Adaptive responses to heat stress, quality of hide and meat from indigenous Nguni and non-descript crossbred cattle

By

CHIKWANDA DENICE

A dissertation submitted in fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE (ANIMAL SCIENCE)

Department of Livestock and Pasture Science

Faculty of Science and Agriculture

University of Fort Hare

P. Bag X1314

Alice

South Africa

University of Fort Hare
Together in Excellence

Promoter: Prof. V. Muchenje

Co-promoters: Prof. L.C. Hoffman

Prof. A. Hugo

Declaration

I, **Denice Chikwanda,** declare that this dissertation has not been submitted to any University and that it is my original work conducted under the supervision of Prof. V. Muchenje. The research was approved by the University of Fort Hare Research Ethics Committee (Certificate No.: MUC131SCHI01). All assistance towards the production of this work and all the references contained herein have been fully accredited.

29 January 2016

Mrs. Denice Chikwanda **Date**

(Signature)

Approved as to style and content by:

……

Prof. V. Muchenje

(Promoter)

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Notes:

This dissertation is presented in the format prescribed by the Department of Livestock and Pasture Science at the University of Fort Hare. The structure comprises of several chapters in the form of papers to be published in various journals. The dissertation was compiled starting with an introduction chapter, which includes study objectives. The literature review follows the introduction chapter, after which experimental chapters are presented. The last chapter presents the general discussion and recommendations.

The language, style and referencing used in this dissertation are in accordance with the requirements of the Livestock and Pasture Science Department.

Results from this study have been presented at the following conferences:

1. D. Chikwanda & V. Muchenje. Cortisol, rectal and skin temperatures as affected by body condition, hair-coat and skin traits in Nguni and non-descript cattle. A poster presented at the 48th SASAS conference in Durban, Kwazulu-Natal, 6-9 September, 2015.
2. D. Chikwanda & V. Muchenje. Blood metabolite concentrations, skin thickness and hide weights of Nguni and non-descript cattle reared on a sweetveld. A poster presented at the 48th SASAS conference in Durban, Kwazulu-Natal, 6-9 September, 2015.

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Abstract

Adaptive responses to heat stress, quality of hide and meat from indigenous Nguni and non-descript crossbred cattle

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The main objective of this study was to determine the adaptive responses of Nguni and non-descript crossbred cattle (NDCC) to heat stress, nutritionally-related blood metabolite profiles, fatty acid profiles, carcass and meat characteristics, physico-mechanical properties of automotive upholstery crust leather and the associated collagen fibre architecture of hides and crust leather. Forty steers (20 Nguni and 20 NDCC) which were approximately 14 months of age with live weights ranging between 153 kg and 203 kg at the beginning of the study were used. Environmental variables (ambient temperature, relative humidity, wind parameters, solar radiation) were collected from a weather station at the research farm. Temperature-humidity index (THI) values were computed. Rectal and skin temperature, skin traits and blood metabolites were determined at two-week intervals over 16 weeks. Hair coat scores ranged from extremely short (score 1) to very woolly (score 7). At slaughter, blood samples were collected after exsanguination. Meat samples were collected from the right *muscularis longissimus thoracis et lumborum* (LTL) and *Triceps brachii* (TB) muscles after 24 hours of chilling of carcasses for physico-chemical quality tests. Fatty acid profiles and physico-chemical quality of meat were determined on the LTL and TB. An additional fifty-four hides (27 Nguni and 27 NDCC) were obtained from a commercial abattoir at slaughter. The hides were tanned into automotive crust leather and tested for physico-mechanical quality. Results showed that week and environmental variables affected skin temperature; also, the rectal and skin temperatures were negatively correlated to body condition, skin pigment, coat score and skin thickness. Non-descript crossbred cattle had higher coat scores

(2.1 ± 0.36 to 4.1 ± 4.20) than Nguni cattle (1.6 ± 0.36 to 4.1 ± 0.36). Body condition scores, blood creatinine, urea, total protein, albumin and globulin were affected by genotype and week of sampling. At the end of the trial, NDCC had higher slaughter and hide weights (285.9 ± 6.52 kg and 18.4 ± 0.54 kg, respectively) than Nguni cattle (232.6 ± 6.5 kg and 14.7 ± 0.54 kg, respectively). The majority of NDCC carcasses (73.7 %) had a fatness level of 1 compared to Nguni carcasses (50 %). Intramuscular fat was higher in Nguni (1.8 ± 0.09 %) compared to NDCC (1.5 ± 0.09 %) steers. Nguni steers had darker muscle colour (L*=33.6 ± 0.01) than NDCC (L*= 35.7 ± 0.54). Nguni and NDCC had similar thawing loss, cooking loss, WBSF tenderness, fat-free dry matter, moisture content, fatty acid profiles and health-related lipid indices. Ultimate muscle pH, meat colour and chroma were similar in the LTL and TB. Concerning the skin, Nguni and NDCC had similar physico-mechanical properties. However, breaking load and tensile strength were higher (1257.1 ± 70.72 N and 28.3 ± 1.23 MPa) in samples taken parallel to the backbone compared to that taken perpendicular to the backbone (979.5 ±70.72 N and 23.6 ±1.23MPa) across the two genotypes. Non-descript crossbred crust leather varied in physico-mechanical tests by direction of sampling. Collagen fibre orientation in hides and crust samples also varied between longitudinal and cross-sections. Collagen fibre diameters in the Nguni were similar in longitudinal and cross-sections (3.4 ± 0.12 µm and 3.2 ± 0.11 µm, respectively). From this study, it is concluded that THI, hair coat, skin traits and body condition affect skin temperature, but not rectal temperature, cortisol and CK activity in Nguni and NDCC reared extensively. The two genotypes differ in nutritionally-related blood metabolites, growth performance, hide weights and carcass traits. Beef from Nguni and NDCC differs in the IMF and meat lightness but is similar in the meat fatty acid composition and some physico-chemical quality parameters. Automotive crust leathers from the two genotypes were similar in some physico-mechanical properties. Collagen architecture varied among different regions of hides and crust leathers.

Dedication

To my family.

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a*	redness of meat
AA	arachidonic acid
ADG	average daily gain
AG	albumin-globulin ratio
APDP	Automotive Development and Production Programme
b*	yellowness of meat
BCS	body condition score
CIE	Commision International De I' Eclairage
CK	creatine kinase
CLA	conjugated linoleic acid
CO^2	carbon dioxide
DAFF	Department of Agriculture, Forestry and Fisheries
DFD	dark firm dry
DPA	docosapentaenoic acid
ECDC	Eastern Cape Development Corporation
EPA	eicosapentaenoic acid
FAO	Food and Agriculture Organisation of the United Nations
FAMEs	Fatty acid methy esters
GLM	Generalised Linear Model
HDL	high density lipoprotein
IMF	intra-muscular fat
L*	lightness of meat
LA	linoleic acid
LDL	low density lipoprotein

LNA	α-linolenic acid
LSMean	Least Square Mean
LTL	*muscularis longissimus thoracis et lumborum*
MIDP	Motor Industry Development Programme
MUFA	mono unsaturated fatty acid
n-3	omega-3 fatty acids
n-6	omega-6 fatty acids
NDCC	non-descript crossbred cattle
pH_u	ultimate pH
PROC	Procedure
PUFAs	poly unsaturated fatty acids
RMAA	Red Meat Abattoir Association
SAS	Statistical Analysis System
SAMIC	South African Meat Industry Company
SE	Standard error
SEM	Scanning electron microscopy
SFA	saturated fatty acids
SNP	single nucleotide polymorphism
TB	*Triceps brachii*
THI	Temperature-humidity index
TP	total protein
UFH	University of Fort Hare
WBSF	Warner Bratzler Shear Force

