.44****	**0.40***	
16 SF	-0.07	-0.16	-0.02	0.08	0.06	0.07	-0.09	0.09	0.07	**0.39***	0.03	**0.35***	0.17	**0.42****	0.07
Semimembranosus															
2 WHC	**0.36***														
3 Thaw loss	0.26	-0.14													
4 Cook loss	-0.16	-0.04	-0.2												
5 Drip loss	-0.18	-0.31	-0.24	**0.50****											
6 Evap. loss	-0.14	0.05	-0.17	**0.97*****	0.28										
7 DMB	**0.45****	0.24	0.22	-0.03	0.07	-0.06									
8 OMD	**-0.39***	-0.20	-0.21	-0.01	-0.1	0.02	**-0.98*****								
9 MMB	**-0.54*****	-0.31	-0.21	0.14	0.03	0.15	**-0.88*****	**0.77*****							
10 L*	**-0.33***	-0.17	**-0.42****	0.02	0.11	-0.01	**-0.33***	**0.35***	0.21						
11 a*	**-0.46****	-0.18	-0.25	-0.06	0.14	-0.1	**-0.72*****	**0.70*****	**0.65*****	0.09					
12 b*	-0.21	-0.06	-0.22	-0.13	0.01	-0.16	**-0.58*****	**0.67*****	0.25	**0.52*****	**0.59*****				
13 Chroma	**-0.32***	-0.07	-0.19	-0.19	0.03	-0.23	**-0.68*****	**0.73*****	**0.45****	0.21	**0.83*****	**0.86*****			
14 Hue	-0.12	-0.04	-0.19	-0.11	0.00	-0.14	**-0.46****	**0.57*****	0.11	**0.60*****	**0.42****	**0.97*****	**0.72*****		
15 SL	0.19	**0.36***	0.04	0.05	-0.07	0.06	0.03	0.02	-0.17	-0.1	0.12	0.19	0.25	0.15	
16 WBSF	-0.13	-0.08	0.12	0.09	0.27	0.04	-0.04	-0.06	0.27	0.1	0.07	-0.21	-0.09	-0.22	-0.04

WHC-waterholding capacity; DMB-deoxymyoglobin; OMB-oxymyoglobin; MMB-metmyoglobin; SL-sarcomere length; WBSF-Warner-Bratzler shear force

CHAPTER 5

5 DISCUSSION

5.1 Live weight and carcass characteristics of goats and their implication on meat quality

Live weight has been used in many studies to define the size of goats (reviewed by Webb, 2014). The live weight of goats used in this study compares well to yearling goats of various breeds /genotypes (Kouakou et al., 2005; Kadim et al., 2006; Gadiyaram et al., 2008). In this study, Boer goats were heavier and their carcasses were heavier than those of indigenous goats (Table 4.1). Breed differences in live weight and carcass weight are attributable to heavier weaning weights and higher rates of gain of Boer goats. Although the indigenous goats were smaller than the Boer goats, they are of the same type as large goats of Southern Africa, and these goats have a high potential for commercial chevon production (reviewed by Simela & Merkel, 2008).

Knowledge of the dressing percentage can assist farmers in achieving target carcass weights before the goats are slaughtered. In the present study, the dressing percentage for both the indigenous and Boer goats compares well to values previously reported for goats (Hogg et al., 1992; Marichal et al., 2003; Sen et al., 2004; Safari et al., 2011; Simela et al., 2011). In agreement with the results of Tshabalala et al. (2003), dressing percentage was not different between the two goat breeds. According to Warmington and Kirton (1990), goats are generally lean hence there are very little breed differences in their dressing percentages. Studies which have reported breed differences in dressing percentages of goats have attributed such variations

to factors such as age, the degree of gut fill at slaughter and the dressing procedure (Dhanda et al., 1999a; Kadim et al., 2003; Gokdal, 2013).

Overall, the chilling losses for this study were marginally higher than 3%, which is usually estimated for goat carcasses (Webb et al., 2005). High chilling losses are undesirable because they reduce the weight and the quality of the carcass. In this study, a positive correlation between chilling loss and WBSF of the LD (Table 4.47), indicate that high chilling losses may have deleterious effects on the tenderness of loin cuts. Spray chilling of low weight and lean beef carcasses has been reported to reduce chilling losses without affecting tenderness of the *m. longissimus lumborum* (Prado and Felicio, 2010). A similar strategy can be considered to minimise chilling losses in goat carcasses.

The chilling losses were higher in carcasses of Boer goats than in carcasses of indigenous goats (Table 4.1). This is confounding considering that chilling losses should be higher in smaller carcasses than in larger carcasses (Webb et al., 2005). However, Kadim et al. (2006) in their study with three Omani goat breeds reported that the Jabal Akhdar goat breed had higher carcass weight, hence they had higher chilling losses (shrinkage) when compared to the Dhofari and Jabal Akhdar goat breeds. In this study, the relationship between carcass weight and chilling loss was weak (Appendix A.1), therefore breed variations in chilling losses can be attributed to factors other than carcass weight.

It has been previously reported in lamb (Sanudo, Santolaria, María, Osorio & Sierra 1996) that heavier carcasses yielded meat with better objective properties in terms of pH_u, colour, juiciness and tenderness. In the present study, the correlation between both live weight and carcass weight with meat quality traits (both LD and SM) suggests that selecting heavier goats or carcasses may be beneficial for achieving chevon with lower pH_u values and improved colour (Table 4.47). On the other hand, a positive correlation between both live weight and carcass weight with WBSF of the LD samples suggests that heavier carcasses may yield tough

meat, as previously discussed in the review of Webb (2014). According to Simela and Merkel (2008) chevon of better quality is obtained from carcasses weighing at least 15 kg. Therefore more studies should be conducted to determine the optimal slaughter weight in relation to the quality of goat meat.

5.2 Muscle fibre characteristics

The influence of muscle fibre characteristics on meat quality has been studied extensively in other livestock species (Choe, Choi, Lee, Shin, Ryu, Hong & Kim, 2008; Bünger et al., 2009; Hwang et al., 2010). However very few studies, if any, have been conducted to characterise and interrelate muscle fibres to the development of chevon quality. This section discusses fibre characteristics in LD and SM of indigenous and Boer goats in a quest to understand the mechanisms underlying the development of chevon quality.

An overview of the results shows clear distinction in the size of muscle fibres (Figs. 4.1A & B). Red fibres had the smallest CSA in comparison to intermediate and white fibres. These results confirm that muscle fibres vary in size, with red fibres being the smallest and white fibres, the largest as previously reported in other species (Klont et al., 1998; Wegner et al., 2000). Between the breeds, the LD samples of Boer goats had larger intermediate fibres than corresponding samples of indigenous goats (Table 4.2; Fig. 4.1A). In other species, it was previously established that breed differences in the muscle fibre size are related to differences in the degree of maturity (Bünger et al., 2009). In the present study, there was a positive relationship between live weight and CSA of red and intermediate fibre types in LD samples (Appendix A.1), an indication that an increase in live weight is accompanied by enlargement of muscle fibres. According to literature, post-natal muscle growth is mainly achieved by an increase in CSA of muscle fibres with some differences in muscle and fibre type (Lefaucher & Vigneron, 1986). For example, Candek-Potokar, Lefaucheur, Zlender and Bonneau (1999)

reported only CSA of β-red (red), α white (white) fibres, but not of α-red (intermediate) fibres in pigs *m. longissimus dorsi* increased at heavier weight.

Histochemical analysis indicated that the goats' LD and SM samples evaluated in this study were dominated by red fibres (Figs 4.2A & B). These muscles are usually dominated by glycolytic (white) fibres in other species (Kirchofer et al., 2002; Bee et al., 2007; Hwang et al., 2010). The contrast between muscle fibre profiles of goats in this study to those cited for other species shows that goats are unique and should not be viewed as a variation of lamb. Between the breeds, the LD samples of indigenous goats had a higher percentage of red fibres than the corresponding muscle of Boer goats (Table 4.3; Fig 4.2A). Marichal et al. (2003) reported that the proportion of oxidative fibres in *m. longissimus* of Spanish goats decreased as body weight increased, probably as a result of general differentiation pathway of muscle fibre types during the early stages of muscle hypertrophy (Lefaucher & Vigneron, 1986). In this study, there was no relationship between live weight and the percentage of fibre types in both the LD and SM that could substantiate this claim (Appendix A.1).

In some studies, the *m. longissimus dorsi* and *m. semimembranosus* have been used together for meat quality evaluation (Babiker et al., 1990; Schonfeldt et al 1993a; Simela, 2005). In species such as cattle, there are indications that the *m. longissimus* and *semimembranosus* are of similar type (Kirchofer et al., 2002). However, the results of this study showed that there may be variations in fibre characteristics between the *m. longissimus* and *m. semimembranosus* of goats (Table 4.4). Therefore any biochemical analysis and meat quality evaluation based on one of these muscles should not be extended to the other.

Muscle fibre composition has been shown to be an important determinant of meat quality (Hwang et al., 2010). In this study, correlation analysis showed that fibre characteristics may have an implication on the quality of meat. There were positive correlations between fibre cross sectional area and drip losses of LD samples (Table 4.47). It can only be speculated that

muscles with larger cross sectional areas have more intramuscular fat which contributed to drip losses (Larzul, Lefaucheur, Ecolan, Gogue, Talmant, Seiller, LeRoy & Monin, 1997). In SM samples, the correlation analysis indicated that increasing the size of muscle fibres may result in lower pH_u, reduced thawing losses and deoxymyoglobin pigments and conversely increased the oxymyglobin pigments (Table 4.47). Although the correlations obtained in this study suggest that increasing the size of muscle fibres may result in meat with better objective properties, the universal relation between fibre size and meat quality still remains controversial (Lefaucheur, 2010).

In LD samples, there was a negative relationship between the percentage of white fibres and Chroma (Table 4.47). This finding is consistent with the fact that white fibres have less myoglobin content which give them a lighter appearance than red fibres (Lefaucheur, 2010). In addition, a negative correlation between the percentage of white fibres and metmyoglobin supports the notion that increasing glycolytic fibres improve colour stability (Hwang et al. 2010). The percentage of white fibres was inversely correlated the WBSF value of LD samples (Table 4.47), as previously reported by Karlsson, Enfält, Essén-Gustavsson, Lundström, Rydhmer and Stern (1993) in pigs fed a low protein diet. It is known that white fibres are less susceptible to cold shortening due to an efficient calcium recapture system than red fibres (Smulders et al., 1990). A review by Ouali (1990) indicated that the rate of proteolytic degradation is faster in white muscles than in red muscles. Any of the above mentioned factors could explain the negative correlations between the percentage of white fibres and WBSF of LD samples. The inverse correlations between the percentage of red fibres and both the sarcomere length and L* of SM samples (Table 4.47) confirm the detrimental effects of increasing the percentage of red fibres at the expense of white fibres.

5.3 Biochemical changes in *post mortem* muscles of goats

Glycolysis is the key process in the conversion of muscle to meat (Scheffler & Gerrard, 2007). However very few studies, if any, have attempted to investigate the biochemistry controlling the development of goat meat quality. This section discusses the biochemical changes in *post mortem* muscles of goats under electrical stimulation or delayed chilling conditions. This information improves our knowledge on the biochemical processes underlying the conversion of muscle to meat in goats.

5.3.1 Muscle energy status at slaughter

The acidification of meat is closely related to the muscle energy status at slaughter (Scheffler & Gerrard, 2007). During the course of *post mortem* energy metabolism, creatine phosphate is the first metabolite to be degraded in order to maintain the muscle energy levels. Glycolysis proceeds after creatine phosphate has been reduced to approximately 30% of its rest value (Scheffler & Gerrard, 2007). In this study, the initial muscle creatine phosphate in both the LD and SM samples (Table 4.5) were close to the average value reported by Simela et al. (2004b) for the *m. longissimus thoracis* of South Africa indigenous goats (3.74 ± 1.74 µmol/g), collected at 15 minutes *post mortem*. In bovine muscles, creatine phosphate content at slaughter varies between 13.1 to 23 µmol/g (Pearson & Young, 1989). This could be different for small stock such as goats, hence the relatively low concentrations of creatine phosphate observed in this study. In addition, the initial samples were collected at ~15 minutes *post mortem*. This delay in sampling could have contributed to the low creatine phosphate levels, as energy levels decrease rapidly after slaughter (Scopes, 1974). Another possibility is that anaerobic metabolism was pronounced in the *ante* and *peri mortem* phase, causing an early depletion of muscle creatine phosphate (Hertzman, Olsson & Tornberg, 1993). The low creatine phosphate

content at slaughter could imply that there was no delay phase in glycogen degradation and consequently ATP depletion (Schafer, Rosenvold, Purslow, Andersen & Henckel, 2002).

The rate and extent of *post mortem* glycolysis depends on muscle glycogen content at slaughter (Immonen et al., 2000). Insufficient muscle glycogen, limits the acidification of meat, resulting in high pH and in extreme cases, DFD meat (Fabiansson & Reuterswärd, 1984). In bovine muscles, at least 40 - 45 µmol/g of glycogen is required for the normal acidification of meat (Immonen et al., 2000). However, the critical threshold value for pre-slaughter muscle glycogen has not been established in goats. Stress has been implicated as the main cause of *ante mortem* glycogen depletion (Ferguson & Warner, 2008). In the present study, feed withdrawal time was minimised in an attempt to limit *ante mortem* stress. However, the initial glycogen concentrations were relatively low in both the LD and SM samples (less than 24 µglycosyl units/g; Table 4.8). Kannan et al. (2003) reported glycogen concentration of ~20 µmol/g for the *m. longissimus* of transport-stressed young Alpine goats (6 - 12 months old) in comparison to 40 µmol/g for corresponding muscles of unstressed young goats. The relatively low concentrations of muscle glycogen observed in this study could be due to a delay in initial sampling, or probably the goats were susceptible to inevitable *ante mortem* stress associated with pre-slaughter handling.

As outlined in Fig 2.3 (§2.4.2) glucose and glucose-6-phosphate are intermediates of glycolysis. Thus the concentration of these metabolites in a muscle are an indication of the rate at which glycolysis proceeds. The initial glucose (Table 4.11) and glucose-6-phosphate (Table 4.14) levels observed in the present study were within the range published by Simela et al. (2004b) for the *m. longissimus thoracis* of indigenous South African goats (5.17 ± 0.74 µmol/g). However, the latter authors reported a higher average glucose-6-phosphate concentration (1.25 ± 0.60 µmol/g) than observed is the present study. Perhaps the muscles evaluated in this study were more efficient in maintaining their levels, as indicated by higher

initial ATP concentrations (Table 4.17) than previously reported by Simela et al. (2004b). In addition, the initial ATP levels observed in this study were within the range of 5.7-8.7 µmol/g, stated by Pearson and Young (1989) for a relaxed muscle.

The initial lactate levels observed in this study (Table 4.20) compares well to lactate values reported by Simela et al. (2004b) in *m. longissimus* of South African indigenous goats (30.19 ± 10.57 µmol/g). According to Pearson and Young (1989), the initial lactate levels for the *m. longissimus* of cattle falls within a range of 6 µmol/g to 16 µmol/g. The high muscle lactate levels observed in this study could either be related to a delay in sampling or is an indication of pronounced *ante* and/or *peri mortem* anaerobic metabolism, as mentioned for low muscle glycogen content.

5.3.2 The effect of breed on muscle energy metabolism

At slaughter, the indigenous and Boer goats had similar muscle (both LD and SM) energy levels (Figs 4.3 to 4.8). As mentioned above, the low concentration of muscle creatine phosphate, glycogen and high lactate observed at slaughter, indicate that the goats used in this study were metabolically exhausted (Hertzman et al., 1993), possibly from the psychological stress associated with the transportation from the farm to the abattoir (Kannan et al., 2000). Further studies should consider transportation and lairage conditions that would minimise *ante mortem* stress.

The two goat breeds exhibited similar energy metabolism patterns in early *post mortem* (Figs 4.3 to 4.8), but the muscles of Boer had higher residual creatine phosphate (Table 4.5) and ATP (Table 4.17). Comparison of muscles showed than the SM had lower residual glycogen and glucose concentration than the LD (Table 4.26). These results are evidence to suggest that *post mortem* glycolysis progressed to a different extent in each breed and muscle type (Lawrie, 1953). The observed breed and muscle differences in the concentration of

residual energy metabolites (creatine phosphate, ATP and glycogen) may not have contributed to variation in any meat quality trait, as suggested by the weak correlations (Table 4.48).

5.3.3 The effect of carcass treatment on muscle energy metabolism

Electrical stimulation has been reported to accelerate muscle energy metabolism, allowing rapid chilling of goat carcasses without the risk of cold shortening (Kondos & Taylor, 1987). In this study, electrical stimulation had an immediate effect on energy content of LD samples, showing a rapid depletion of creatine phosphate (Table 4.6 and Fig 4.3A), glycogen (Table 4.9 and Fig 4.4A) and ATP (Table 4.18 and Fig 4.7A) content with a corresponding increase lactate concentration (Table 4.21 and Fig 4.8A). Electrical stimulation further accelerated muscle energy metabolism for at least 3 hours *post mortem*. These results are in agreement with those of Rhee and Kim (2001), who reported a rapid energy metabolism during the first 3 hours of electrical stimulation. The SM samples did not show much differences in the rate of glycogen degradation (Table 4.9 and Fig. 4.4B) or ATP depletion (Table 4.18 and Fig 4.7B). However, the increased early *post mortem* glucose (Table 4.12 and Fig 4.5B) and lactate concentration (Table 4.21 and Fig 4.8B), support the notion that electrical stimulation accelerated the rate of early *post mortem* muscle energy metabolism.

5.3.4 Regulation of *post mortem* glycolysis

Biochemical studies of this nature are crucial in identifying enzymes which are rate-limiting during *post mortem* glycolysis. It has been postulated that different enzymes may be rate-limiting at different times during the conversion of muscle to meat (Scheffler & Gerrard, 2007). In the present study, electrical stimulation increased glucose-6-phosphate concentration, in LD samples during the first 3 hours *post mortem* (Fig. 4.7A). In contrast, glucose-6-phosphate concentration in delayed chilling treatment decreased during the same period of time

and then increased afterwards. The early increase in glucose-6-phosphate observed in LD samples of electrical stimulation treatment is indicative of increased *glycogen phosphorylase* activity, when glycogen was rapidly degraded (Bendall, 1979). Similarly, Kastenschmidt et al. (1968) previously reported that "slow glycolysing" muscles had lower glucose-6-phosphate concentrations than "fast glycolysing" muscles during the first hour *post mortem* and later rebounded to levels equal to or higher than the initial levels. In the present study, the decrease in early *post mortem* glucose-6-phosphate concentration observed in LD samples of delayed chilling treatment adds support to the concept that *glycogen phosphorylase* is rate-limiting in early *post mortem* glycolysis (Hammelman et al., 2003). Since there was no stimulus for glycogen breakdown, the higher levels of ATP in delayed chilling treatment may have inhibited the activity of *glycogen phosphorylase*. Therefore the available pool of glucose-6-phosphate was rapidly metabolised. Loss of enzyme inhibition due to glycogen breakdown could have caused the rebound of glucose-6-phosphate that was observed at 24 hours *post mortem* in LD samples of delayed chilling treatment.

Glycolysis stops when all glycogen reserves have been used up or due to inactivation of the glycolytic enzymes by low pH (Scopes, 1974). In the present study, the residual glycogen concentrations were similar between the two carcass treatments, in both LD and SM samples (Table 4.9). In addition, the glycolytic metabolites were not completely exhausted at 24 hours *post mortem*. Frylinck, Strydom, Webb and du Toit (2013) reported a similar phenomenon in *m. longissimus dorsi* of various cattle breeds. These researchers concluded that either the muscles did not attained full *rigor mortis* or the normal glycolytic process was affected by number of *ante* and *peri mortem* interventions. Another possible explanation is that *phosphofructokinase* may have exerted some glycolytic control before exhaustion of glycolytic metabolites (England et al., 2014). *Phosphofructokinase* is a glycolytic enzyme, which requires ATP to convert fructose-6-phosphate into fructose 1.6 biphosphate (Scheffler & Gerrard,

2007). The activity of *phosphofructokinase* may have been hindered by lowered amounts of ATP and the rapid accumulation of lactate (Hamm, 1977). The results on the metabolic concentrations at 24 hours *post mortem*, support *phosphofructokinase* as a rate limiting enzyme in the later stages of *post mortem* glycolysis (Hammelman et al., 2003).

Scheffler, Matarneh, England and Gerrard (2015) raised the possibility that mitochondria participate in energy production *post mortem* and play a role in controlling the extent of pH decline. In the present study, despite low glycogen content at slaughter, the goat muscles had high GP values (Table 4.23). In addition, the pH_u values were within the range acceptable for normal meat. Muscle fibre composition indicated that goat muscles evaluated in this study contained primarily oxidative fibres (Figs. 4.2A & B). Oxidative fibres are known to have an increased mitochondrial content (Lefaucheur, 2010). Therefore the possibility of mitochondrial function in extending *post mortem* metabolism cannot be dispelled.

5.4 Kinetics of pH and temperature decline in goat muscles

It is known that controlling the rate of pH and temperature decline prior to the onset of *rigor mortis* is crucial for improved meat quality (Hannula & Puolanne, 2004). In this study, the rates of pH and temperature decline were monitored in carcasses of the indigenous and Boer goats under electrical stimulation or delayed chilling conditions. The purpose was to investigate slaughter conditions that would improve the conversion of muscle to meat in goat carcasses.

5.4.1 The rate and extent of pH decline in goat muscles

Both the rate and extent of pH decline are known to affect the development of key meat quality attributes (Scheffler & Gerrard, 2007). Ideally, pH should drop from neutral to a pH_u of 5.3 - 5.7 (Briskey & Wismer-Pedersen, 1961). In the present study, pH dropped from ~6.6

to pH_u of 5.71 - 5.80. The pH_u values for this study, corresponded to the values previously reported for various goat breeds (Dhanda et al., 2003; Simela et al., 2004a; Pratiwi et al., 2007). In beef muscles, a pH_u of 5.5 results in meat with desirable eating quality, whilst muscles with a pH higher than 5.8 are classified as being DFD (Tarrant & Sherington, 1980). This has not been established in goats, but Simela et al. (2004a) reported a tendency towards the DFD condition for chevon with a pH_u higher than 6.

Glycolytic potential can be used to predict the pH_u of meat (Maribo et al., 1999b). In bovine muscles, there is a GP threshold of approximately 100 µmol/g, below which result in high pH meat whilst values less than 70 µmol/g are associated with the DFD condition (Wulf et al., 2002). In goats, Simela et al. (2004b) reported GP values above 100 µmol/g for goat meat with normal pH and high pH meat had an average GP value of 87 µmol/g. In the present study, the GP values at 24 hours *post mortem* were between 80 and 100 µmol/g, corresponding to pH_u between 5.7 and 5.8. Accordingly the pH values for this study were marginally higher than the recommended pH for desirable meat quality, but not in the DFD region.

The pH measured at 3 hours *post mortem* has been used as an indicator of the rate of glycolysis (Simela et al., 2004). Slow glycolytic rate (pH measured at 3 hours *post mor*tem higher than 6.3) leading to high pH_u (pH higher 5.8), results in dark meat with a tendency towards the DFD condition (Simela et al., 2004a). In the present study, the rate of pH decline was relatively slower in the LD of indigenous goats than that of Boer goats (Table 4.27). However, muscles (both LD and SM) of both goat breeds exhibited intermediate glycolytic rates (pH_3 in the range of 6.1 - 6.3), as stated by Simela et al. (2004).

The results on the effect of electrical stimulation on pH decrease (Table 4.28) seem to agree with the results of King et al. (2004) and Kadim et al. (2010). These researchers reported that electrical stimulation of goat carcasses led to rapid pH decline during the first 4 - 6 hours.

Other studies have indicated that electrical stimulation affects both the rate and extent of pH decline in goat carcasses (Cetin & Topcu, 2009).

5.4.2 The relationship between muscle pH and temperature at the onset of *rigor mortis*

The muscle temperature when pH is 6 is an important determinant of meat tenderness and overall eating quality in lamb (Hopkins et al., 2011). It is known that cold shortening and subsequent muscle toughening may occur if muscle temperature drops to below 10 - 12 °C while pH is above 6 (Bendall, 1972). The known effects of pH/temperature combinations at the onset of *rigor mortis* has led to the development of the pH/temperature window concept, implemented by Meat Standards Australia in their beef and sheep carcass grading system, to identify carcasses at risk of heat or cold shortening (Thompson, 2002; Pearce et al., 2010). In order to avoid the heat or cold shortening window, carcass pH should drop from a pH greater than 6 to less than 6 whilst temperature is dropping from 35 °C to 12 °C. A similar concept was implemented in the present study to assess the usefulness of both electrical stimulation and delayed chilling as strategies of minimising cold shortening in goat carcasses. The pH-temperature profiles indicate that cold shortening did not occur in both slaughter conditions set for this study (Fig 5.1). However, it seems that that delaying for too long before chilling might also induce cold shortening of carcasses.

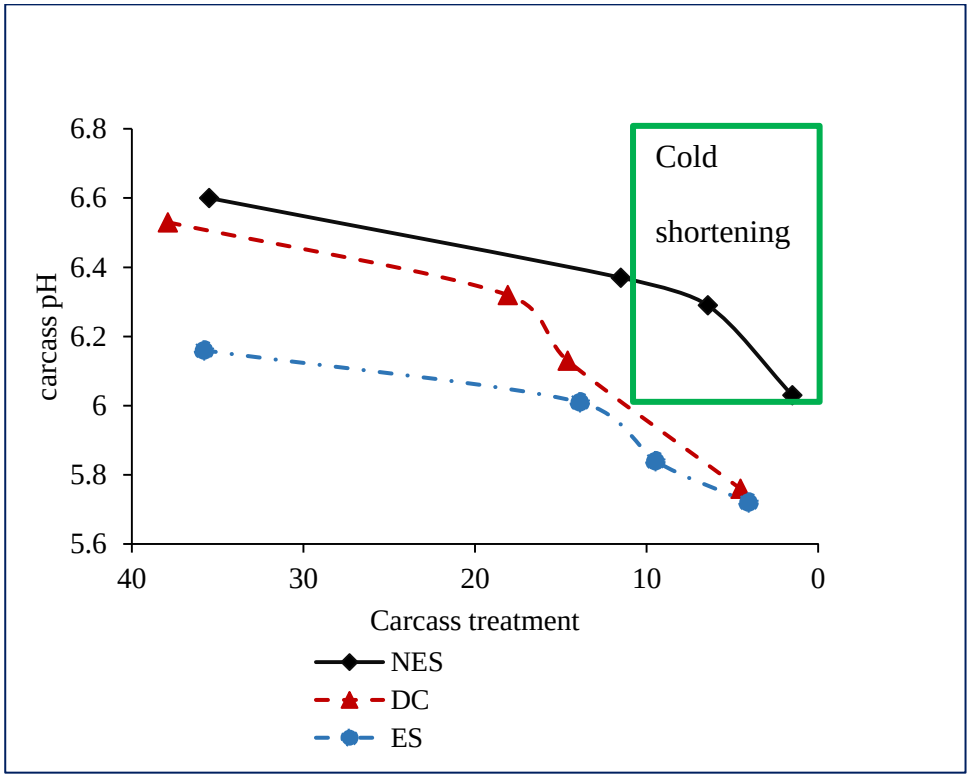


Figure 5.1 The pH/temperature window showing the decline in carcass pH in relation to carcass temperature in three scenarios, namely electrical stimulation (ES), delayed chilling (DC) and non-electrical stimulation treatment (NES). Data for non-electrical stimulation treatment was adapted from Simela (2005). Cold shortening window according to Pearson & Young (1989), as discussed in the review of Thompson (2002).

5.5 Objective properties of goat muscles

Quality attributes associated with visual appeal and palatability are considered as key factors that determine the acceptability and continued interest in the product (Maltin et al., 1997). In the present study, indices related to visual appearance (colour and water holding capacity) and palatability (juiciness and tenderness) were used to explain variation in the quality of goat meat between breeds, carcass treatment and their combinations.

5.5.1 Water holding capacity and juiciness of goat meat

The average values for WHC as indicated by the amount of juice expressed were within the range reported by Kadim et al. (2003) in their study with various muscles of the Batina, Dhofari and Jabal Akhdar goat breeds. Water holding capacity was not affected by breed (Table 4.34) as previously reported by the latter authors.

In contrast to the findings of this study (Table 4.35), electrical stimulation with variable voltages (35, 110, 330, 550 and 1100) has been previously reported to reduce the water holding capacity of goat meat (Biswas et al. 2007). In the study of Biswas et al. (2007) electrical stimulation was applied for 3 minutes, whereas in the present study, electrical stimulation was applied for a short duration (30 seconds) in order to minimise tissue damage. It is known that pH_u is the main factor that influence the meat's WHC (Bouton et al., 1971), as supported by a positive correlation between WHC and pH_u of both the LD and SM (Table 4.49). In the present study electrical stimulation had no effect on both the pH_u and WHC of meat, an observation previously reported by Kadim et al. (2014) for the *m. longissimus* of unstressed Dhofari goats.