Chapter 1: General Introduction

The livestock sector is increasingly becoming an important agro-economic subsector in many sub-Saharan African countries due to its significant contribution to national income (Food and Agriculture Organisation (FAO), 2011), national food security (Wayua and Kagunyu, 2012), household income and household food security (Phiri, 2009; Labadarios *et al.*, 2011). In South Africa, the livestock sector is considered to be a very crucial component of the agricultural economy as it has experienced rapid growth over the recent past (Department of Agriculture, Forestry and Fisheries (DAFF), 2011a). This growth in the livestock sector is attributed to several factors such as the growth in disposable income, advances in technology and implementation of structural changes such as infrastructure development and deregulation of marketing of agricultural products in 1997 (DAFF, 2013). For the 2009/2010 period, the red meat sector in South Africa contributed 14.8 % to the total gross value of agriculture, the highest proportion (10.1 %) being from cattle (DAFF, 2011a). According to Spies (2011), the red meat sector in South Africa contributed 13.2 % to the total gross value of agriculture production over a long period from 1996/97 to 2008/2009. The contribution from beef was 9.4 % over the same period (Spies, 2011). In addition, the red meat sector is the main supplier of the raw materials for the skins, hides and leather industry (DAFF, 2011b).

Skins, hides and leather contributed in excess of US$ 55 million in exports of raw hides and US$17million in further processed leather in 2013 as foreign currency earnings in South Africa (DAFF, 2014). Globally, the value of the leather industry is increasing (Mwinyihija, 2014). The value of global exports in raw hides, skins, leather and shoes doubled from about US$40 million to approximately US$80 million from 1999 to 2011 (FAO, 2013). In addition to meat and hides, livestock provide milk, manure and draught power for the livelihood of

small-scale farmers (Mapiye *et al*., 2007; Musemwa *et al*., 2008). Small-scale farmers, however, have a very small contribution (2-5 %) to the total beef off-take (Mapiye *et al*., 2009) in the formal sector, despite owning approximately 40 % of the national cattle herd (Scholtz *et al*., 2008; DAFF, 2014).

The increasing demand for food of animal origin in developing countries of sub-Saharan Africa is projected to continue for a long time. Furthermore, rising concerns about animal abuses in intensively managed farming systems and calls by consumers for organic farm products over the past decade, have led to widespread promotion of veld-finished beef reared without supplementation. This has created market opportunities for extensive cattle producers to participate in the global beef supply chain. The same trend is also observed for organically produced milk, manure and leather (Musemwa *et al*., 2008; Mapiye *et al*., 2009), creating opportunities for value-added approaches to livestock production from extensive systems. When livestock are slaughtered for meat, skins and hides are generated as co(by)-products. Among the by-products generated at slaughter, hides and skins are the most valuable as they can be processed into high utility value-added products such as leather.

The majority of small-scale farmers in South Africa rear cattle in extensive production systems (Scholtz *et al.,* 2008). Most of the cattle in this sector are non-descript crossbred cattle (NDCC) which are indiscriminate crosses between the indigenous Sanga breeds such as the Nguni and imported breeds (Scholtz *et al*., 2008; Mapiye *et al*., 2009). These breeds are not usually preferred in the formal beef market due to the perceived poor quality of their meat and poor carcass conformation (Soji *et al*., 2015). The poor performance of cattle in the smallholder communities results from a number of challenges which can be addressed to improve product quality and participation of the small-scale farmers in the formal market

(Mapiye *et al*., 2009; Soji *et al.*, 2015). These challenges include feed shortages, diseases and parasites, the multi-purpose nature of the animals, lack of knowledge (production as well as market-related) by the small-scale farmers (Mapiye *et al*., 2009; Soji *et al*., 2015).

In addition, the production and reproductive capacity of beef cattle in extensive systems is generally poor as animals are exposed and vulnerable to natural environmental conditions (Nardone *et al*., 2010). In South Africa, there have been reports of increasing frequencies of droughts, water scarcity and climate change (Fourie *et al*., 2013). Evidence exists as experienced by the present drought. Production risks are, thus, becoming higher and increasing in extensive systems than in intensively managed systems as a result of global warming. Therefore, beef cattle in extensive systems need to withstand stressors in the harsh environment for them to grow and reproduce (Burrow and Prayaga, 2004). Environmental heat stress in the tropics, has been reported to have both direct and indirect effects on the animals and their physiology (Bernabucci *et al*., 2010), energy and nutrient metabolism, growth rate, carcass and meat quality (Baumgard and Rhoads, 2012). The harsh conditions and reduced animal performance lower the quality and yield of animal products for unadapted animals, thereby reducing the food available for household consumption and income earnings.

Improved cattle breeds and their crosses that are reared in the commercial sector in South Africa due to their desirable traits such as high growth rate, ability to reach market weight at an early age and good meat quality, have, however failed to perform in the smallholder, emerging and communal sectors. These breeds require large amounts of good quality feed which are not affordable to resource-poor farmers in smallholder low input systems (Mapiye *et al*., 2009). Furthermore, improved breeds require intensive management which most small-

scale communal farmers fail to provide due to lack of skills and poor educational background (Musemwa *et al*., 2008; Mapiye *et al*., 2009). Improved breeds are more prone to heat stress compared to indigenous breeds (Foster *et al*., 2009; Fourie *et al*., 2013).

Of late, programmes to re-introduce indigenous breeds such as the Nguni cattle have gained momentum. According to Pilling and Hoffmann (2011), livestock breeds that have been exposed to environmental stressors such as climatic extremes and poor quality feeds often develop adaptations that enable them to thrive where other animals struggle to survive. Furthermore, studies by Muchenje *et al*. (2008a) and Muchenje *et al*. (2009) have shown that Nguni cattle are able to produce good quality meat comparable to improved breeds such as the Angus and Bonsmara under free-ranging systems with little to no supplementation. It is therefore, prudent for small-scale farmers to rear animals that are adapted to the environment to maximise utilisation of natural resources (Foster *et al*., 2009; Nardone *et al*., 2010). This will enable them to meet the demands of consumers for naturally produced meat (Burrow and Prayaga, 2004) under the pressure of climate change and extreme weather factors (Nardone *et al*., 2010).

Indigenous cattle breeds such as the Nguni have additional unique characteristics such as multi-coloured skins with various patterns which now attract huge interest in the leather industry (Brits, 2014). With increased red meat consumption, there is an increased production of by-products such as hides which are valuable raw materials in the leather industry. Hides and skins have significant national and international value (Kanagaraj *et al*., 2005). They are converted into high value leather products such as footwear, clothing, automotive and furniture upholstery which are perceived as luxury items mostly destined for the export market. Therefore, the quality of leather goods must meet the demands of the world market

(Ballard, 2001; Venter, 2015). For tanners, importers and leather manufacturers and consumers, quality is a primary concern and very critical for market success (Mokhothu-Ogolla and Wanjau, 2013). Factors affecting hide and leather quality include animal factors such as breed, gender and age (Jacinto *et al*., 2004; Engelbrecht *et al*., 2009; Salehi and Bitaraf, 2013), nutrition (Engelbrecht *et al*., 2009), animal husbandry, slaughter methods, preservation methods, storage conditions (FAO, 2010) and processing methods (Jacinto *et al*., 2004; Engelbrecht *et al*., 2009). The properties of leather vary due to the physical structure and chemical composition (Bitlisli *et al*., 2004), collagen fibre architecture and collagen fibre orientation in the hide and leather matrix (Basil-Jones *et al*., 2010; 2013). Good animal husbandry is essential for high quality hides and leather products. The growing automotive leather sector provides an opportunity for the smallscale famers to participate in the leather sector in South Africa. A potential exists for value-addition in the South African beef market using locally adapted breeds while conserving them through utilization for buffering against future environmental shocks and for future generations.