Thawing is known to exacerbate water loss in meat. There is limited information on thawing losses of goat meat, but Schönfeldt et al. (1993b) reported thawing losses lower than 1% in *m. longissimus thoracis et lumborum* and *m. semimembranosus* of Angora and Boer goats. The latter authors aged the meat samples for seven days prior to freezing which could have improved the WHC and minimised the thawing losses (Kristensen & Purslow, 2001).

Meat's juiciness is the moisture sensation of the cooked product and it is directly related to the intramuscular fat and moisture content of the meat (Schönfeldt et al., 1993a; Aaslyng, Bejerholm, Ertbjerg, Betram & Andersen, 2003). Generally, goat muscles have low intramuscular fat content, hence they tend to have low drip losses and high evaporative losses during cooking (Casey, 1992). In the present study, the average values for cooking losses were

marginally higher than values for the *m. longissimus dorsi* of Spanish and cross breed goats (15 - 16%) previously reported by Gadiyaram et al. (2008). Other studies have reported higher cooking losses than observed in the present study. For example, Kadim et al. (2003) reported cooking losses of 29.9 - 33.6% for the *m. longissimus* and *m. semimembranosus* of three Omani goat breeds. Pratiwi et al. (2007) reported cooking losses as high 40% for the *m. longissimus thoracis* of Feral goats. Variation in cooking losses reported in different studies can be attributed to the method, time and temperature of cooking, pH_u and the muscle used.

Breed had no effect on cooking loss of goat meat (Table 4.34), as previously reported (Madruga, Torres, Carvalho, Queiroga, Narain, Garrutti, Neto, Mattos and Costa, 2008). Electrical stimulation led to an increase in evaporative and cooking losses of LD samples (Table 4.35). Bouton, Fisher, Harris and Baxter (1973) reported lower cooking losses in stretched muscles than in contracted muscles. Palka and Daun (1999) reported inverse correlations between sarcomere length and cooking losses. However, in the present study, the relationship between sarcomere length and cooking loss of LD samples was weak to substantiate any claim (Table 4.50).

Comparison of muscles showed that the LD samples had higher moisture content (higher WHC and lower thawing and cooking losses) than the SM samples (Table 4.46). Other authors have also reported non-significant differences in expressible moisture between the *m. longissimus dorsi* and the *m. semimembranosus* of goats (Schönfeldt et al., 1993b).

5.5.2 Surface myoglobin redox forms

Very few studies have been conducted to quantify surface myoglobin redox forms of goat meat, despite their importance in determining meat colour (Brewer, 2004). For instance, accumulation of metmyoglobin fractions is known to be the basis for meat discolouration (Mancini & Hunt, 2005). In this study, the metmyoglobin percentages for both LD and SM

(Table 4.39) were lower than values previously reported by Kannan et al. (2001) for various muscles of Spanish does (26.5 - 28.7%). Considering that consumer rejection may occur at metmyoglobin as low as 20% (Hood & Riordan, 1973), the goat meat samples evaluated in this study were not visibly discoloured at 1 day *post mortem*. However, ageing may have a negative influence on the colour of goat meat, as previously reported (Kannan et al., 2001).

The LD samples of delayed chilling treatment had reduced deoxymyoglobin fractions which resulted in an increase in both oxy- and metmyoglobin fractions (Table 4.38), corresponding to higher instrumental colour values (Table 4.41). These results supports the notion that *rigor* temperature may have an influence on the development of meat colour (Janz, Aalhus, Price & Schaefer, 2000). Correlation analysis indicated that deoxymyoglobin pigments in LD samples decreased whilst oxymyoglobin pigments increased at elevated early *post mortem* temperatures (Table 4.49). It is therefore possible that the elevated temperatures of delayed chilling treatment may have created conditions that inactivate or exhaust the enzyme systems and intermediates, which are associated with the respiratory pathway (Atkinson & Follett, 1973). The surviving respiratory enzymes are known to compete with myoglobin for oxygen uptake, causing the muscle to remain dark even after blooming (Kadim et al., 2006).

The correlation analysis show that the formation of oxymyoglobin was coupled by an increase in metmyoglobin (Table 4.50). This finding can be related to the fact that myoglobin is either oxygenated to oxymyoglobin or oxidised to metmyoglobin, on exposure to oxygen (Mancini & Hunt, 2005). According to Kannan et al. (2014), goat meat is high in PUFAs, which could make the meat more susceptible to both lipid and myoglobin oxidation. Thus it is possible that the rapid formation of metmyoglobin may have reduced the depth of oxygen penetration in goat meat samples evaluated in this study.

The LD samples were less discoloured than the SM samples (Table 4.46). Correlation analysis indicate that reduced metmyoglobin on the surface of LD samples may be attributed

to an increase in the percentage of white fibres (Table 4.47). This finding is in agreement with Faustman, Sun, Mancini and Suman (2010) that oxidative muscles appear to discolour more quickly. In this study, the LD samples had a higher percentage of white fibre and a lower percentage of intermediate fibres (Table 4.4), hence they were less oxidative and therefore less discoloured than the SM samples.

5.5.3 Instrumental colour of goat meat

Meat colour is an important characteristic by which the consumers judge the quality and acceptability of meat (Bekhit & Faustman, 2005). A bright red colour is the usual consumer preference for red meat. The instrumental colour values obtained in this study compares well to values previously reported for chevon of various goat breeds (Table 2.3). For example, the average L* values (lightness) were within the range reported by Kadim et al. (2006) for various muscles of Omani goat breeds (31.9 - 42.1). The average a* values (redness) were close to the values reported by Kannan et al. (2001) for various muscles of Spanish does (16.2 - 17.8). The average b* values (yellowness) were similar to those reported by Lee et al (2008b) for the *m. longissimus dorsi* of cross breed goats (11.1 - 12.5).

Previous studies have shown that there may be little or no variation in the colour of goat meat and that of lamb/mutton (Babiker et al., 1990; Sen et al., 2004). Considering the established threshold values for acceptable lamb colour (Khliji, van de Ven, Lamb, Lanza & Hopkins, 2010), the goat meat samples evaluated in this study presumably had the preferred bright red meat colour, since the L* and a* values were above 35 and 9.5, respectively. Animals exposed to chronic *ante-mortem* stress are known to yield high pH meat with lower L* values (dark meat). For example, Kadim et al. (2006) reported a pH of 6.02 and a corresponding L* value of 31.9 for the *m. longissimus dorsi* of transport stressed Batina goats, whilst muscle with a pH values lower than 6 had L* values higher than 34.

It is generally recognised that the main factor influencing meat colour is the pH_u, therefore any treatment designed to promote a rapid *post mortem* pH decline has the potential to cause the development of brighter and more red meat (Abril, Campo, Önenç, Sañudo, Albertí & Negueruela, 2001). Although electrical stimulation had been reported to accelerate the rate and extent of pH, its efficiency in improving the colour of goat meat colour has not been established (King et al., 2004; Gadiyaram et al., 2008; Cetin et al., 2012). In the present study, the LD samples of delayed chilling treatment were brighter and intensely red (higher L*, a*, Chroma values) than corresponding samples of electrical stimulation treatment (Table 4.41). These results concur with those of Janz et al. (2000) who reported that holding carcasses at elevated temperatures (above 10 - 12 °C) at the onset of *rigor mortis* resulted in meat with a brighter and of more intense red colour than rapidly chilled carcasses.

Comparison of muscles indicated that the LD had better colour scores than the SM. Similarly, Kadim et al., (2003) reported higher L* values in the *m. longissimus dorsi* relative to *m. semimembranosus* of the Batina and Jabal Khadar goat breeds.

5.5.4 Muscle contraction and meat tenderness

The toughness of goat meat is believed to be caused by excessive sarcomere shortening during normal chilling conditions (Webb et al., 2005; Kadim & Mahgoub, 2012; Kannan et al., 2014). Studies in other species have shown that muscles with longer sarcomeres are more tender than those with shorter sarcomeres (Kerth et al., 1999), although such relationship is not universal (Smulders et al., 1990; Veiseth et al., 2004). Marsh and Leet (1966) reported that 20% shortening in sarcomeres caused negligible effects on beef tenderness. If a resting sarcomere is 2.2 µm long (Marsh & Leet, 1966), then the sarcomeres in the present study shortened by about 5 - 10%. This percent shortening was within the range associated with increased meat tenderness (Wheeler et al., 2000). Simela (2005) obtained sarcomere lengths of

1.77 ± 0.15 µm for non-stimulated *m. longissimus thoracis et lumborum* of South African goats, a value corresponding to 20 - 40% shortening, which associated with muscle toughening (Marsh & Leet, 1966). It is therefore possible that the slaughter procedures (both electrical stimulation and delayed chilling) applied in this study were effective in counteracting the effects of cold shortening. In both the LD and SM samples there was no relationship between WBSF values and sarcomere lengths (Table 4.50), an indication that muscle toughening was independent of sarcomere lengths.

Breed had no effect on sarcomere lengths, but the SM samples of Boer goats were more tender than those of indigenous goats (Table 4.43). According to Kadim et al. (2003) breed differences in goat meat tenderness may be due to variations in connective tissue content. Between the two treatments, the LD samples of electrical stimulation treatment had shorter sarcomeres than corresponding samples of delayed chilling treatment, but the WBSF values were not different between the two carcass treatments (Table 4.44). This tendency has been previously reported with the use of high voltage (580 V) electrical stimulation in *m. longissimus dorsi* samples of Spanish goats (Gadiyaram et al., 2008).

The WBSF of LD samples obtained in this study compares well to the values reported by Gadiyaram et al (2008) in *m. longissimus dorsi* samples of Spanish and crossbreed goats. Studies in other species have shown that WBSF values are closely associated with consumer acceptability. For example, Shackelford, Morgan, Cross and Savell (1991) found that meat with a shear force value of less than 5.5 kg is often considered to be tender by consumers. Many researchers have used the WBSF value of 5.5 kg as a determinant of chevon tenderness (Johnson et al., 1995; Dawkins, McMillin, Phelps, Gebrelul, Beyer & Howard, 2000; Sen et al., 2004; Santos et al., 2008; Bonvillani, Peña, Domenech, Polvillo, García & Casal, 2010). In this study the LD samples of both electrical stimulation and delayed chilling treatment would presumably have an acceptable degree of tenderness at 24 hours *post mortem* (WBSF between

4.0 and 4.5 kg). This finding may partly be ascribed to the fact that the *m. longissimus dorsi* is inherently tender with low insoluble collagen content (Torrescano et al., 2003). Kadim et al. (2014) reported shear force values in the range of 6.7 - 10 kg for *m. longissimus dorsi* of rapidly chilled goat carcasses. These workers attributed the increased goat meat toughness to excessive sarcomere shortening (sarcomeres of 1.4 - 1.6 µm) under normal chilling conditions. In the present study, prevention of cold shortening by both electrical stimulation and delayed chilling of carcasses may contributed to the increased tenderness of the LD samples. Another possible explanation is related to the proteolytic enzyme activity in both slaughter procedures. A combination of lower pH and higher temperature, is known to stimulate µ-calpain-mediated proteolysis (Hwang, Park, Cho & Lee, 2004). It can only be speculated that the tenderness of LD samples was due to either of the above-mentioned factors or their combinations.

Simela (2005) reported WBSF value of 74.81 N (7.63 kg) for the non-electrically stimulated SM, a value lower than observed in delayed chilling treatment, but higher than obtained for electrical stimulation treatment, for the same muscle (Table 4.43). The results of this study show that electrical stimulation improved meat tenderness more than delayed chilling (Fig 4.13B). The difference in WBSF values with no change in sarcomere lengths (Table 4.43) corroborates with workers who have indicated that electrical stimulation improve meat tenderness by means other than counteracting the effects of cold shortening (Savell et al., 1978; King et al., 2004; Gadiyaram et al., 2008).

The efficiency of electrical stimulation in improving the tenderness of goat meat is well documented (King et al., 2004; Gadiyaram et al., 2008; Cetin et al., 2012; Kadim et al., 2014). In the present study, the effectiveness of electrical stimulation in improving meat tenderness was different between the two goat breeds, with the SM of Boer goats responding better to electrical stimulation than the corresponding muscle of indigenous goats (Table 4.45). This variation may be related to breed differences in connective tissue content (Smith, Dutson,

Hostetler & Carpenter, 1976) and /or the proteolytic activity (Ferguson, Jiang, Hearnshaw, Rymill & Thompson, 2000) in these muscles. Since meat tenderness was evaluated on samples collected at 24 *post mortem*, ageing may further improve tenderness of goat meat (Kadim et al., 2003). In the present study, the effects of ageing on goat meat quality could not be investigated because the goat muscles were very small and limited.

Comparison of muscles showed that the LD samples were more tender than the SM samples, as previously reported by Schönfeldt et al. (1993a). An increase in the percentage of white fibres may have contributed to the improved tenderness of LD samples (Tables 4.47), a fact was previously reported by Ryu and Kim (2005).

CHAPTER 6

6 CONCLUSIONS

6.1 Conclusions

Boer goats were heavier and their carcasses were heavier than those of indigenous goats. Dressing percentage was similar between the two goat breeds. However, chilling losses were marginally higher in carcasses of Boer goats that those of indigenous goats.

Histochemical analysis indicated that the goat muscles evaluated in this study were oxidative (red) in nature. There were some breed differences in muscle fibre characteristics. The LD samples of the indigenous goats had smaller and more oxidative fibres than the corresponding samples of Boer goats, but fibre characteristics of SM samples were similar between the two goat breeds. Histochemical properties of goat muscles varied between muscle types, with the *m. semimembranosus* being more oxidative than the *m. longissimus dorsi*.

The rate of early *post mortem* muscle energy metabolism was similar between the two goat breeds, however indigenous goats seemed to have extended energy metabolism patterns than Boer goats. Electrical stimulation accelerated the rate of pH decline and muscle biochemical changes, allowing rapid chilling of carcasses without the risk of cold shortening. Delayed chilling was effective in slowing the rate of temperature decline ensuring that the onset of *rigor mortis* occurs (pH = 6) at temperatures above 10 °C, thus minimising the risk of cold shortening. The measured sarcomeres (~ 2 µm long) confirmed that both electrical stimulation and delayed chilling were effective in minimising the risk of cold shortening in goat carcasses.

Breed was not a main factor pertaining to quality attributes such as colour, tenderness and juiciness of goat meat. The *m. longissimus dorsi* had better colour scores, greater moisture

content and lower shear force values than the *m. semimembranosus*. Electrical stimulation improved meat tenderness more than delayed chilling. However, delayed chilling of carcasses gave better meat colour scores than electrical stimulation.

This study has shown that there is potential to market chevon as a product of acceptable colour and tenderness, if proper slaughter procedures are practised.

6.2 Recommendations

Some aspects of this section were presented at the 12th *Meat Symposium* held on 1 November 2014 in Pretoria, South Africa.

Pophiwa P. (2014). An evaluation of the South African goat carcass classification system. 12th *Meat Symposium*: *Relevance of the South African Carcass Classification Systems*, Pretoria, South Africa. Abstract available on Red Meat Research and Development South Africa website http://www.rmrdsa co.za in Proceedings of the 12th Meat Symposium, pp 18.

6.2.1 Suggestions for a new goat carcass classification system

In South Africa, goat carcasses are classified according to the South African Red Meat Carcass Classification System (RSA Government Notice no. R55 of 2015). This system uses age, level of fatness, conformation and degree of damage to predict meat yield and eating quality of a carcass. Since the adoption of this system in 1992, considerable changes have occurred in the production systems, slaughtering technologies and consumer demands and the system needs to be updated.

Firstly, the system uses age, as estimated by dentition, to predict meat tenderness. Carcasses of animals with no permanent teeth get better ratings than those with a higher number of permanent teeth. The use of "age" as the only indicator of meat tenderness is not very reliable

in goat carcasses. Various intrinsic and extrinsic factors coupled with *post mortem* handling procedures "overshadow" the effects of age on a meat tenderness (Strydom, 2011). In this study it had been demonstrated that controlling pH/temperature relationship during the conversion of muscle to meat can result in meat low shear force (improved meat tenderness), as previously reported by Devine, Payne, Peachey, Lowe, Ingram and Cook (2002). Since goat carcasses are prone cold shortening and subsequent muscle toughening during normal chilling conditions (Kannan et al., 2014), the present study showed that electrical stimulation and delayed chilling are some of the techniques that can be considered in order minimise the risk of cold shortening.

Secondly, seven fat classes denoted by numerals from 0 (no fat) to 6 (excessively fat) are used to predict the eating quality of a carcass. In this study, subcutaneous fat was not determined, but Simela (2005) reported subcutaneous fat levels of less than 5%, with goats similar to those used in the present study. Therefore, the use of "level of fatness" as a determinant of juiciness and flavour of meat should be reconsidered in a goat carcass classification system. Instead of promoting the leanness of goat carcasses, a criteria based on subcutaneous fat cover downgrades goat carcasses. Fat accretion in goats occur very late and only reaches considerable levels when the animals are near or at their mature body weight (Webb et al., 2005).

Thirdly, five conformation scores denoted by numerals from 1 (very flat) to 5 (very round) are used to predict meat yield of a carcass. The use of a "conformation score" to predict meat yield, is not relevant for classifying goat carcasses. Goats are smaller and they mature later than sheep, and a good conformation occur as they get older (reviewed by Webb et al., 2005). Due to the leanness of goat carcasses, carcass weight is considered to be the best predictor of meat yield and it should be included in a goat carcass classification system (Simela et al., 1999).

Although the inadequacies of the current South African red meat carcass classification makes its use for goat carcasses limited, it would appear to discriminate on all carcasses from young goats equally. A new criteria, which values the uniqueness of goats should be considered. This will ensure fair remuneration of goat farmers as well as meet the expectations of diverse consumers in South Africa.

6.2.2 Proposed model for improved quality of goat meat

Goats slaughtered in the commercial abattoirs of South Africa are quickly chilled at 0 - 4 °C, immediately after the dressing procedure (Simela, 2005). However this chilling method is not recommended for goat carcasses as it has deleterious effects on the ultimate quality of goat meat (reviewed by Webb et al., 2005; Kannan et al., 2014). The results of Simela (2005) showed that non-stimulated goat carcasses were susceptible to cold shortening (sarcomere lengths ~1.7 µm), under the above-mentioned chilling conditions. Considering the potential consumer acceptance of goat meat (Simela, Webb & Bosman, 2008), we cannot afford to have the adverse effects caused by inappropriate slaughter procedures.

Based on the findings of this study, it is recommended that the meat industry of South Africa develops guidelines for the production of goat meat with acceptable quality attributes. It is important to focus on techniques that have the potential to improve the meat quality of the local goat breeds. In the present study, electrical stimulation and delayed chilling were tested as strategies of improving the conversion of muscle to meat and the resultant meat quality traits of indigenous and Boer goats.

The findings of this study showed that electrical stimulation hastened early *post mortem* glycolytic rate allowing rapid chilling of carcasses without the risk of cold shortening. On the other hand, delayed chilling ensured that carcasses enter into *rigor mortis* at elevated temperatures (above 10 °C). Thus both electrical stimulation and delayed chilling of carcasses

were effective strategies of avoiding the deleterious effects associated with cold shortening of goat carcasses. The proposed model (Fig 6.1) for better could be implemented as a strategy to ensure better chevon quality. This study further showed that electrical stimulation could be more beneficial in improving the tenderness of goat meat, although delayed chilling would give better meat colour.

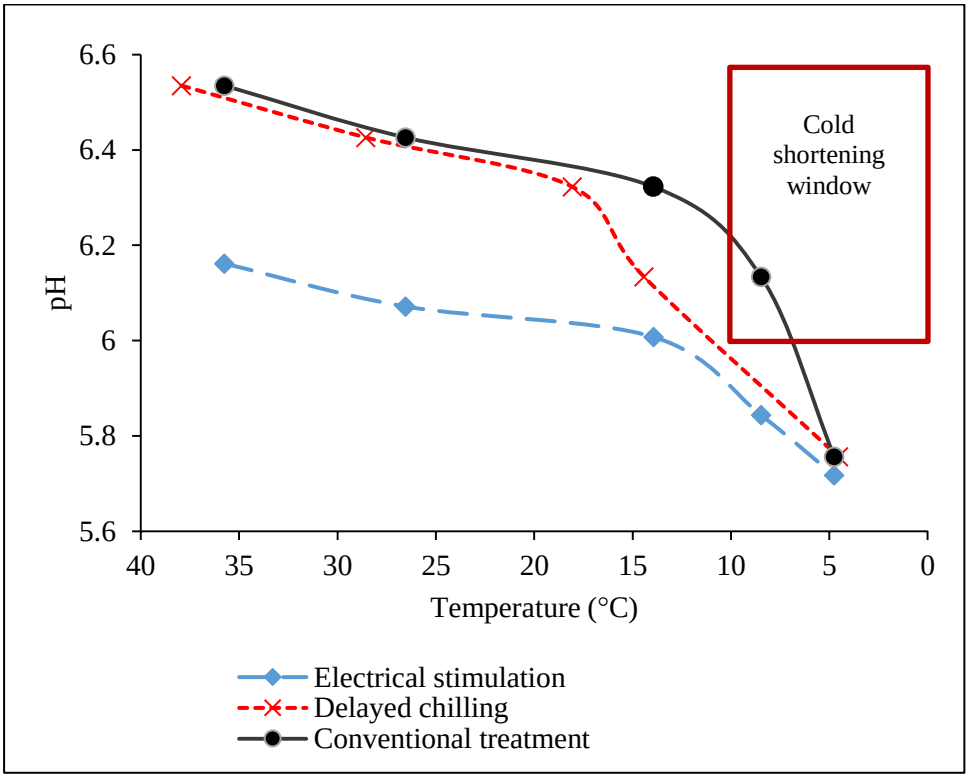


Figure 6.1 The proposed model for better goat meat quality, showing the decline in pH relation to carcass temperature, under electrical stimulation, delayed chilling or conventional chilling conditions. Data for the conventional treatment was adapted from Simela (2005). Cold shortening window according to Pearson & Young (1989), as discussed in the review of Thompson (2002).

6.2.3 Areas for further research

Optimum meat quality can only be guaranteed if most factors that affect meat quality along the production chain "from farm to fork" are controlled. Therefore, a holistic approach

which integrates good animal genetics, nutrition and management practises should be developed and implemented. Areas suggested for further research include:

1) Stress responsiveness of goats.
2) Conditions which would minimise *ante mortem* stress during transportation from farm to abattoir and in lairage.
3) The intensity and duration of electrical stimulation of goat carcasses which would produce better meat quality.
4) The effects of storage conditions and *post mortem* ageing on colour stability of goat meat.

CHAPTER 7

7 LIST OF REFERENCES

Aalhus, J.L., & Price, M.A. (1991). Endurance-exercise growing sheep: I. Post-mortem and histological changes in skeletal muscles. *Meat Science, 29*, 43-56.

Aaslyng, M.D., Bejerholm, C., Ertbjerg, P., Bertram, H.C., & Andersen, H.J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Quality and Preference, 14*, 277-288.

Abdullah A.Y., & Musallam, H.S. (2007). Effect of different levels of energy on carcass composition and meat quality of male black goat kids. *Livestock Science, 107,* 70-80.

Abril, M., Campo, M. M., Önenç, A., Sañudo, C., Albertí, P., & Negueruela, A. I. (2001). Beef colour evolution as a function of ultimate pH. *Meat Science, 58*, 69-78.

Apple, J.K., & Yancey, J.W.S. (2013). Water-holding capacity of meat. In C.R. Kerth (Ed.), *The Science of Meat Quality* (pp. 119-145). Oxford: John Wiley & Sons, Inc.

Argüello, A., Castro, N., Capote, J., & Solomon, M. (2005). Effects of diet and live weight at slaughter on kid meat quality. *Meat Science, 70*, 173-179.

Ashmore, C.R., & Doerr, L. (1971). Comparative aspects of muscle fiber types in different species. *Experimental Neurology, 31*, 408-418.

Atkinson, J.L., & Follett, M.J. (1973). Biochemical studies on the discoloration of fresh meat. *International Journal of Food Science and Technology, 8*, 51-58.

Babiker, S.A., El Khider, I.A., & Shafie, S.A. (1990). Chemical composition and quality attributes of goat meat and lamb. *Meat Science, 28*, 273-277.

Bee, G., Calderini, M., Biolley, C., Guex, G., Herzog W., & Lindemann, M.D. (2007). Changes in the histochemical properties and meat quality traits of porcine muscles during the

growing-finishing period as affected by feed restriction, slaughter age, or slaughter weight. *Journal of Animal Science, 85*, 1030-1045.

Bekhit, A.E.D., & Faustman, C. (2005). Metmyoglobin reducing activity. *Meat Science, 71*, 407-439.

Bendall, J.R. (1972). The influence of rate of chilling on the development of rigor and 'cold shortening'. In C.L. Cutting (Ed.), *Meat Chilling-Why and How?* (pp. 3.1-3.6.)Bristol: Meat Research Institute.

Bendall, J.R. (1979). Relations between muscle pH and important biochemical parameters during the post-mortem changes in mammalian muscles. *Meat Science, 3*, 143-157.

Biswas, S.D., Das, A.K., Banerjee, R., & Sharma, N. (2007). Effect of electrical stimulation on quality of tenderstretched chevon sides. *Meat Science, 75*, 332-336.

Bonvillani, A., Peña, F., De Gea, G., Gómez, G., Petryna, A., & Perea, J. (2010). Carcass characteristics of Criollo Cordobés kid goats under an extensive management system: Effects of gender and liveweight at slaughter. *Meat Science, 86*(3), 651-659.

Bouton, P., Fisher, A.L., Harris, P., & Baxter, R. (1973). A comparison of the effects of some post-slaughter treatments on the tenderness of beef. *International Journal of Food Science and Technology, 8*, 39-49.

Bouton, P.E., Ford, A.L., Harris, P.V., & Ratcliff, D. (1975). Objective assessment of meat juiciness. *Journal of Food Science, 40*, 884-885.

Bouton, P.E., Harris, P.V., & Shorthose, W.R. (1971). Effect of ultimate pH upon the water holding capacity and tenderness of mutton. *Journal of Food Science, 36*, 435-439.

Brandebourg, T. (2013). Growth of Muscle from the myoblast to whole muscle. In C.R. Kerth (Ed.), *The Science of Meat Quality* (pp. 1-21). Oxford: John Wiley & Sons, Inc.

Braden, K.W. (2013). Converting muscle to meat: The physiology of rigor. In C.R. Kerth (Ed.), *The Science of Meat Quality* (pp. 79-97). Oxford: John Wiley & Sons, Inc.

Brandstetter, A.M., Picard, B., & Geay, Y. (1998). Muscle fibre characteristics in four muscles of growing male cattle II. Effect of castration and feeding level. *Livestock Production Science, 53*, 25-36.

Brewer, S. (2004). Irradiation effects on meat color - a review. *Meat Science, 68*, 1-17.

Briskey, E.J., & Wismer-Pedersen, J. (1961). Biochemistry of pork muscle structure. I. Rate of anaerobic glycolysis and temperature change versus the apparent structure of muscle tissue. *Journal of Food Science, 36*, 297-305.

Brooke, M.H., & Kaiser, K.K. (1970). Three "myosin adenosine triphosphatase" systems: The nature of their pH lability and sulfhydryl dependence. *Journal of Histochemistry and Cytochemistry*, *18*, 670-672.

Bünger, L., Navajas, E.A., Stevenson, L., Lambe, N.R., Maltin, C.A., Simm, G., Fisher, A.V., & Chang, K.C. (2009). Muscle fibre characteristics of two contrasting sheep breeds: Scottish Blackface and Texel. *Meat Science, 81*, 372-381.

Čandek-Potokar, M., Lefaucheur, L., Zlender, B., & Bonneau, M. (1999). Effect of slaughter weight and/or age on histological characteristics of pig longissimus dorsi muscle as related to meat quality. *Meat Science, 52*, 195-203.

Carroll, M.A., & O' Carroll, F.M. (1964). Differences between left and right sides of lamb carcasses. *Irish Journal of Agricultural Research*, 223-237.

Casey, N.H. (1992). Goat meat in human nutrition. *Proceedings of the 5th International Conference on Goats*, New Delhi, India.

Casey, N.H., & Webb, E.C. (2010). Managing goat production for meat quality. *Small Ruminant Research, 89*, 218-224.

Cetin, Ö., Bingol, E.B., Colak, H., & Hampikyan, H. (2012). Effects of electrical stimulation on meat quality of lamb and goat meat. *Scientific World Journal*. 2012, Article ID 574202, 9 pages.

Cetin, Ö., & Topcu, T. (2009). Effects of electrical stimulation on meat quality in goat carcasses. *Journal of Food, Agriculture & Environment, 7*, 101-105.

Choe, J.H., Choi, Y.M., Lee, S.H., Shin, H.G., Ryu, Y.C., Hong, K.C., & Kim, B.C. (2008). The relation between glycogen, lactate content and muscle fiber type composition, and their influence on postmortem glycolytic rate and pork quality. *Meat Science*, *80*, 355-362.

Colomer-Rocher, F., Morand-Fehr, P., & Kirton, A.H. (1987). Standard methods and procedures for goat carcass evaluation, jointing and tissue separation. *Livestock Production Science*, *17*, 149-159.

Cornforth, D., 1994. Color-Its basis and importance. In: A.M. Pearson & T. R. Dutson (Eds.), *Quality Attributes and their Measurement in Meat, Poultry and Fish Products* (pp 34-78). London: Chapman and Hall.