1.2 Problem Statement

The beef supplied by the two farming sectors meets only 85 % of the beef requirements in South Africa leaving a deficit of about 15 % which is catered for through imports, making South Africa a net importer of beef (DAFF, 2011a). More than 70 % of all beef slaughtered in the formal sector in South Africa originates from commercial feedlots, where 67 % of the feedlot animals are crossbreeds, or British and European imported breeds (53 %) (Scholtz *et al*., 2008). Emerging and communal farmers who own 40 % (5.69 million) of the national cattle herd have a low off-take rate of between 2 - 5 % (Mapiye *et al*., 2009), contributing to the observed shortage of beef on the local market. Livestock production is mainly carried out on small-scale communal or subsistence levels (Scholtz *et al*., 2008; Nengovhela, 2010). The

communal smallholder sector mainly keeps indigenous breeds of the Sanga type such as the Nguni cattle and Afrikander while the emergent small-scale farmers mainly rear the non-descript crossbred cattle (Scholtz *et al*., 2008). These breeds have, however, been discriminated against for a long time by extension agents as being unsuitable for beef production compared to improved breeds due to their small frame (Mapiye *et al*., 2009). However, very little information exists on the performance and quality of beef from indigenous and non-descript crossbred cattle genotypes kept under similar conditions. Furthermore, there is a paucity of information on the adaptive physiological responses of Nguni and non-descript crossbred cattle reared under similar conditions in extensive systems considering the changing climate and effects of the production environment on product quality.

The shortages in the beef value chain subsequently affect the leather industry in South Africa as it is currently facing huge shortages of skins and hides. The industry is increasingly relying on imports and substitutes to cover the deficit in annual requirements. This has led to a very significant import penetration in South Africa. For example, the local shoe manufacturing sector has been converted into a commercial division mainly involved in importing shoes (Baron, 2012). Furthermore, the automotive upholstery leather sector imports substantial amounts of raw hides and finished leather annually to cater for the demand for leather seats in the local and export markets (Brits, 2015; Venter, 2015). There have been reports of high rates of return of leather car seats and complaints by customers due to inconsistence in quality (Ballard, 2001). General leather goods and footwear manufacturers also complain of shortages of good quality hides leading to a reliance on imported raw hides and semi-processed leather, which in turn leads to viability problems (Baron, 2012).

Very few hides enter the local leather market from the smallholder sector due to perceived poor quality (Ballard, 2001). The small proportion that is collected by hide merchants is exported as the local leather market cannot make use of them due to perceived poor quality (Ballard, 2001). However, no research has been carried out the quality of hides and leather that can be commercialised from the Nguni and non-descript crossbred cattle.

1.3 Objectives

The major aim of this study was to determine the adaptive responses of Nguni and non-descript crossbred cattle to heat stress by measuring the nutritionally-related blood metabolite profiles, fatty acid profiles, carcass and meat characteristics. A second aim was to also quantify this adaptive response to the physico-mechanical properties of automotive upholstery crust leather and the associated collagen fibre architecture of hides and crust leather. The specific objectives are to determine:

1. the effects of environmental thermal load, body condition, coat characteristics and skin traits on rectal temperature, skin temperature, serum cortisol and creatine kinase in Nguni and non-descript crossbred cattle raised extensively on a sweetveld during a hot wet season
2. the changes in blood metabolite concentrations and their relationship to growth performance, carcass characteristics and weights of hides of Nguni and non-descript crossbred cattle raised on a sweetveld during a hot wet season.
3. fatty acid profiles and physico-chemical quality of beef from Nguni and non-descript crossbred cattle raised on a sweetveld during a hot wet season.
4. the physico-mechanical characteristics of automotive upholstery leather from Nguni and non-descript crossbred cattle hides and the associated collagen fibre architecture of specimens of hides and leather sampled from the neck, belly and butt regions

1.4 Hypotheses

1. There are no differences in the effects of environmental thermal load, body condition, coat characteristics and skin traits on rectal temperature, skin temperature, serum cortisol and creatine kinase in Nguni and non-descript crossbred cattle raised on a sweetveld during a hot wet season.
2. Blood metabolite concentrations and their relationship to growth performance, carcass characteristics and weights of hides of Nguni and non-descript crossbred cattle raised on a sweetveld during a hot wet season are similar.
3. Fatty acid profiles and physico-chemical quality of beef from Nguni and non-descript crossbred cattle raised on a sweetveld during a hot wet season are similar.
4. Physico-mechanical characteristics of automotive upholstery leather from Nguni and non-descript crossbred cattle hides and the associated collagen fibre architecture of specimens of hides and leather sampled from neck, belly and butt regions are similar

1.5 Justification

The increasing demand for high quality meat from naturally raised livestock and high quality leather products on the global market presents opportunities for extensive beef farmers to increase their income earnings by taking advantage of these niche markets. Improving beef production from the smallholder farming sector improves their income earnings and employment opportunities, leads to a reduction in imports and increases foreign currency earnings. The University of Fort Hare (UFH) Nguni Cattle Project that commenced in 1994 is one such avenue that has been undertaken to encourage re-adoption of indigenous breeds that can perform well under climatic and socio-economic conditions prevailing in the Eastern Cape Province and other provinces in South Africa. Studies have been done to determine the

performance of the Nguni cattle under controlled ecological conditions and the breed has been found to perform as good as improved breeds or even better in terms of reproductive performance and meat quality (Strydom *et al*., 2000; Muchenje *et al*., 2008; Mapiye *et al*., 2009). Studies which compare the performance of indigenous and non-descript crossbred cattle genotypes kept under similar conditions in terms of meat quality will assist in assessing the risk posed by the farming with these genotypes in view of climate change and global warming.

For the leather industry stakeholders to be competitive in local and international markets, they require hides that meet minimum quality standards for the intended application of the finished leather (Oliviera *et al*., 2007). For instance, automotive leather upholstery uses only the top 1-2 mm of the hide (the grain) and requires only good quality hides due to the stringent demands of the automotive industry (Ballard, 2001). The South African automotive industry promotes the use of indigenous resources such as cattle hides in the manufacture of automotive leather upholstery through the recently ended Motor Industry Development Programme (MIDP) and the current Automotive Development and Production Programme (APDP) (Bronkhorst *et al*., 2013). In addition, Nguni skins and hides can be used in furniture upholstery, luggage leather and fashion leather apparels. However, these products are destined for international luxury goods markets which require high quality leather products. Studies on hide and leather quality from Nguni and non-descript cattle genotypes reared by smallholder farmers will assist in decisions on how to improve the products to meet the requirements of the formal markets.