Cornforth, D.P., Pearson, A.M., & Merkel, R.A. (1980). Relationship of mitochondria and sarcoplasmic reticulum to cold shortening. *Meat Science, 4*, 103-121.

Crouse, J.D., Koohmaraie, M., & Seideman, S.D. (1991). The relationship of muscle fibre size to tenderness of beef. *Meat Science*, *30*, 295-302.

DAFF (2012). *Profile of the South African goat market value chain* (research report). Pretoria, South Africa: National Department of Agriculture, Forestry and Fisheries. Retrieved from http://www.daff.agric.za.

Dalrymple, R.A., & Hamm, R. (1973). A method for the extraction of glycogen and metabolites from a single muscle sample. *International Journal of Food Science and Technology, 8*, 439-444.

Dawkins, N.L., Mcmillin, K.W., Phelps, O., Gebrelul, S., Beyer, A.J., & Howard, A. (2000). Palatability studies as influenced by consumer demographics and chevon characteristics. *Journal of Muscle Foods, 11*, 45-59.

Devendra, C. (2010). Concluding synthesis and the future for sustainable goat production. *Small Ruminant Research, 89*, 125-130.

Devine, C.E., Payne, S.R., Peachey, B.M., Lowe, T.E., Ingram, J.R., & Cook, C.J. (2002). High and low *rigor* temperature effects on sheep meat tenderness and ageing. *Meat Science, 60*, 141-146.

Dhanda, J.S., Taylor, D.G., McCosker, J.E., & Murray, P.J. (1999a). The influence of goat genotype on the production of Capretto and Chevon carcasses. 1. Growth and carcass characteristics. *Meat Science, 52*, 355-361.

Dhanda, J.S., Taylor, D.G., & Murray, P.J. (2003). Part 1. Growth, carcass and meat quality parameters of male goats: effects of genotype and liveweight at slaughter. *Small Ruminant Research, 50*, 57-66.

Dhanda, J.S., Taylor, D.G., Murray, P.J., & McCosker, J.E. (1999b). The influence of goat genotype on the production of Capretto and Chevon carcasses. 2. Meat quality. *Meat Science, 52*, 363-367.

Dreyer, J.H., Naudé, R.T., Henning, J.W.N., & Rossouw, E. (1977). The influence of breed, castration and age on muscle fibre type and diameter in Friesland and Afrikaner cattle. *South African Journal of Animal Science, 7*, I71-180.

Dreyer, J.H., van Rensburg, A.J.J., Naudé, R.T., Gouws, P.J., & Stiemie, S. (1979). The effect of chilling temperatures and mode of suspension of beef carcasses on sarcomere length and meat tenderness. *South African Journal of Animal Science, 9*, 1-9.

Egbert, W.R., & Cornforth, D.P. (1986), Factors Influencing Color of Dark Cutting Beef Muscle. *Journal of Food Science, 51*, 57–59.

England, E.M., Matarneh, S.K., Scheffler, T.L., Wachet, C., & Gerrard, D.E. (2014). pH inactivation of phosphofructokinase arrests post mortem glycolysis. *Meat Science, 98*, 850-857.

Fabiansson, S., & Reutersward, A.L. (1984). Glycogen determination in post-mortem beef muscles. *Food Chemistry*, *15*, 269-284.

FAO (2015). In *Food and Agriculture Organization of the United Nations* online. Retrieved on September 1, 2016, from http://fenix.fao.org/faostat/beta/en/#data/QA.

Faustman, C., Sun, Q., Mancini, R., & Suman, S.P. (2010) Myoglobin and lipid oxidation interactions: Mechanistic bases and control. *Meat Science, 86*, 86-94.

Ferguson, D.M., Jiang, S.-T., Hearnshaw, H., Rymill, S.R., & Thompson, J.M. (2000). Effect of electrical stimulation on protease activity and tenderness of M. longissimus from cattle with different proportions of Bos indicus content. *Meat Science, 55*, 265-272.

Ferguson, D.M., & Warner, R.D. (2008). Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? *Meat Science*, 80, 12-19.

Fernández, A.M., & Vieira, C. (2012). Effect of chilling applied to suckling lamb carcasses on hygienic, physicochemical and sensory meat quality. *Meat Science*, 92, 569-574.

Frylinck, L., Strydom, P.E., Webb, E.C., & du Toit, E. (2013). Effect of South African beef production systems on post-mortem muscle energy status and meat quality. *Meat Science*, 93, 827-837.

Gadiyaram, K.M., Kannan, G., Pringle T D., Kouakou B., McMillin K.W., & Park Y.W. (2008). Effects of postmortem carcass electrical stimulation on goat meat quality characteristics. *Small Ruminant Research, 78*, 106-114.

Gault, N.F.S. (1985). The relationship between water-holding capacity and cooked meat tenderness in some beef muscles as influenced by acidic conditions below the ultimate pH. *Meat Science, 15*, 15-30.

Gauthier, G.F. (1969). On the relationship of ultrastructural and cytochemical features to color in mammalian skeletal muscle. *Zeitschrift für Zellforschung und Mikroskopische Anatomie, 95*, 462-482.

Goetsch A.L., Merkel, R.C., & Gipson T.A. (2011) Factors affecting goat meat production and quality. *Small Ruminant Research*, 101,173-181

Gökdal, Ö. (2013). Growth, slaughter and carcass characteristics of Alpine × Hair goat, Saanen × Hair goat and Hair goat male kids fed with concentrate in addition to grazing on rangeland. *Small Ruminant Research, 109*, 69-75.

Griffin, C.L., Orcutt, M.W., Riley, R.R., Smith, G.C., Savell, J.W., & Shelton, M. (1992). Evaluation of palatability of lamb, mutton, and chevon by sensory panels of various cultural backgrounds. *Small Ruminant Research, 8*, 67-74.

Gutmann, I., & Wahlefeld, A.W. (1974). L-(+)-Lactate determination with lactate dehydrogenase and NAD. In H.U. Bergmeyer (Ed.), *Methods of enzymatic analysis (*pp 1464-1468). New York: Academic Press.

Hamm, R. (1975). Water-holding capacity of meat. In: D. J. A. Cole, & R. A Lawrie (Eds.), *Meat* (pp. 321-338). London: Butterworth.

Hamm, R. (1977). Post mortem breakdown of ATP and glycogen in ground muscle: A review. *Meat Science, 1*, 15-39.

Hammelman, J.E, Bowker, B.C, Grant, A.L., Forrest, J.C, Schinckel, A.P, & Gerrard, D.E. (2003). Early postmortem electrical stimulation simulates PSE pork development. *Meat Science, 63*, 69-77.

Hannula, T., & Puolanne, E. (2004). The effect of cooling rate on beef tenderness: The significance of pH at 7 ^{0}C. *Meat Science, 67*, 403–408.

Hegarty, P.V.J., & Naudé, R.T. (1970). The accuracy of measurement of individual skeletal muscle fibres separated by a rapid technique. *Laboratory Practice, 19*, 161-163.

Hertzman, C., Olsson, U., & Tornberg, E. (1993). The influence of high temperature, type of muscle and electrical stimulation on the course of rigor, ageing and tenderness of beef muscles. *Meat Science, 35*, 119-141.

Hogg, B.W., Mercer, G.J.K., Mortimer, B.J., Kirton, A.H., & Duganzich, D.M. (1992). Carcass and meat quality attributes of commercial goats in New Zealand. *Small Ruminant Research, 8,* 243-256.

Honikel, K.O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science, 49,* 447-457.

Honikel, K.O., Kim, C.J., Hamm, R., & Roncales, P. (1986). Sarcomere shortening of prerigor muscles and its influence on drip loss. *Meat Science, 16,* 267-282.

Honikel, K.O., Roncalés, P., & Hamm, R. (1983). The influence of temperature on shortening and rigor onset in beef muscle. *Meat Science, 8,* 221-241.

Hood, D.E., & Riordan, E.B. (1973). Discolouration in prepackaged beef: measurement by reflectance spectrophotometry and shopper discrimination. *International Journal of Food Science and Technology, 8,* 333-343.

Hopkins, D.L. (2011) Processing technology changes in the Australian sheep meat industry: an overview *Animal Production Science, 51,* 399–405

Hopkins, D.L., Toohey, E.S., Lamb, T.A., Kerr, M.J., van de Ven, R., & Refshauge, G. (2011). Explaining the variation in the shear force of lamb meat using sarcomere length, the rate of rigor onset and pH. *Meat Science, 88,* 794–796.

Hostetler, R.L., Link, B.A., Landmann, W.A., & Fitzhugh, H.A. (1972). Effect of carcass suspension on sarcomere length and shear force of some major bovine muscles. *Journal of Food Science, 37,* 132-135.

Huff-Lonergan, E., & Lonergan, S.M. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. *Meat science, 71,* 194-204.

Hunt, M.C., & Hedrick, H.B. (1977). Profile of fiber types and related properties of five bovine muscles. *Journal of Food Science, 42,* 513-517.

Hwang, Y-H., Kim, G-D., Jeong, J-Y., Hur , S-J., & Joo, S-T. (2010). The relationship between muscle fiber characteristics and meat quality traits of highly marbled Hanwoo (Korean native cattle) steers. *Meat Science, 86*, 456-461.

Hwang, I.H., Park, B. Y., Cho, S.H., & Lee, J.M. (2004). Effects of muscle shortening and proteolysis on Warner–Bratzler shear force in beef longissimus and semitendinosus. *Meat Science*, *68*, 497-505.

IBM SPSS, 2015. *IBM SPSS Statistics for windows version 23.0*. Armonk, NY: IBM, Corp.

Immonen, K., Ruusunen, M., & Puolanne, E. (2000). Some effects of residual glycogen concentration on the physical and sensory quality of normal pH beef. *Meat Science, 55*, 33-38.

Irie, M., Izumo, A., & Mohri, S. (1996). Rapid method for determining water holding capacity in meat using video image analysis and simple formulae. *Meat Science, 42*, 95-102.

Janz, J.A.M., Aalhus, J.L., Price, M.A., & Schaefer, A.L. (2000). The influence of elevated temperature conditioning on bison (Bison bison bison) meat quality. *Meat Science, 56*, 279-284.

Johnson, D.D., McGowan, C.H., Nurse G., & Anous M.R. (1995) Breed type and sex effects on carcass traits, composition and tenderness of young goats. *Small Ruminant Research, 17*, 57-63.

Joo, S.T., Kim, G.D., Hwang, Y. H., & Ryu, Y.C. (2013). Control of fresh meat quality through manipulation of muscle fiber characteristics. *Meat Science*, *95*, 828-836.

Kadim, I.T., & Mahgoub, O. (2012). Nutritive value and quality characteristics of goat meat. In O. Mahgoub, I.T. Kadim, & E.C. Webb (Eds.), *Goat Meat Production and Quality* (pp. 292-323). Oxfordshire/Cambridge: CABI.

Kadim, I.T., Mahgoub, O., Al-Ajmi, D.S., Al-Maqbaly, R.S., Al-Saqri, N.M., & Ritchie, A. (2003). An evaluation of the growth, carcass and meat quality characteristics of Omani goat breeds. *Meat Science, 66*, 203-210.

Kadim, I.T, Mahgoub, O., Al-Kindi, A., Al-Marzooqi, W., & Al-Saqri, N.M. (2006). Effects of transportation at high ambient temperatures on physiological responses, carcass and meat quality characteristics of three breeds of Omani goats. *Meat Science, 73*, 626-634.

Kadim, I.T, Mahgoub, O., & Khalaf, S. (2014). Effects of the transportation during hot season and electrical stimulation on meat quality characteristics of goat Longissimus dorsi muscle. *Small Ruminant Research, 121*, 120-124.

Kannan, G., Terrill, T.H., Kouakou, B., Gazal, O.S., Gelaye, S., Amoah, E.A., & Samake, S. (2000). Transportation of goats: effects on physiological stress responses and live weight loss. *Journal of Animal Science, 78*, 1450-1457.

Kannan, G., Gadiyaram, K.M., Galipalli, S., Carmichael, A., Kouakou, B., Pringle, T.D., McMillin, K.W., & Gelaye S. (2006). Meat quality in goats as influenced by dietary protein and energy levels, and postmortem aging. *Small Ruminant Research, 61*, 45-52.

Kannan, G., Kouakou, B., & Gelaye, S. (2001). Colour changes reflecting myoglobin and lipid oxidation in chevon cuts during display. *Small Ruminant Research, 42,* 67-75.

Kannan, G., Kouakou B., Terrill, T.H., & Gelaye, S. (2003). Endocrine, blood metabolite, and meat quality changes in goats as influenced by short-term, preslaughter stress. *Journal of Animal Science, 81*, 1499-1507.

Kannan, G., Lee, J.H., & Kouakou, B. (2014). Chevon quality enhancement: Trends in pre-and post-slaughter techniques. *Small Ruminant Research, 121*, 80-88.

Karlsson, A., Enfält, A.C., Essén-Gustavsson, B., Lundström, K., Rydhmer, L., & Stern, S. (1993). Muscle histochemical and biochemical properties in relation to meat quality

during selection for increased lean tissue growth rate in pigs. *Journal of Animal Science, 71*, 930-938.

Karlsson, A.H., Klont, R.E., & Fernandez, X. (1999). Skeletal muscle fibres as factors for pork quality. *Livestock Production Science, 60*, 255-269.

Kastenschmidt, L.L., Hoekstra, W.G., & Briskey, E.J. (1968). Glycolytic intermediates and co-factors in "fast-"and "slow-glycolyzing" muscles of the pig. *Journal of Food Science, 33*, 151-158.

Kauffman, R.G., Eikelenboom, G., van der Wal, P.G., Engel, B., & Zaar M. (1986). A comparison of methods to estimate water-holding capacity in post-rigor porcine muscle. *Meat Science, 18*, 307-322.

Kemp, C.M., Sensky, P.L., Bardsley, R.G., Buttery, P.J., & Parr, T. (2010). Tenderness-An enzymatic view. *Meat Science, 84*, 248-256.

Keppler, D., & Decker, K., 1974. Glycogen determination with amyloglucosidase. In H.U. Bergmeyer (Ed.), *Methods of enzymatic analysis (*pp 1127-1131). New York: Academic Press.

Kerth, R., Cain, T.L., Jackson, S.P., Ramsey, C.B., & Miller, M.F. (1999). Electrical stimulation effects on tenderness of five muscles from Hampshire x Rambouillet crossbred lambs with the callipyge phenotype. *Journal of Animal Science, 77*, 2951-2955.

Khliji, S., van de Ven, R., Lamb, T.A., Lanza, M., & Hopkins, D.L. (2010). Relationship between consumer ranking of lamb colour and objective measures of colour. *Meat Science, 85*, 224-229.

King, D.A., Voges, K.L., Hale, D.S., Waldron, D.F, Taylor, C.A., & Savell, J.W. (2004). High voltage electrical stimulation enhances muscle tenderness, increases aging response, and improves muscle color from cabrito carcasses. *Meat Science, 68*, 529-535.

Kirchofer, K.S., Calkins, C.R., & Gwartney, B.L. (2002). Fiber-type composition of muscles of the beef chuck and round. *Journal of Animal Science, 80*, 2872-2878.

Klont, R.E., Brocks, L., & Eikelenboom, G. (1998). Muscle fibre type and meat quality. *Meat Science* 49, 219-229.

Koohmaraie, M., & Geesink, G.H. (2006). Contribution of post mortem muscle biochemistry to the delivery of consistent meat quality with particular focus on the calpain system. *Meat Scienc*e, 74, 34-43.

Kondos, A.C., & Taylor, D.G. (1987). Effect of electrical stimulation and temperature on biochemical changes in beef muscle. *Meat Science, 19*, 207-216.

Kouakou, B., Gelaye, S., Kannan, G., Pringle, T.D., & Amoah, E.A. (2005). Blood metabolites, meat quality and muscle calpain-calpastatin activities in goats treated with low doses of recombinant bovine somatotropin. *Small Ruminant Research, 57*, 203-212.

Kristensen, L., & Purslow, P.P. (2001). The effect of ageing on the water-holding capacity of pork: role of cytoskeletal proteins. *Meat Science, 58*, 17-23.

Krzywicki, K. (1979). Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of beef. *Meat Science, 3*, 1-10.

Lamprecht, W., Stein, P., Heinz, F., & Weisser, H., (1974). Creatine phosphate. Determination with creatine kinase, hexokinase, and glucose 6-phosphate dehydrogenase. In H.U. Bergmeyer (Ed.), *Methods of enzymatic analysis (*pp. 1777-1785). New York: Academic Press.

Larzul, C., Lefaucheur, L., Ecolan, P., Gogue, J; Talmant, A., Seiller, P., LeRoy, P., & Monin, G. (1997). Phenotypic and genetic parameters for longissimus muscle fiber charcateristics in relation to growth, carcass and meat quality traits in large white pigs *Journal of Animal Science, 75*, 3126-3137

Lawrie, R.A. (1953). The onset of rigor mortis in various muscles of the draught horse. *The Journal of Physiology*, *121*, 275-288.

Lawrie, R.A., & Ledward, D.A. (2006). *Lawrie's Meat Science*. Cambridge, England: Woodhead.

Lee, S.H., Joo, S.T., & Ryu, Y.C. (2010). Skeletal muscle fiber type and myofibrillar proteins in relation to meat quality. *Meat Science, 86*, 166-170.

Lee, J.H., Kannan, G., Eega, K.R., Kouakou, B., & Getz, W.R. (2008a). Nutritional and quality characteristics of meat from goats and lambs finished under identical dietary regime. *Small Ruminant Research*, *74*, 255-259.

Lee, J.H., Kouakou, B., & Kannan G. (2008b). Chemical composition and quality characteristics of chevon from goats fed three different post-weaning diets. *Small Ruminant Research, 75*, 177-184.

Lefaucheur, L. (2010). A second look into fibre typing – Relation to meat quality. *Meat Science, 84*, 257-270.

Lefaucheur, L., & Vigneron, P. (1986). Post-natal changes in some histochemical and enzymatic characteristics of three pig muscles. *Meat Science, 16*, 199-216.

Leygonie, C., Britz, T.J., & Hoffman, L.C. (2012). Impact of freezing and thawing on the quality of meat. *Meat Science*, *91*, 93-98.

Locker, R.H., & Hagyard, C.J. (1963). A cold shortening effect in beef muscles. *Journal of the Science of Food and Agriculture, 14*, 787-793.

MacDougall, D.B. (1986). The chemistry of colour and appearance. *Food Chemistry*, *21*, 283-299.

Madruga, M.S., Torres, T.S., Carvalho, F.F., Queiroga, R.C., Narain, N., Garrutti, D., Neto, M.S., Mattos, C.W., & Costa, R.G. (2008). Meat quality of Moxotó and Canindé goats as affected by two levels of feeding. *Meat Science, 80*, 1019-1023.

Mahgoub, O. & Lu, C.D. (1998). Growth, body composition and carcass tissue distribution in goats of large and small sizes. *Small Ruminant Research, 27*, 267-278.

Malan, S.W. (2000). The improved Boer goat. *Small Ruminant Research, 36*, 165-170.

Maltin, C., Balcerzak, D., Tilley, R., & Delday, M. (2003). Determinants of meat quality: tenderness. *Proceedings of the Nutrition Society, 62*, 337–347.

Maltin, C.A., Warkup, C.C., Matthews, K.R., Grant, C.M., Porter, A.D., & Delday, M.I. (1997). Pig muscle fibre characteristics as a source of variation in eating quality. *Meat Science, 41*, 231-248.

Mancini, R.A., & Hunt, M.C. (2005). Current research in meat color. *Meat Science, 71*, 100-121.

Maribo, H., Ertbjerg, P., Andersson, M., Barton-Gade, P, & Moller, A.J. (1999a). Electrical stimulation of pigs -effect on pH fall, meat quality and Cathepsin B+L activity. *Meat Science,* 52, 179-187.

Maribo, H., Støier, S., & Jørgensen P.F. (1999b). Procedure for determination of glycolytic potential in porcine m. *longissimus dorsi*. *Meat Science, 51*, 191-193.

Marichal, A., Castro, N., Capote, J. Zamorano, M.J., & Argüello, A. (2003). Effects of live weight at slaughter (6, 10 and 25 kg) on kid carcass and meat quality. *Livestock Production Science, 83*, 247-256.

Marsh, B.T., & Leet, N.G. (1966). Studies in meat tenderness. III. The effects of cold shortening on tenderness. *Journal of Food Science*, *31*, 450-459.

Masika, P.J., & Mafu, J.V. (2004). Aspects of goat farming in the communal farming systems of the central Eastern Cape, South Africa. *Small Ruminant Research, 52*, 161–164.

McKeith, F.K., Savell, J.W., Smith, G.C., Dutson T.R., & Shelton, M. (1979) Palatability of goat meat from carcasses electrically stimulated at four different stages during the slaughter-dressing sequence. *Journal of Animal Science, 49*, 972-978.

McKenna, D.R., Mies, P.D., Baird, B.E., Pfeiffer, K.D., Ellebracht, J.W., & Savell, J.W. (2005). Biochemical and physical factors affecting discoloration characteristics of 19 bovine muscles. *Meat Science, 70*, 665-682.

McMillin K.W., & Brock A.P. (2005) Production practices and processing for value-added goat meat. *Journal of Animal Science*, *83*, 57–68.

Molette, C., Rémignon, H., & Babilé, R. (2003). Maintaining muscles at a high post-mortem temperature induces PSE-like meat in turkey. *Meat Science, 63*, 525–532.

Monin G., & Sellier, P. (1985). Pork of low technological quality with a normal rate of muscle pH fall in the immediate post-mortem period: The case of the Hampshire breed. *Meat Science, 13*, 49-63.

Morita, S., Iwamoto, H., Fukumitsu, Y., Gotoh, T., Nishimura, S., & Ono, Y. (2000). Heterogeneous composition of histochemical fibre types in the different parts of M. longissimus thoracis from Mishima (Japanese native) steers. *Meat Science, 54*, 59-63.

Mushi, D.E., Safari, J., Mtenga, L.A., Kifaro, G.C., & Eik, L.O. (2009). Effects of concentrate levels on fattening performance, carcass and meat quality attributes of Small East African× Norwegian crossbred goats fed low quality grass hay. *Livestock Science, 124*, 148-155.

NAMC (2005). *Report on the investigation into potential for the South African goat industry* (research report). Pretoria, South Africa: National Agricultural Marketing Council. Retrieved from http://www.nda.agric.za/docs/AAPS/NAMC1.pdf

Newton, K.G., & Gill, C.O. (1980). The microbiology of DFD fresh meats: A review. *Meat Science, 5*, 223-232.

Nishimura, T. (2010). The role of intramuscular connective tissue in meat texture. A*nimal Science Journal, 81*, 21-27.

Offer, G., & Trinick, J. (1983). On the mechanism of water holding in meat: the swelling and shrinking of myofibrils. *Meat Science, 8*, 245-281.

Ouali, A. (1990). Meat tenderization: Possible causes and mechanisms. *Journal of Muscle Foods, 1*, 129-165.

Partmann, W. (1963). Post-mortem changes in chilled and frozen muscle. *Journal of Food Science, 28*, 15-27.

Palka, K., & Daun, H. (1999). Changes in texture, cooking losses, and myofibrillar structure of bovine M. semitendinosus during heating. *Meat Science, 51*, 237-243.

Peacock, C. (2005). Goats—A pathway out of poverty. *Small Ruminant Research, 60*, 179-186.

Pearce K.L., van de Ven R., Mudford C., Warner R.D., Hocking-Edwards J., Jacob R., Pethick D.W., & Hopkins, D.L. (2010) Case studies demonstrating the benefits on pH and temperature decline of optimising medium-voltage electrical stimulation of lamb carcasses. *Animal Production Science 50*, 1107-1114.

Pearce, K.L., Rosenvold, K., Andersen, H.J., & Hopkins, D.L. (2011). Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes - A review. *Meat Science, 89*, 111-124.

Pearse, A.G.E. (1968). *Histochemistry: Theoretical and applied*. London: Churchill-Livingstone.

Pearson A.M., & Young, R.B. (1989). *Muscle and Meat Biochemistry*. San Diego, California: Academic press inc.

Picard, B., Robelin, J., & Geay Y. (1995). Influence of castration and postnatal energy restriction on the contractile and metabolic characteristics of bovine muscle. *Annales de zootechnie, 44*, 347-357.

Pieters, A., van Marle-Köster, E., Visser, C., & Kotze A. (2009). South African developed meat type goats: A forgotten animal genetic resource? *Agri*, *44*, 33-44.

Pösö, A.R., & Puolanne, E. (2005). Carbohydrate metabolism in meat animals. *Meat Science, 70*, 423-434.

Prado, C.S., & de Felício, P.E. (2010). Effects of chilling rate and spray-chilling on weight loss and tenderness in beef strip loin steaks. *Meat science*, *86*, 430-435.

Pratiwi, W.N.M., Murray, P.J., & Taylor, D.G. (2007). Feral goats in Australia: A study on the quality and nutritive value of their meat. *Meat Science, 75*, 168-177.

Ramsay K.A., & Donkin E.F. (2000) A review of the current status of goat research and development in South Africa. *Regional workshop on goat development in Southern Africa,* Mangochi, Malawi.

Rhee M.S., & Kim, B.C. (2001). Effect of low voltage electrical stimulation and temperature conditioning on glycolysis and calpain activities of Korean native cattle (Hanwoo). *Meat Science*, *58*, 231-237.

RSA Government Notice no. R55 (2015). *Regulations regarding the classification and marking of meat intended for sale in the Republic of South Africa*. Cape Town: Government Gazette of South Africa, 38431.

Ruusunen, M., & Puolanne, E. (2004). Histochemical properties of fibre types in muscles of wild and domestic pigs and the effect of growth rate on muscle fibre properties. *Meat Science, 67*, 533-539.

Ryu, Y.C., & Kim, B.C. (2005). The relationship between muscle fiber characteristics, post mortem metabolic, and meat quality of pig *longissimus dorsi* muscle. *Meat Science, 71*, 351–357.

Safari, J., Mushi, D.E., Mtenga, L.A., Kifaro, G.C., & Eik, L.O. (2011). Growth, carcass and meat quality characteristics of Small East African goats fed straw based diets. *Livestock Science, 135*, 168-176.

Sañudo, C., Santolaria, M.P., Maria, G., Osorio, M., & Sierra, I. (1996). Influence of carcass weight on instrumental and sensory lamb meat quality in intensive production systems. *Meat Science, 42*, 195-202.

Santos, V.A.C, Silva, S.R., & Azevedo, J.M.T. (2008) Carcass composition and meat quality of equally mature kids and lambs. *Journal of Animal Science,* 86, 1943-1950.

Sanz, M.C., Verde, M.T., Sáez T., & Sañudo, C. (1996). Effect of breed on the muscle glycogen content and dark cutting incidence in stressed young bulls. *Meat Science, 43*, 31-42.

Savell, J.W., Dutson, T. R., Smith, G.C., & Carpenter, Z.L. (1978). Structural changes in electrically stimulated beef muscles. *Journal of Food Science, 43*, 1606-1607.

Savell, J.W., Mueller, S.L., & Baird, B.E. (2005). The chilling of carcasses. *Meat Science, 70*, 449-459.

Savell, J.W., Smith, G.C., Dutson, T.R., Carpenter, Z.L., & Suter, D.A. (1977). Effect of electrical stimulation on palatability of beef, lamb and goat meat. *Journal of Food Science, 42*, 702-706.

Schafer, A., Rosenvold, K., Purslow, P.P., Andersen, H.J., & Henckel, P. (2002) Physiological and structural events post mortem of importance for drip loss in pork. *Meat Science, 61*, 355–366

Scheffler, T.L., & Gerrard, D.E. (2007). Mechanisms controlling pork quality development: The biochemistry controlling postmortem energy metabolism. *Meat Science, 77*, 7-16.

Scheffler, T.L., Matarneh, S.K., England, E.M., & Gerrard, D.E. (2015). Mitochondria influence post mortem metabolism and pH in an in vitro model. *Meat Science, 110*, 118-125.

Scheffler, T.L., Park, S., & Gerrard, D.E. (2011). Lessons to learn about postmortem metabolism using the AMPKγ3R200Q mutation in the pig. *Meat Science, 89*, 244-250.

Schnöfeldt, H.C., Naudé, R.T., Bok, W., van Heerden S.M., Smit, R., & Boshoff, E. (1993a) Flavour- and tenderness-related quality characteristics of goat and sheep meat. *Meat Science, 34*, 363–379.

Schnöfeldt, H.C., Naudé, R.T., Bok, W., van Heerden S.M., Sowden, L., & Boshoff, E. (1993b). Cooking- and juiciness-related quality characteristics of goat and sheep meat. *Meat Science, 34*, 381-394.

Scopes, R.K. (1974). Studies with a reconstituted muscle glycolytic system: The rate and extent of glycolysis in simulated post-mortem conditions. *Biochemical Journal, 142*, 79-86.

Sen, A.R., Santra, A., & Karim, S.A. (2004). Carcass yield, composition and meat quality attributes of sheep and goat under semiarid conditions. *Meat Science, 66*, 757-763.

Shackelford, S.D., Morgan, J.B., Cross, H.R., & Savell, J.W. (1991). Identification of threshold levels for Warner Bratzler shear press in beef top loin steaks. *Journal of Muscle Foods, 2*, 289-296.