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Chapter 2: Literature review

[Part of the literature review was submitted to *South African Journal of Animal Science*]

2.1 Introduction

Livestock production in smallholder communities is mainly practised on small-scale communal or subsistence levels (Scholtz *et al*., 2008; Nengovhela, 2010). In South Africa, the smallholder communal sector mainly rears indigenous cattle breeds of the Sanga type such as the Nguni and Afrikander while the emergent small-scale farmers mainly rear the non-descript crossbred cattle (Scholtz *et al*., 2008). Most of the farmers use informal markets to sell their livestock for fear of condemnation of their livestock in formal beef markets. According to Mapiye *et al*. (2009a), feed shortages, diseases and parasites are the most common problems faced by smallholder and communal farmers and these challenges could result in animals that are in poor body condition. While informal markets are readily available, the income that the farmers get from these markets is very low. Most of the farmers are poor and depend mainly on agriculture for their livelihoods (Ndhleve *et al*., 2013).

Improvements in livestock productivity and marketing of livestock products from the smallholder sector have the potential to improve household food security and reduce poverty (Musemwa *et al*., 2008; FAO, 2011). Furthermore, participation of the small-scale farmers in the formal beef and hides markets will assist in reducing shortages of beef and hides currently being experienced by these two sectors. The following literature review focuses on various factors that affect the quality of products such as meat and co-(by)products such as hides from indigenous cattle reared in smallholder livestock production systems and options that can be used to address them. Challenges to value addition of hides and skins and options for reducing vulnerability of cattle to heat stress will also be explored.

2.2. Cattle breeds kept by smallholder farmers

The beef sub-industry in South Africa consists of approximately 50 000 commercial farmers, 240 000 emerging farmers and about 3 million communal farmers (DAFF, 2013). The major cattle breeds in the commercial sector are British or European imported breeds and their crossbreeds (Scholtz *et al*., 2008). A large proportion of cattle owned by small-scale and emerging farmers in South Africa are the non-descript crossbred genotype (Scholtz *et al*., 2008; Mapiye *et al*., 2009a). This is followed by indigenous breeds such as the Nguni cattle. According to Tada *et al*. (2012), the Eastern Cape Province of South Africa is considered as the homeland of the indigenous Nguni cattle. The population of the Nguni cattle was decimated in the period spanning from the apartheid era to soon after independence at the end of the apartheid era in 1994 (Bester *et al*., 2004; Phiri, 2009). This scenario stemmed from efforts to improve the productivity of cattle in the communal areas of South Africa which, however, resulted in replacement, substitution and random indiscriminate mating with improved European and British breeds of cattle (Mapiye *et al*., 2009a; Tada *et al*., 2012). The random mating of the Nguni breed resulted in the proliferation of the non-descript crossbred cattle genotype (Mapiye *et al*., 2009a). Over time, it was realised that the improved breeds were unsuitable for the low input systems that characterise the smallholder communal sector (Mapiye *et al*., 2009a; Tada *et al*., 2012) and would therefore, not result in improved livestock productivity. Currently, there is widespread promotion of adapted breeds such as the Nguni cattle in small-holder farming areas (Raats *et al*., 2004).

Nguni cattle are able to produce good quality beef comparable to improved breeds such as the Angus (Ramsay *et al*., 2000; Mapiye *et al*., 2007; Muchenje *et al*., 2008a; Mapiye *et al*., 2010a; Tada *et al*., 2012) under ecologically controlled low-input free-ranging systems due to their adaptability and disease tolerance. They are reported to be adapted to low management

levels and have low maintenance requirements (Mapiye *et al*., 2009b). Furthermore, they are resistant to diseases and parasites and are multi-purpose animals, a combination desired by low-input resource poor farmers (Mapiye *et al*., 2007; Muchenje *et al*., 2008b; Mapiye *et al*., 2009b). They are also reported to be heat tolerant (Bester *et al*., 2003) and have a good reproductive capacity, producing a calf per year under low input systems (Bester *et al*., 2003). Furthermore, they have a sought-after, frequently symmetrical, multi-coloured hide which has potential to produce high quality hair-on-hides and tanned leather (Ramsay *et al*., 2000; Brits, 2014; Koro, 2015). Local Nguni hides are reported to be in demand in the lucrative automotive leather upholstery industry (Ramsay *et al*., 2000; Koro, 2015). The resistance of Nguni cattle to ticks increases the chances of producing high quality hides with minimal tick damage. Premium prices are paid for hides with very little tick damage (Ramsay *et al*., 2000; Tolossa, 2013). According to Tada *et al*. (2012), it is anticipated that the genetically upgraded Nguni cattle will be sold at premium prices. Monetary values of Nguni cattle as perceived by smallscale farmers range from approximately R2 900.00 for suckling calves to about R9 800.00 for breeding bulls (Tada *et al*., 2012). Cows and castrates were perceived to be worth between R5 000.00 – R7 000.00 (Tada *et al*., 2012).

Appreciation of the important adaptive and economic traits resulted in development programs aimed at the restoration of the Nguni breed in its original homeland in Eastern Cape Province (Musemwa *et al*., 2008) and for conservation of animal genetic resources as a result of the Convention on Conservation on Animal Genetic Resources' goals (Tada *et al*., 2012). Several institutions which include the UFH and the Eastern Cape Provincial Department of Agriculture collaborated to implement some nucleus breeding schemes aimed at re-stocking communal areas with the Nguni cattle breed (Raats *et al*., 2004; Mapiye *et al*., 2007). Participating communities are required to have fenced grazing areas and implement improved

rangeland management strategies such as rotational resting and use of appropriate stocking rates (Mapiye *et al*., 2007). A rangeland management committee oversees the implementation of the overall day-to-day grazing management practices (Mapiye *et al*., 2007). The project has benefited 72 communities to date (Tada *et al*., 2012). The initially targeted beneficiary communities were 100 (Raats *et al*., 2004). The project has, however, been expanded to seven Provinces, namely Mpumalanga, Limpopo, North West, Free State, Northern Cape, Kwazulu-Natal (Mojapelo, undated; Mashala, 2012) and Gauteng (Koro, 2015). The long-term goal of the project is to aid communal farmers in accessing niche markets such as organic food markets with the Nguni beef, venture into product processing and participate in the leather value chain using Nguni hides (Raats *et al*., 2004).

Various research projects have been carried out aimed at identifying production constraints (Mapiye *et al*., 2009a; 2009b), beef quality (Muchenje *et al*., 2008a; 2008c), breeding objectives (Tada *et al*., 2013), cattle marketing constraints and opportunities (Musemwa *et al*., 2007; Musemwa *et al*., 2008; Tada *et al*., 2013) and monetary valuation of the indigenous Nguni cattle by smallholder farmers (Tada *et al*., 2013) in the Eastern Cape Province. Mapiye *et al*. (2007) reported that very little value addition of Nguni cattle products, if any, is being undertaken despite the efforts to improve cattle productivity in the smallholder communities. To date, no research has been carried out to identify challenges and opportunities for value addition and possible niche markets for Nguni cattle products (Musemwa *et al*., 2008). Very little information is available on quality of hides and leather from Nguni and non-descript crossbred cattle reared in communal areas.

2.3 Hides and leather

The economic value of hides, leather, leather products and their by-products has increased

significantly over the past three decades (FAO, 2013a; Salehi *et al*., 2013). On a global scale, hides and their products earned a marketing value of around US$53 824.8 million from 2003 to 2005 (FAO, 2010a). The projected international trade value of the leather industry is roughly $100 billion per annum (UNIDO, 2010).

Raw hides, skins and leather are among the important agricultural commodities in South Africa, as they generate foreign currency earnings (DAFF, 2012). In 2013, for example, the value of exports of raw hides and further processed leather from South Africa exceeded US$ 55 million and US$17million, respectively in foreign currency earnings (DAFF, 2014) at an average exchange rate of R1: US$0.104 (X-rates, 2015). As a proportion of the value of South Africa's total exports, the value of exports of raw hides and leather is very low; only 0.3% (Jordaan and Eita, 2012). However, the demand for hides in the local and international leather industry outstrips the supply (FAO, 2013a; DAFF, 2014).

Hides and skins constitute significant proportions of animal liveweights and are valuable co-products when animals are slaughtered for meat (Covington, 2009; Leach and Wilson, 2009; Skunmun, 2013). According to Snyman and Jackson-Moss (2000), establishment of the true value of hides from different animal breeds assists livestock producers to be paid accordingly. For cattle slaughtered at liveweights ranging between 300 and 546 kg, hides and skins constitute between 6.1 – 8.4 % of the liveweights (Skunmun, 2013). FAO (2010a) reported that the weights of hides are generally 17 % of the carcass weight and around 7 % of the liveweight. Furthermore, the value of hides is estimated to be approximately 12 % of the total value of the animal (FAO, 2010a). In South African abattoirs, producer prices for hides increased from approximately R11/kg in January 2013 to approximately R18/kg in June 2015, with feedlot hides fetching slightly higher prices compared to veld hides against beef

carcass producer prices of R25.26 – R32.18/kg and R29.17 – R33.72/kg over the same period (RMAA, 2015). Therefore, a potential huge exists for industry stakeholders (from livestock producers to leather product manufacturers) to improve income earnings from trading in raw hides, leather and leather products. Income and employment opportunities available in this industry could help alleviate income generation constraints faced by resource-poor smallholder farmers. If the challenges besetting the small-scale farmers in South Africa can be addressed, they could play a significant role in the Hides, Skins and Leather industry in South Africa.

While any skin can be converted into leather, cattle hides and skins are most commonly used raw materials in the leather industry globally. The red meat sector in South Africa is an important source of raw hides and skins for the leather industry (DAFF, 2012), mainly from beef and dairy cattle. The hides and skins are supplied by the two livestock farming sub-sectors, namely commercial and small-scale sectors. Most of the hides that enter the leather value chain originate from the commercial sector and are mostly recovered from formal abattoirs linked to commercial feedlots which slaughter over 70% of all beef animals (DAFF, 2013).

Provinces such as Mpumalanga, Gauteng, Free State and Kwazulu-Natal provinces are the major suppliers of hides as they have large abattoirs and feedlots (DAFF, 2011a; DAFF, 2013). Only a small proportion of the hides that enter the leather value chain are recovered from the smallholder sector (DAFF, 2014). For example, the Eastern Cape Province, which has the largest cattle population and the highest proportion of resource-poor small-scale farmers (Scholtz *et al*., 2008; Nengovhela, 2010; Ndhleve *et al*., 2013), contributes very little to the hides, skins and leather industry (DAFF, 2012). This low contribution results from a

low annual cattle offtake, at approximately six percent (DAFF, 2012). This situation is also common in other African countries with large populations of indigenous livestock owned by smallholder farmers (Wayua and Kagunyu, 2012; Mwinyihija, 2014). Additionally, the smallholder sector in South Africa faces a number of challenges which affect beef cattle production (Nengovhela, 2010) and participation in the leather industry. There is a need to look into the challenges limiting offtake and contribution of smallholder farmers to beef and leather value chains to improve their participation in formal markets.

2.3.1 Factors affecting the quality of hides and leather from the smallholder farming sector

Quality is the major determinant of the competitiveness of both hides and leather in local and international markets as leather products are considered as luxury goods (FAO, 2010a; Wayua and Kagunyu, 2012; Mokhothu-Ogolla and Wanjau, 2013). The major concern of current and potential importers of hides, skins and leather from Africa is that of poor quality mainly caused by a number of factors, including poor livestock production practices (DAFF, 2012), inadequate flaying, poor hide preservation skills, poor branding (Chemonics International Inc., 2002; FAO, 2010a), prevalence of defects and lack of compliance with delivery dates (Mokhothu-Ogolla and Wanjau, 2013). Furthermore, the contribution of the smallholder sector to the leather industry is hampered by poor livestock marketing infrastructure (Musemwa *et al*., 2008; Tada *et al*., 2012), slaughtering methods, lack of leather processing skills, poor access to information and poor access to hide and leather markets (FAO, 2010). These factors affect both the extrinsic (prevalence of defects) and intrinsic quality of the hides and leather.

2.3.1.1 Animal husbandry practices

The environment in which an animal is reared and animal husbandry practices such as farming methods, transportation and slaughter methods contribute significantly to the quality of hides and leather, especially the absence or presence of pre-slaughter defects. Skin defects are classified as either pre-slaughter (pre-mortem) or post-slaughter (post-mortem) defects. Animals acquire pre-slaughter defects during their lifetime (Tolossa, 2013; Kahsay *et al*., 2015). They may be caused by natural (intrinsic) or acquired (extrinsic) factors (Tolossa, 2013). Animal husbandry practices contribute approximately 80% of the pre-slaughter defects (Tolossa, 2013).

Good animal husbandry practises can significantly reduce occurrence of defects on animal skins and hides (FAO, 2010a). In South Africa, animal husbandry practices differ in the two farming sectors. Large-scale commercial farmers use improved cattle breeds, have technological support and better animal health care (Nengovhela, 2010; DAFF, 2013). Most cattle reared in commercial systems are fattened in feedlots before slaughter (Scholtz *et al*., 2008; DAFF, 2012) and during this period scars and tick bites have time to heal. On the other hand, small scale farmers use indigenous cattle breeds and low-input farming systems with little to no management and veterinary care (Ramsay *et al*., 2000; Scholtz *et al*., 2008). Mapiye *et al*. (2009b) attributed poor performance of livestock in the small-scale sector to poor breeding practices and poor nutrition. Consequently, hides from the smallholder sector can be of poor quality (Mwinyihija, 2006; FAO, 2010a; Tolossa, 2013). In the Eastern Cape Province, for example, *Acacia* species, are invading natural rangelands resulting in proliferation of the Bisho Thornveld. Thorns and spines from woody species such as *Acacia* cause scratch marks on cattle skins, reducing the value of the hides. Furthermore, barbed wires used as boundary fences cause scratch marks when animals brush against them.

Besides mechanical scratches from thorns, brand marks also leave permanent scars on the hide. In South Africa, all animal owners are required to mark all cattle according to the Animal Identification Act (Act No. 6 of 2002) to curb stock theft, for positive identification, positive proof of ownership and to enable traceability (DAFF, 2011c). Marking can be done by tattooing, hot iron branding or freeze branding. However, there are high chances of damaging hides due to unskilled hot iron-branding. Furthermore, brands leave permanent marks that are visible after tanning and reduce the value of the leather (Kahsay *et al.*, 2015). It is recommended to place the brand on a visible, less valuable part of an animal (DAFF, 2011c). Freeze-branding has been shown to have less severe effects compared to hot iron branding when the dry ice method is used (Wright, 2002).