Sheridan, R., Hoffman, L.C., & Ferreira, A.V. (2003). Meat quality of Boer goat kids and mutton Merino lambs 1. Commercial yields and chemical composition. *Animal Science, 76*, 63-71.

Shija, D.S. Mtenga, L.A. Kimambo, A.E. Laswai G.H., Mushi D.E., Mgheni D.M., Mwilawa A.J., Shirima E.J.M., & Safari J.G. (2013). Chemical composition and meat quality attributes of indigenous sheep and goats from traditional production system in Tanzania. *Asian-Australasian Journal of Animal Science, 26*, 295-302

Simela, L. (2005). Meat characteristics and the acceptability of chevon from South African indigenous goats. (PhD Thesis), University of Pretoria, South Africa.

Simela, L., & Merkel, R. (2008). The contribution of chevon from Africa to global meat production. *Meat Science, 80,* 101-109.

Simela, L., Ndlovu, L. R., & Sibanda, L.M. (1999). Carcass characteristics of the marketed Matebele goat from south-western Zimbabwe. *Small Ruminant Research, 32,* 173-179.

Simela, L., Webb E.C., & Bosman, M.J.C. (2008) Acceptability of chevon from kids, yearling goats and mature does of indigenous South African goats: A case study. *South African Journal of Animal Science* 2008, 38 247-259.

Simela, L., Webb, E.C., & Bosman, M.J.C. (2011). Live animal and carcass characteristics of South African indigenous goats. *South African Journal of Animal Science,* 41, 1-15.

Simela, L., Webb, E.C., & Frylinck, L. (2004a). Effect of sex, age, and pre-slaughter conditioning on pH, temperature, tenderness and colour of indigenous South African goats. *South African Journal of Animal Science, 34,* 208-211.

Simela, L., Webb, E.C., & Frylinck, L. (2004b). Post-mortem metabolic status, pH and temperature of chevon from indigenous South African goats slaughtered under commercial conditions. *South African Journal of Animal Science, 34,* 204-207.

Smith, G.C., Carpenter, Z.L., & Shelton, M. (1978). Effects of age and quality level on the palatability of goat meat. *Journal of Animal Science, 46,* 1229–1235.

Smith, G.C., Dutson, T.R., Hostetler, R.L., & Carpenter, Z.L. (1976). Fatness, rate of chilling and tenderness of lamb. *Journal of Food Science, 41,* 748-756.

Smith, G.C., Pike, M.I., & Carpenter, Z.L. (1974). Comparison of the palatability of goat meat and meat from four other animal species. *Journal of Food Science, 39,* 1145-1146.

Smulders, F.J.M., Marsh, B.B., Swartz, D.R., Russell, R.L., & Hoenecke, M.E. (1990). Beef tenderness and sarcomere length. *Meat Science,* 28, 349-363.

Strydom, P. (2011). Quality related principles of the South African beef classification system in relation to grading and classification systems of the world. *South African Journal of Animal Science, 41*, 177-193.

Strydom, P.E., Frylinck, L., & Smith, M.F. (2005). Should electrical stimulation be applied when cold shortening is not a risk? *Meat Science, 70*, 733-742.

Swan, J.E., Esguerra, C.M., & Farouk, M.M. (1998). Some physical, chemical and sensory properties of chevon products from three New Zealand goat breeds. *Small Ruminant Research, 28*, 273–280.

Takahashi, K. (1996). Structural weakening of skeletal muscle tissue during post-mortem ageing of meat: The non-enzymatic mechanism of meat tenderization. *Meat Science, 43*, 67-80.

Tarrant, P.V., & Sherington, J. (1980). An investigation of ultimate pH in the muscles of commercial beef carcasses. *Meat Science, 4*, 287-297.

Todaro, M., Corrao, A., Alicata, M.L., Schinelli, R., Giaccone, P., & Priolo, A. (2004). Effects of litter size and sex on meat quality traits of kid meat. *Small Ruminant Research, 54*, 191-196.

Torrescano, G., Sánchez-Escalante, A., Giménez, B., Roncalés, P., & Beltrán, J.A. (2003). Shear values of raw samples of 14 bovine muscles and their relation to muscle collagen characteristics. *Meat Science, 64*, 85-91.

Totland, G.K., & Kryvi, H. (1991). Distribution patterns of muscle fibre types in major muscles of the bull (Bos taurus). *Anatomy and Embryology, 184*, 441-450.

Thompson, J. (2002). Managing meat tenderness. *Meat Science, 62*, 295–308.

Thompson, J.M., Perry, D., Daly, B., Gardner, G.E., Johnston, D.J., & Pethick, D.W. (2006). Genetic and environmental effects on the muscle structure response post-mortem. *Meat Science, 74*, 59-65.

Troy, D.J., & Kerry, J.P. (2010). Consumer perception and the role of science in the meat industry. *Meat Science, 86*, 214-226.

Tshabalala, P.A., Strydom, P.E., Webb, E.C., & de Kock, H.L. (2003). Meat quality of designated South African indigenous goat and sheep breeds. *Meat Science, 65*, 563-570.

Van Niekerk, W.A., & Casey, N.H. (1988). The Boer Goat. II. Growth, nutrient requirements, carcass and meat quality. *Small Ruminant Research, 1*, 355-368.

Veiseth, E., Shackelford, S.D., Wheeler, T.L., & Koohmaraie, M. (2004). Factors regulating lamb *longissimus* tenderness are affected by age at slaughter. *Meat Science, 68*, 635-640.

Visser, C., Hefer, C.A., van Marle-Köster, E., & Kotze, A. (2004) Genetic variation of three commercial and three indigenous goat populations in South Africa. *South African Journal of Animal Science, 34*, 24-27.

Warmington, B.G., & Kirton, A.H. (1990). Genetic and non-genetic influences on growth and carcass traits of goats. *Small Ruminant Research, 3*, 147-165.

Webb, E.C. (2014). Goat meat production, composition, and quality. *Animal Frontiers, 4*, 33-37.

Webb, E.C., Casey, N.H., & Simela, L. (2005). Goat meat quality. *Small Ruminant Research, 60*, 153–166.

Webb E.C., & Mamabolo M.J. (2004) Production and reproduction characteristics of South African indigenous goats in communal farming systems. *South African Journal of Animal Science, 34*, 236-239.

Wegner, J., Albrecht, E., Fiedler, I., Teuscher, F., Papstein, H.J., & Ender, K. (2000). Growth- and breed-related changes of muscle fiber characteristics in cattle. *Journal of Animal Science, 78*, 1485-1496.

Wheeler, T.L., Shackelford, S.D. & Koohmaraie, M. (2000). Variation in proteolysis, sarcomere length, collagen content, and tenderness among major pork muscles. *Journal of Animal Science, 78*, 958-965.

Wulf, D.M., Emnett, R.S., Leheska, J.M., & Moeller, S.J. (2002). Relationships among glycolytic potential, dark cutting (dark, firm, and dry) beef, and cooked beef palatability. *Journal of Animal Science, 80*, 1895-1903.

Young, O.A., & Bass, J.J. (1984). Effect of castration on bovine muscle composition. *Meat Science, 11*, 139-156.

Young, O.A., Priolo, A., Simmons, N.J., & West, J. (1999). Effects of rigor attainment temperature on meat blooming and colour on display. *Meat Science, 52*, 47-56.

Young, O.A., West, J., Hart, A.L., & van Otterdijk, F.F.H. (2004). A method for early determination of meat ultimate pH. *Meat Science, 66*, 493-498.

Zimerman, M., Grigioni, G., Taddeo, H., & Domingo, E. (2011). Physiological stress responses and meat quality traits of kids subjected to different pre-slaughter stressors. *Small Ruminant Research, 100*, 137-142.

APPENDIX

Correlations of carcass traits, muscle fibre properties, biochemical properties as well as among muscle pH and temperature are summarised in Tables A.1 to A.5.

Table A.51 Correlation-matrix showing correlation coefficients of live weight, carcass weight, chilling losses and muscle fibre characteristics of goats

Parameter	Live weight	Cold carcass weight	Chilling losses	Fibre cross sectional areas			Fibre percentage		
				Red	Intermediate	White	Red	Intermediate	White
Live weight	1								
Cold carcass weight	**0.90*** **								
Chilling loss	-0.20	-0.19							
Longissimus dorsi									
Red fibre CSA[1]	0.17	0.03	-0.03						
Intermediate fibre CSA	0.19	0.14	-0.12	**0.93*** **					
White fibre CSA	0.16	0.08	-0.24	**0.91*** **	**0.96*** **				
Red fibre%	-0.23	-0.18	0.26	-0.13	-0.14	-0.10			
Intermediate fibre%	0.21	0.24	-0.09	0.15	0.18	0.11	**-0.69*** **		
White fibre%	0.13	0.03	-0.28	0.04	0.03	0.03	**-0.75*** **	0.03	1
Semimembranosus									
Red fibre CSA	**0.33***	0.18	-0.11						
Intermediate fibre CSA	**0.37***	0.26	-0.15	**0.93*** **					
White fibre CSA	0.29	0.26	-0.15	**0.80*** **	**0.92*** **				
Red fibre%	-0.01	0.01	-0.17	0.10	0.13	0.05			
Intermediate fibre%	0.14	0.11	-0.07	-0.06	-0.03	-0.01	**-0.52*** **		
White fibre%	-0.11	-0.11	0.25	-0.06	-0.13	-0.05	**-0.65*** **	**-0.32***	1

*P <0.05; **P <0.01; P <0.001

[1]Cross sectional areas

Table A.52 Correlation-matrix showing correlation coefficients of live weight, carcass weight, chilling losses muscle fibre characteristics of goats and biochemical metabolites

Parameter	Time post mortem	Live weight	Cold carcass weight	Chilling losses	Fibre cross sectional areas			Fibre percentage		
					Red	Intermediate	White	Red	Intermediate	White
Longissimus dorsi										
Creatine phosphate	15 min	0.27	0.25	-0.16	-0.13	-0.05	-0.06	-0.06	0.17	-0.07
	3 h	0.19	0.24	-0.15	-0.18	-0.03	-0.02	0.00	-0.01	0.01
	24 h	-0.14	-0.11	-0.19	-0.02	0.04	0.07	-0.23	0.10	0.23
Glycogen	15 min	0.10	0.17	0.19	-0.06	-0.15	-0.22	-0.06	0.24	-0.14
	3 h	0.26	**0.40****	0.08	-0.25	-0.25	-0.31	0.12	0.15	-0.30
	24 h	0.08	0.08	**0.40****	-0.18	-0.23	-0.30	0.31	-0.16	-0.28
ATP	15 min	**0.45****	**0.34***	0.02	-0.10	-0.18	-0.15	0.03	0.05	-0.09
	3 h	0.26	0.17	0.02	-0.16	-0.15	-0.11	0.10	-0.13	-0.01
	24 h	-0.04	-0.15	0.05	-0.01	-0.04	0.01	-0.06	0.07	0.02
Lactate	15 min	**-0.32***	**-0.34***	0.10	0.10	0.02	0.02	0.05	-0.09	0.02
	3 h	-0.24	**-0.33***	0.11	0.18	0.10	0.15	0.05	-0.17	0.09
	24 h	-0.18	-0.30	0.20	0.16	0.04	0.04	0.27	-0.21	-0.18
Glycolytic potential	15 min	-0.15	-0.10	0.21	0.02	-0.14	-0.19	-0.04	0.14	-0.07
	3 h	0.00	0.04	0.18	-0.09	-0.21	-0.19	0.22	-0.10	-0.22
	24 h	-0.07	-0.15	**0.34***	0.08	-0.06	-0.10	**0.42****	-0.27	**-0.34***
Semimembranosus										
Creatine phosphate	15 min	0.01	0.04	-0.09	-0.23	-0.24	-0.29	-0.13	0.18	-0.01
	3 h	-0.03	0.04	-0.04	-0.01	-0.06	-0.08	-0.10	0.19	-0.06
	24 h	0.17	0.08	-0.24	0.15	0.17	0.12	-0.11	**0.35***	-0.19
Glycogen	15 min	0.04	0.09	0.25	0.15	0.22	0.21	0.18	**-0.35***	0.12
	3 h	-0.26	-0.18	0.26	0.13	0.19	0.25	0.08	-0.24	0.12
	24 h	-0.23	-0.22	0.27	-0.17	-0.11	-0.04	-0.04	-0.07	0.11
ATP	15 min	-0.25	-0.13	0.14	**-0.34***	**-0.36***	**-0.36***	0.06	-0.06	-0.02
	3 h	-0.24	-0.15	0.17	-0.11	-0.25	**-0.33***	-0.08	0.08	0.02
	24 h	0.13	0.12	-0.08	0.04	0.07	0.07	-0.26	**0.57*****	-0.23
Lactate	15 min	-0.06	-0.11	0.00	0.26	0.19	0.24	0.08	-0.24	0.13
	3 h	0.05	-0.01	0.04	0.25	0.23	0.28	0.00	-0.10	0.08
	24 h	-0.05	0.03	-0.23	0.17	0.24	0.22	-0.04	-0.22	0.24
Glycolytic potential	15 min	0.01	0.02	0.17	0.24	0.25	0.27	0.19	**-0.36***	0.11
	3 h	-0.18	-0.17	0.23	0.29	**0.33***	**0.42****	0.07	-0.21	0.11
	24 h	-0.08	0.01	-0.15	0.19	0.27	0.31	-0.03	-0.24	0.25

*P <0.05; **P <0.01; P <0.001

Table A.53 Correlation-matrix showing correlation coefficients of live weight, carcass weight, chilling losses muscle fibre characteristics of goats with muscle pH and temperature