2.3.1.2 Animal disposal, transportation and existing market opportunities for small-scale farmers

In South Africa, there is a free marketing system for livestock. The deregulation of the South African meat industry in 1992 and the Marketing of Agricultural Products Act, Act no. 47 of 1996, permitted livestock producers to sell animals to any customer. The prices in such markets are determined by market forces of demand and supply. As a result, animals are sold through various routes in both the formal and informal markets (Musemwa *et al*., 2008).

In smallholder farming systems, cattle mainly exit farmers' herds through live cattle sales, slaughters, gifts-out and death (Mapiye *et al*., 2009a). These various routes determine the movement of hides from the farm of origin and their fate. Various marketing channels are used to market cattle in South Africa, although they can be broadly categorised into formal and informal channels (Musemwa *et al*., 2007). In formal markets, livestock owners sell directly to butcheries, auctions or abattoirs (Musemwa *et al*., 2007). However, smallholder

farmers prefer auctions (Musemwa *et al*., 2007; Tada *et al*., 2012). From auctions, cattle can be taken to feedlots before release for slaughter, to other livestock markets or straight to the abattoir. Abattoirs pay farmers based on grading system and small-scale farmers shun them for fear of loss of capital if their cattle get condemned (Musemwa *et al*., 2007).

Informal markets include selling of livestock to individual buyers for slaughter, traditional ceremonies such as funerals, customary celebrations, weddings and religious celebrations or for investment (Musemwa *et al*., 2007). Several factors including distance from the market, inadequate infrastructure, poor pricing of animal products and limited marketing options hamper access to formal markets. Consequently, most smallscale communal farmers use informal markets to sell their cattle (Scholtz *et al*., 2008).

2.3.1.3 Slaughterhouse and flaying expertise

Slaughter activities and flaying are very crucial for production of good quality hides and skins (FAO, 2010). Good quality skins are generated from appropriate slaughtering practices and advanced technologies such as equipment for hoisting animals up, animal hanging devices to enable complete bleeding and ease of flaying, automatic hide-pullers for prevention of flay cuts (FAO, 2010a), skilled flaying, use of appropriate flaying tools and training of slaughterhouse and flaying workers.

Smallholder farmers in South Africa slaughter cattle at different times of the year for consumption and traditional ceremonies such as funerals (Musemwa *et al*., 2008). Indigenous cattle breeds such as the Nguni are preferred in traditional ceremonies (Mapiye *et al*., 2009a). Sometimes cattle die due to various causes (FAO, 2010a). Such activities generate hides and skins on the farm/ homestead. If recovered, these skins and hides can be sold for income.

However, the major challenges are that such animals are often mostly hand-slaughtered and hand-flayed outside formal abattoirs resulting in incomplete bleeding as large animals are not hang-slaughtered. As a result, hides acquire defects such as flay cuts from use of improper knives and inexperienced flayers. Incomplete bleeding results in defects such as veininess in the leather as a result of the blood that remains in skin blood vessels (Mwinyihija, 2006). The blood can also lead to putrefaction of hides as it is a good medium for microbial growth (Orlita, 2004).

2.3.1.4 Recovery of hides

The time taken to preserve the hides after flaying is crucial. Hides become perishable soon after the death of the animal. The rate of decomposition is much faster in hot and humid environments compared to cold environments (Gudro *et al*., 2014). Raw skin (green hide) is made up of 60-65 % water, 25-30 % protein (Leach, 1995; Kudit *et al*., 2013), 4 % fat and about 1 % ash (Leach, 1995). Within 5 to 6 hours after animal slaughter, hides are susceptible to autolytic and bacterial decomposition as they are a good medium for enzymatic and microbial action (Cadirci *et al*., 2010). The hides decompose if they are kept wet (Thanikaivelan *et al*., 2004). They contain huge populations of different types of microorganisms derived from the air, water, soil, manure or other types of dirt. These microorganisms secrete proteolytic and collagenolytic enzymes which degrade the hide (Orlita, 2004).

Some of the defects due to bacterial action are hair-slip, red discolouration (or red heat), grain pilling and microbial biofilm (Cadirci *et al.*, 2010). These defects affect the quality and value of tanned leather (Cadirci *et al.*, 2010). In the case of Nguni hair-on hides, hair slip is totally unacceptable. On the other hand, hides can become hard and brittle when they are allowed to

dry out (Umney and Rivers, 2003). The collagen fibres shrivel and stick together (Covington, 2009). Both decomposition and drying out to a hard and brittle mass lead to loss of value addition opportunities. It is therefore, important that hides are quickly recovered following slaughter of meat animals.

2.3.1.5 Preservation and storage of hides

Many tanneries are not within reach of the farmers and abattoirs. Therefore, hides have to be stored for long periods of time and transported across long distances to tanneries. Various preservation methods are used ranging from short-term to long-term preservation. Use of common salt is one of the traditional methods of curing and is still the most common method of preservation of hides to date. However, pollution problems due to discharge of large amounts of salt in effluent have led to other methods of preservation being researched (Kanagaraj *et al*., 2015).

2.3.1.6 Processing techniques

Trade in raw hides, which are primary products, leads to losses in potential income they fetch very little compared to value-added products such as crust leather and finished leather products (Mwinyihija, 2014). Raw hides can be processed into automotive leather, furniture upholstery leather, fashion items, hair-on leather, footwear, luggage leather, saddler, industrial protective clothing and footwear, floor rugs, wall hangings and book binding leather (Brits, 2014). However, the leather industry in South Africa is strongly oriented to automotive leather manufacture (Ballard, 2001; ECDC, 2005; Venter, 2015). The Eastern Cape Province in South Africa offers excellent opportunities for value addition of raw hides. It is regarded as the hub of the automotive industry with various car assemblers such as DaimlerChrysler, BMW and Ford located in the Province (Eastern Cape Development

Corporation (ECDC), 2005). The car assemblers utilise leather car seats as components in luxury vehicles such as Mercedes Benz (ECDC, 2005). Furthermore, some large quantities of leather car seats are exported (ECDC, 2005). Such opportunities need to be harnessed for income generation at household and national levels.

There is a dearth of information on the standard physico-mechanical quality of automotive leather as different automotive manufacturers specify their desired physico-mechanical properties for automotive leather (BASF, 2009). Nevertheless, automotive leather must have high tensile and tear resistance, high light fastness, high heat resistance and high perspiration resistance (BASF, 2009). This is because high quality leather results in exceptionality, durability and serviceability while being easy to maintain (BASF, 2009).

2.3.2 Intrinsic leather quality

There are wide variations in properties of leather as animals are reared in various environments and production systems (Musa and Gasmelseed, 2013). According to Bitlisli *et al*., 2004), different leather products require leather with physico-mechanical properties that meet specified standards (Bitlisli *et al*., 2004). The properties are influenced by the physical structure, chemical composition and mechanical operations used in leather manufacturing (Bitlisli *et al*., 2004). Factors affecting the intrinsic quality of hides and leather include breed, gender, age (Engelbrecht *et al*., 2009; Salehi and Bitaraf, 2013; Tolossa; 2013), nutrition and processing methods (Engelbrecht *et al*., 2009).