	Time post mortem	Live weight	Cold carcass weight	Chilling losses	Fibre cross sectional areas			Fibre percentage		
					Red	Intermediate	White	Red	Intermediate	White
Longissimus dorsi										
pH	15 minutes	0.18	**0.33***	0.02	-0.16	-0.10	-0.12	0.01	0.14	-0.14
	1 hour	0.13	0.25	-0.09	-0.16	-0.11	-0.12	-0.12	0.15	0.03
	3 hours	-0.01	0.08	0.05	**-0.36***	**-0.37***	**-0.31***	0.14	-0.01	-0.19
	6 hours	-0.23	-0.14	-0.01	**-0.41****	**-0.35***	-0.29	0.16	-0.10	-0.13
	24 hours	**-0.34***	**-0.32***	0.07	-0.11	-0.08	-0.02	-0.10	0.03	0.11
Temperature	15 minutes	**-0.35***	**-0.39***	-0.05	-0.02	-0.07	-0.01	0.04	-0.24	0.16
	1 hour	0.20	0.17	0.07	0.14	0.20	0.19	0.17	-0.04	-0.19
	3 hours	0.10	0.10	0.06	0.23	0.26	0.22	0.03	0.06	-0.09
	6 hours	0.13	0.09	0.02	0.09	0.09	0.07	0.05	-0.01	-0.06
	24 hours	-0.15	-0.10	0.21	-0.10	-0.11	-0.08	0.30	-0.14	-0.28
Semimembranosus										
pH	15 minutes	0.11	0.26	-0.06	-0.20	-0.22	-0.30	0.15	-0.03	-0.14
	1 hour	-0.02	0.16	0.12	-0.22	-0.21	-0.18	-0.23	0.11	0.16
	3 hours	-0.16	-0.04	0.15	**-0.33***	-0.29	-0.24	-0.30	0.23	0.13
	6 hours	**-0.34***	-0.25	-0.01	-0.27	-0.19	-0.22	-0.09	0.07	0.03
	24 hours	**-0.40****	-0.23	-0.15	**-0.49****	**-0.55*****	**-0.47****	-0.28	0.20	0.13
Temperature	15 minutes	0.07	0.07	-0.21	-0.10	-0.02	0.06	0.04	-0.03	-0.02
	1 hour	-0.05	0.03	0.12	-0.23	-0.19	-0.05	-0.28	**0.47*****	-0.11
	3 hours	0.17	0.15	-0.13	-0.02	0.04	0.10	-0.11	0.16	-0.03
	6 hours	0.24	0.20	-0.12	0.11	0.13	0.12	0.04	0.02	-0.06
	24 hours	0.08	0.21	-0.21	-0.15	-0.11	-0.14	0.16	-0.07	-0.12

*P <0.05; **P <0.01; P <0.001

Table A.54 Correlation-matrix showing correlation coefficients of muscle pH and temperature and biochemical parameters

Parameter	Time post *mortem*	pH					Temperature				
		15 min	1 hour	3 hours	6 hours	24 hours	15 min	1 hour	3 hours	6 hours	24 hours
Longissimus dorsi											
pH	15 min	1									
	1 hour	**0.67*** **									
	3 hours	**0.71*** **	**0.54*** **								
	6 hours	**0.56*** **	**0.64*** **	**0.67*** **							
	24 hour	0.25	0.20	0.26	**0.55*** **						
Temperature	15 min	0.25	**0.47** **	0.14	0.31	0.25					
	1 hour	**0.32***	0.06	0.02	-0.10	-0.16	0.13				
	3 hours	**0.55*** **	**0.32***	0.25	0.21	-0.04	0.18	**0.62** **			
	6 hours	**0.74*** **	**0.48** **	**0.52*** **	**0.45** **	0.10	0.30	**0.46** **	**0.83*** **		
	24 hour	-0.21	-0.16	-0.07	0.00	-0.11	-0.04	-0.11	-0.17	-0.20	1
Creatine phosphate	15 minutes	**0.46** **	**0.58*** **	**0.38***	**0.47** **	0.06	0.13	0.13	0.15	0.28	-0.07
	3 hours	0.29	**0.41** **	0.22	0.29	0.09	0.13	0.10	0.04	0.19	-0.04
	24 hours	0.09	0.20	0.10	0.28	0.29	0.19	-0.06	0.10	0.05	**-0.32***
Glycogen	15 minutes	**0.38***	**0.37***	**0.35***	0.21	-0.13	-0.04	0.19	0.29	**0.40** **	-0.07
	3 hours	**0.64*** **	**0.50*** **	**0.53*** **	**0.46** **	0.04	-0.01	0.18	**0.03***	**0.53*** **	0.00
	24 hours	-0.16	-0.27	-0.06	-0.19	-0.23	-0.25	0.13	-0.06	-0.08	**0.35***
Glucose	15 minutes	-0.29	-0.29	-0.12	-0.20	-0.10	-0.15	-0.23	-0.19	-0.22	-0.15
	3 hours	**-0.39***	-0.28	-0.21	**-0.32***	-0.12	-0.03	-0.30	**-0.37***	**-0.32***	0.12
	24 hours	**-0.59*** **	**-0.49** **	**-0.56*** **	**-0.64*** **	**-0.34***	-0.15	-0.12	**-0.33***	**-0.48** **	0.24
Glucose-6-phosphate	15 minutes	-0.20	-0.14	-0.19	-0.20	**-0.37***	-0.30	0.05	0.03	-0.17	-0.04
	3 hours	**-0.48** **	**-0.45** **	**-0.39***	-0.28	**-0.34***	-0.22	-0.11	**-0.42** **	**-0.55*** **	**0.44** **
	24 hours	0.00	-0.12	-0.16	-0.17	**-0.36***	-0.13	0.10	-0.20	-0.13	0.14
ATP	15 minutes	**0.34***	**0.45** **	**0.41** **	0.31	0.06	0.06	0.06	0.11	0.31	0.09
	3 hours	**0.60*** **	**0.54*** **	**0.58*** **	**0.50*** **	0.16	0.31	0.04	0.26	**0.54*** **	-0.07
	24 hours	-0.01	0.03	0.26	0.12	0.09	0.05	0.06	0.09	0.00	-0.31
Lactate	15 minutes	**-0.70*** **	**-0.78*** **	**-0.60*** **	**-0.59*** **	-0.15	-0.25	-0.27	**-0.49** **	**-0.72*** **	0.26
	3 hours	**-0.54*** **	**-0.54*** **	**-0.48** **	**-0.45** **	0.00	-0.14	-0.28	**-0.38***	**-0.54** **	0.13
	24 hours	-0.12	**-0.38***	-0.25	-0.27	0.03	-0.06	0.04	0.10	0.05	0.05
Glycolytic potential	15 minutes	-0.25	-0.31	-0.18	-0.31	-0.28	-0.27	-0.06	-0.14	-0.23	0.13
	3 hours	-0.04	-0.19	-0.05	-0.10	-0.01	-0.20	-0.20	-0.19	-0.16	0.23
	24 hours	-0.23	**-0.51*** **	**-0.34***	**-0.42** **	-0.20	-0.20	0.10	-0.03	-0.08	0.24

*P <0.05; **P <0.01; P <0.001

Table A.4 cont…

Parameter	Time *post mortem*	pH					Temperature				
		15 min	1 hour	3 hours	6 hours	24 hours	15 min	1 hour	3 hours	6 hours	24 hours
Semimembranosus											
pH	15 min	1									
	1 hour	**0.56*** **									
	3 hours	**0.48** **	**0.64** **								
	6 hours	**0.55*** **	**0.46*** **	**0.55*** **							
	24 hour	0.28	**0.31***	**0.37***	**0.39***						
Temperature	15 min	**0.35***	0.17	0.26	**0.36***	0.23					
	1 hour	0.05	0.22	0.21	0.17	**0.32***	0.23				
	3 hours	**0.32***	0.31	0.21	0.20	0.09	**0.49** **	0.23			
	6 hours	**0.41** **	0.31	0.27	0.27	-0.07	**0.49** **	0.08	**0.74*** **		
	24 hour	0.03	-0.06	-0.12	-0.18	-0.14	-0.09	-0.14	-0.14	-0.30	
Creatine phosphate	15 minutes	**0.43*** **	0.30	**0.40** **	0.27	**0.35***	0.12	0.11	0.16	0.18	-0.15
	3 hours	0.20	0.03	0.15	0.17	0.23	-0.03	0.10	-0.18	-0.06	-0.20
	24 hours	**-0.31***	-0.22	-0.11	-0.13	0.00	-0.16	0.19	-0.30	-0.31	-0.23
Glycogen	15 minutes	-0.04	0.02	0.05	-0.06	**-0.33***	-0.20	-0.13	-0.19	0.04	-0.04
	3 hours	0.04	0.07	**0.38***	0.12	-0.13	0.08	-0.03	-0.27	-0.01	-0.08
	24 hours	-0.04	0.24	**0.47** **	0.20	0.02	-0.05	0.04	-0.27	-0.22	-0.14
Glucose	15 minutes	-0.02	-0.03	-0.11	-0.19	0.18	-0.12	0.14	-0.24	-0.30	-0.02
	3 hours	**-0.35***	-0.30	-0.11	-0.11	-0.19	-0.17	0.17	-0.21	-0.18	0.02
	24 hours	**-0.33***	-0.17	-0.23	-0.23	-0.28	-0.12	**0.31***	-0.25	-0.18	0.05
Glucose-6-phosphate	15 minutes	-0.05	0.03	0.02	-0.04	0.11	-0.05	-0.01	0.01	-0.19	-0.07
	3 hours	-0.26	-0.24	-0.18	-0.19	-0.24	-0.11	0.10	0.09	-0.02	-0.08
	24 hours	0.03	0.10	-0.04	0.03	-0.13	-0.04	0.02	-0.02	0.21	-0.07
ATP	15 minutes	0.19	0.14	0.18	0.10	0.23	-0.21	-0.10	-0.31	-0.21	-0.14
	3 hours	**0.44** **	0.23	**0.31***	**0.32***	0.22	-0.13	-0.17	-0.08	0.13	-0.24
	24 hours	-0.26	-0.18	-0.05	-0.14	0.05	-0.21	**0.36***	-0.21	-0.26	-0.14
Lactate	15 minutes	**-0.57*** **	**-0.41** **	**-0.55*** **	**-0.46** **	-0.30	**-0.34***	-0.22	**-0.46** **	**-0.54** **	0.14
	3 hours	**-0.63*** **	**-0.38***	**-0.48** **	**-0.49** **	**-0.31***	**-0.54*** **	-0.14	**-0.40** **	**-0.49** **	0.23
	24 hours	0.19	0.15	0.16	0.30	-0.07	-0.02	**-0.33***	-0.06	0.15	0.10
Glycolytic potential	15 minutes	**-0.35***	-0.21	-0.27	**-0.32***	**-0.39***	**-0.36***	-0.21	**-0.43** **	**-0.31***	0.04
	3 hours	**-0.44** **	-0.23	-0.05	-0.26	**-0.34***	**-0.32***	-0.09	**-0.47** **	**-0.34***	0.08
	24 hours	0.12	0.19	0.20	0.27	-0.11	-0.05	-0.22	-0.13	0.11	0.03

*P <0.05; **P <0.01; P <0.001

Table A.55 Correlation-matrix showing correlation coefficients of biochemical parameters

	Time	1Creatine phosphate			2Glycogen			3Glucose			4G-6-P			5ATP			6Lactate	
		15 min	3 h	24 h	15 min	3 h	24 h	15 min	3 h	24 h	15 min	3 h	24 h	15 min	3 h	24 h	15 min	3 h
Longissimus dorsi																		
1	15 min	1																
	3 h	0.22																
	24 h	0.08	**0.32***															
2	15 min	0.23	-0.14	0.05														
	3 h	**0.41****	0.23	-0.07	**0.64*****													
	24 h	-0.15	-0.01	-0.18	0.14	0.28												
3	15 min	**-0.33***	-0.25	0.11	-0.12	**-0.44****	**-0.45****											
	3 h	-0.29	-0.22	-0.16	-0.24	**-0.44****	-0.24	**0.70*****										
	24 h	-0.31	**-0.43****	**-0.38***	-0.18	**-0.45****	-0.11	**0.42****	**0.54*****									
4	15 min	0.07	-0.21	-0.19	-0.13	-0.14	0.13	0.06	0.02	0.15								
	3 h	-0.16	-0.3	**-0.34***	-0.22	-0.22	0.27	0.06	0.2	**0.43****	0.34							
	24 h	0.03	-0.18	**-0.44****	0.22	0.19	-0.04	0.13	0.15	**0.41****	0.02	0.29						
5	15 min	**0.56*****	0.18	-0.14	0.18	**0.39***	0.02	-0.13	0.15	-0.1	0.04	-0.22	0.08					
	3 h	**0.46****	**0.50*****	0.01	0.00	**0.40***	-0.15	**-0.34***	-0.23	**-0.47****	-0.03	**-0.37***	-0.18	**0.57*****				
	24 h	0.15	0.03	**0.63*****	0.06	-0.22	-0.08	0.13	-0.1	-0.25	-0.12	**-0.36***	**-0.44****	-0.01	0.06			
6	15 min	**-0.60*****	**-0.43****	-0.21	**-0.40***	**-0.61****	0.04	**0.39***	**0.46****	**0.62****	0.05	**0.54*****	0.21	**-0.46****	**-0.65*****	-0.15		
	3 h	**-0.55*****	**-0.36***	-0.17	**-0.42****	**-0.68*****	-0.18	**0.39***	**0.42****	**0.50*****	0.07	**0.40****	-0.02	**-0.35***	**-0.34***	-0.1	**0.74*****	
	24 h	-0.28	**-0.33***	-0.29	-0.07	-0.24	-0.1	0.21	0.21	**0.39***	-0.21	-0.03	0.12	-0.14	-0.05	-0.14	**0.33***	**0.51*****
Semimembranosus																		
1	15 min																	
	3 h	**0.43****																
	24 h	0.25	**0.53*****															
2	15 min	-0.12	-0.08	0.02														
	3 h	0.13	0.26	0.04	**0.54*****													
	24 h	0.17	0.07	0.16	0.26	**0.50*****												
3	15 min	0.08	0.10	**0.45****	-0.18	-0.21	0.01											
	3 h	**-0.38***	-0.06	-0.03	0.11	0.25	0.18	-0.20										
	24 h	**-0.33***	0.02	-0.02	0.09	0.31	0.02	-0.20	**0.64*****									
4	15 min	0.00	**-0.37***	-0.07	-0.13	-0.16	0.03	**0.41****	-0.02	-0.05								
	3 h	-0.20	-0.25	0.02	-0.04	-0.05	-0.17	0.15	**0.33***	0.17	**0.40****							
	24 h	0.04	0.26	-0.04	0.13	**0.37***	0.07	0.04	0.21	**0.40****	-0.18	0.04						
5	15 min	**0.45****	0.20	0.24	0.10	0.15	0.19	**0.46****	-0.19	-0.30	**0.36***	-0.05	0.01					
	3 h	**0.38***	**0.66*****	0.05	-0.22	0.12	-0.04	0.05	-0.20	-0.19	-0.09	-0.25	0.09	**0.41****				
	24 h	0.26	**0.53*****	**0.77*****	-0.11	0.01	-0.03	**0.38***	0.00	0.07	-0.14	-0.05	-0.13	0.15	0.16			
6	15 min	**-0.66*****	-0.22	0.16	0.10	-0.14	-0.11	0.20	**0.36***	0.26	0.14	0.22	-0.04	0.02	-0.26	0.03		
	3 h	**-0.42****	-0.26	0.17	0.26	-0.12	0.00	0.12	**0.31***	0.24	0.08	**0.33***	0.06	-0.05	**-0.48****	0.04	**0.71*****	
	24 h	-0.18	0.05	-0.10	**0.36***	**0.37***	0.04	-0.08	0.00	0.04	0.01	-0.09	**0.51*****	0.00	0.11	-0.25	0.08	0.02

*P <0.05; **P <0.01; P <0.001