2.3.2.1 Effect of genotype

Most tanneries receive loads of hides from various beef and dairy breeds from abattoirs (Covington, 2009; Leach and Wilson, 2009; DAFF, 2013). Physico-mechanical

characteristics differ significantly among animal genotypes and direction of sampling as skins and hides are anisotropic (Oliviera *et al*., 2007; Covington, 2009; Li *et al*., 2009). Breed type affects the size of the hide, fineness of the grain and fibre structure (Tolossa, 2013). The inherently small size of mature indigenous cattle breeds translates to smaller hides compared to larger framed imported breeds. Size is used as a basis for sorting hides and for pricing purposes (Skunmun, 2013). Fibre structure is an important determinant of mechanical properties such as strength and resiliency (Asano *et al*., 2009; Basil-Jones *et al*., 2010; Bail-Jones *et al*., 2012). The major component of skin is collagen type 1, a fibrillary protein (Asano *et al.*, 2009). Collagen type 1 is responsible for the mechanical properties of the skin (Liao *et al*., 2005; Asano *et al*., 2009; Basil-Jones *et al*., 2010; Basil-Jones *et al*., 2012). Collagen fibrils and fibres self-aggregate into the characteristic three-dimensional structure of skins and leather (Hagisawa and Shimada, 2005). Hierarchical levels of collagen aggregation contribute to tissue and structural integrity when placed under strain/stress (Hagisawa and Shimada, 2005).

Factors such as collagen content, collagen fibre size and fibril orientation are responsible for the variations observed in mechanical properites of leather (Basil-Jones *et al*., 2013). Furthermore, genetic defects which affect collagen fibre properties have been identified in cattle. The vertical fibre defect, for example, is commonly found in Hereford breeds and their crosses (Covington, 2009). It results in the fibres being less interwoven than in other breeds and, therefore, a weakness in the affected area in physico-mechanical properties (Covington, 2009). There is no remedy for vertical fibre defect.

Oliviera *et al*. (2007) and Salehi *et al*. (2013) reported that indigenous breeds produced leather of better tensile and tear strength than exotics and crossbred animals. Furthermore,

breed effects on hide weights have been reported. Hide weights increase with increasing liveweights, with larger breeds resulting in heavier hides (Wright, 2002). There is not much information on the size, weight and quality of leather made from indigenous cattle breeds such as the Nguni reared by small-scale farmers in South Africa. In addition, non-descript crossbred cattle are currently being upgraded by the Nguni open nucleus herds, have not been characterised in terms of the skin and leather physico-mechanical characteristics.

2.3.2.2 Effect of gender

Female animals produce thinner, finer and better quality skins which produce better quality leathers compared to skins from male animals (Tolossa, 2013). Cows produce leather with higher tensile strength compared to leather from steers (Wright, 2002). Furthermore, hide weight is affected by gender and class of animal (Skunmun, 2013). Steers were reported to produce heavier leathers than cows (Wright, 2002). The quality of Nguni hides has not been characterised by gender or age of the animals.

2.3.2.3 Effect of age

Age at slaughter affects the quality of the skin, where older animals produce coarse-grained skin with thicker substance while younger animals tend to have finer grains and better quality (Tolossa, 2013). Wright (2002) concurs with the findings that leather from heifers is of better quality than that from cows. Cloete *et al*. (2006) also reported that ostriches slaughtered at an older age produced heavier and thicker skins compared to those slaughtered at a younger age.

In South Africa, beef cattle reared in feedlot systems are slaughtered before the eruption of permanent incisor teeth, at approximately 12 – 16 months (classified as A-grade) or after eruption of up to two permanent incisor teeth (AB- grade) (Frylinck *et al.*, 2013). However,

pasture-based systems slaughter animals after the eruption of three to six permanent teeth (classified as B-grade) (Frylinck *et al*., 2013). Old animals, classified as C-grade, are also slaughtered from pasture-based systems especially from the smallholder communal systems (Soji *et al*., 2015). According to Wright (2002), younger animals produce better hides as they have lesser defects and have better, tight grain patterns than older animals. However, hides from younger animals tend to have more soluble collagen and therefore produce less leather which is lighter (Wright, 20002). Hides from older animals also tend to have more elastin and more crosslinking than hides from younger animals (Wright, 2002).

2.3.2.4 Effect of nutrition

Nutrition affects the general performance of the animals and in the process also affects the hide weight and quality (FAO, 2010a). The effects of nutrition on leather quality have been reported by several authors (Passman and Sumner, 1983; Cloete *et al*., 2006; Ebrahiem *et al*., 2014). Animals on a higher plane of nutrition produced thicker, heavier skins and leathers compared to those on lower levels of feeding (Cloete *et al*., 2006). No significant dietary protein level effects were observed on physico-mechanical properties of leather from ostriches (Cleote *et al*., 2006). However, Passman and Sumner (1983) and Ebraheim *et al*. (2014) reported better tear resistance, tensile strength and elongation at break in leathers from better fed animals compared to those on low planes of nutrition. Similarly, Ebrahiem *et al*., (2014) reported that animals grazing on poor condition pastures produce poor quality leather compared to those grazing on better quality pastures. Nutritional effects are mostly associated with provision of adequate nutrients for the full expression of an animal's genetic merit. Optimum diets supply adequate amounts of nutrients for maintenance, growth and reproduction. Conversely, diets that are deficient in certain critical nutrients lead to poor animal performance and product quality.

The long dry spells and droughts experienced in arid and semi-arid regions affect forage production and, therefore, the nutrition of cattle. Cattle experience periods of feed shortages which lead to loss of weight and body condition (Mapiye *et al*., 2009b). Furthermore, smallholder farmers face financial challenges in procuring conventional supplementary feeds (Mapiye *et al*., 2009b). Mapiye *et al*. (2010a) found lower concentrations of serum protein metabolites in Nguni cattle compared to local crossbred cattle. Furthermore, cattle grazing on the sweetveld in the cool-dry season had a higher prevalence of protein deficiencies (Mapiye *et al*. 2010a). Very little information exists on the quality of skins from the smallholder sector in South Africa. Hides from animals in poor condition result in papery leather of poor substance and poor quality (Mwinyihija, 2006). On the other hand, hides from animals in good condition result in the best leather quality (Leach and Wilson, 2009). Well-nourished animals tend to finish off with better carcass grades and generally produce leather of better quality than those with lower carcass grades (Leach and Wilson, 2009).

Cattle that were supplemented with leaf meal from *Acacia karoo*, which was the major invading woody species on communal rangelands, had improved performance, body condition, beef carcass and meat quality attributes (Mapiye *et al.*, 2010b; 2010c). Hide quality was, however, not evaluated; hence there is need to evaluate the quality of hides from cattle supplemented with forages such as *Acacia karroo*. Feeding *Acacia karroo* leaf meal improves cattle nutrition and may simultaneously reduce exposure of cattle to scratch marks from thorns and spines.

2.4 Meat

Studies on global meat consumption trends have shown a tremendous increase in both aggregate meat consumption and *per capita* meat consumption from 1990 (Delgado, 2003).

This increase is attributed to factors such as population growth, an increase in disposable incomes especially in developing countries, urbanisation, a decline in meat prices, trade liberalisation and development of global food markets (Delgado, 2003; Delgado, 2005). Furthermore, meat consumption is affected by other factors such as health-related issues, food safety, quality, convenience, animal welfare and environmental issues (Taljaard *et al*. 2006), ethics, religion and tradition (Font-i-Furnols and Guerrero, 2014).

In South Africa, per capita meat consumption (beef, pork, chicken and mutton) is relatively constant at 41 kg per person per year since 1970 (Taljaard *et al*., 2006). However, beef consumption has been increasing since 2001 and exceeds beef production leaving a deficit of approximately 15 % in annual requirements (DAFF, 2013). The deficit is catered for by importing beef from international markets (DAFF, 2013). The increase in meat consumption locally and on the global market creates income opportunities for livestock producers.

Consumers seek for food products with characteristics that enrich their lifetime beliefs (Barrena and Sanchez, 2009). Food products are also consumed to meet the need for essential nutrients (Binnie *et al*., 2014). Beef is considered to be a highly nutritious and valued food (Scollan *et al*., 2006). It is a rich source of nutrients such as high quality protein. Beef is also a good source of micro-nutrients such as zinc, iron, potassium and B-vitamins (FAO, 2013b; Cabrera and Saadoun, 2014). Meat fats are an important dietary energy source (Wood *et al*., 2008). They also provide essential fatty acids and fat-soluble vitamins. Furthermore, fat enhances cooking attributes of meat such as its palatability and sensory characteristics such as flavour, taste and juiciness (Andersen *et al*., 2005; Wood *et al*., 2008; Cabrera and Saadoun, 2014). Beef is a dietary source of conjugated linoleic acid (CLA) which possesses a range of health promoting biological properties including antitumoral and anticarcinogenic

activities (Scollan *et al*., 2006).

Red meats have also been associated with negative effects on the health and well-being of the consumers and there are some recommendations to limit their intake (Binnie *et al*., 2014). The fat content of meat, for example, has been linked to both positive and negative effects on consumer health (FAO, 2010b). The levels of cholesterol and saturated fatty acid composition are of concern to consumers regarding their effects on low density lipoprotein (LDL) cholesterol and high density lipoprotein (HDL) cholesterol in blood serum (Schaefer, 2002; Scollan *et al*., 2006; Wood *et al*., 2008). These are linked to risks of cardiovascular diseases, atherosclerosis and cancer (Schaefer, 2000; Scollan *et al*., 2006). With regards to meat fat, modern consumers prefer lean meat with little to no visible fat (Morales *et al*., 2013). Total fat, saturated fatty acids (SFA), n-6 poly unsaturated fatty acids (PUFA), n-3 PUFA and trans fatty acids should contribute <15-30 %, <10%, <5-8 %, <1 – 2 % and < 1 % of total dietary energy intake, respectively (WHO, 2003). According to Warner *et al*. (2010), consumers need to be supplied with meat of high quality for continued consumption and their wellbeing.

2.4.1 Meat quality

Similar to the hides, the quality of meat derived from an animal is important in determining the value of the animal as a whole. Meat quality relates to characteristics that are sought after by consumers (Becker, 2000). They include visual, sensory and credence characteristics of meat (Becker, 2000; Maltin *et al.*, 2003). Attributes such as appearance, freshness, juiciness, tenderness and nutritional value are used to make purchasing decisions (Grunert *et al*., 2004; Andersen *et al*., 2005). However, some attributes, referred to as credence or trust characteristics, are not visible to the consumers at the point of purchase (Barrena and Sánchez, 2009; Warner *et al*., 2010). In addition, type of production system used is also

included in the definition of meat quality due to recent concerns about animal welfare.

Despite positive attributes of beef, its consumption has been linked to several negative attributes. The high amounts of saturated fats in beef have been linked to cardiovascular diseases and colon cancer (Schollan *et al*., 2006; Cho *et al*., 2010; Daley *et al*., 2010). Non-nutritional meat safety issues such as animal health scares, have also increased consumer concerns about beef e.g., Bovine spongiform encephalopathy (BSE) (Scollan *et al*., 2006).

Appearance is one of the few criteria used by consumers to judge the quality of meat at point of purchase (Andersen *et al*., 2005), most notably the colour and water holding capacity of meat (Warriss, 2000; Andersen *et al*., 2005; Weglarz, 2010). Consumers relate meat colour to freshness (Weglarz, 2010). They prefer beef with a lighter colour than a dark colour (Font-i-Furnols and Guerrero, 2014). Meat colour is measured according to three colour coordinates, i.e., lightness (L*), redness (a*) and yellowness (b*) (Commission International De' Eclairage, 1976). It is affected by animal breed, diet, age, exercise (Muchenje *et al*., 2008a), pigments, tissue composition, structure of the meat (Weglarz, 2010) and level of the protein pigment (myoglobin) present in the muscle (Maltin *et al*., 2003). It is also associated with variations in intramuscular fat, moisture content and age – dependent changes in myoglobin content (Purchas *et al*., 1999). Water holding capacity relates to the drip or exudate from the meat (Warriss, 2000). Meat with a poor water holding capacity has a high drip loss, which results in a high weight loss in fresh meat and poor juiciness after cooking (Warriss, 2000).

Meat pH gives an indication of the shelf life and technological processing characteristics of meat (Weglarz, 2010). Good quality meat has an ultimate pH (pH_u) ranging between 5.4 and 5.6 (Weglarz, 2010). Prior to slaughter, the pH of animal flesh is neutral at around 7.1 - 7.2

(Immonen *et al*., 2000; Muchenje *et al*., 2008a). After slaughter, meat pH declines due to formation of lactic acid from glycogen through the process of anaerobic glycolysis (Carpenter *et al*., 2001). The rate of pH decline is dependent on glycogen levels at slaughter, which in turn vary due to factors such as animal species, breed, rearing conditions, muscle type and animal handling prior to slaughter (Immonen *et al*., 2000; Muchenje *et al*., 2008a). The rise in pH after attainment of pH_u, to pH > 6.5 leads to decomposition of the meat due to microbial activity (Warriss, 2000). Ultimate pH > 5.8 results in poor taste and reduced shelf life (Weglarz, 2010). Stressful handling or transportation results in dark firm dry (DFD) meat, which has poor quality, short shelf life and is disliked by consumers (Muchenje *et al*., 2009a).

Palatability or eating quality encompasses texture, juiciness and flavour/odour (Warriss, 2000). Beef consumers generally rate tenderness as the most important palatability trait (Warner *et al*., 2010). Variation in meat tenderness is a major concern for consumers as they prefer tender beef (Thompson, 2002; Muchenje *et al*., 2008a, 2008c). Meat tenderness is influenced by age, live weight, sex, breed of the animal, pre-slaughter stress, rate of chilling of the carcass post-slaughter (Maltin *et al*., 2003), collagen content, heat stability of the meat (Muir *et al*., 2000), cooking temperature and duration of cooking (Obuz *et al*., 2003). Meat tenderness varies as a result of modifications of muscle myofibrillar protein structure from time of slaughter to the time of consumption (Muir *et al*., 2000).

Flavour is largely determined by water-soluble constituents, while odour is determined by fat soluble, volatile elements (Warriss, 2000). Juiciness, tenderness and aroma are also influenced by the content and composition of marbling fat (Scollan *et al*., 2006). According to Scollan *et al*., 2006, flavour score markedly increases with increasing fat content above 4 – 5 %. Lean beef has a low intra-muscular fat (IMF) content of between 2 – 5 %, which is

acceptable to consumers (Wood *et al*., 2008). Marbling (intramuscular) fat is the fat depot of most interest in relation to fatty acid composition and human health (Scollan *et al*., 2006).

2.4.2 Factors affecting meat quality

Meat quality is affected by genetic and environmental factors and their interactions (Warner *et al*, 2010). Factors such as intrinsic animal factors, pre-slaughter and post-slaughter conditions affect aspects of production, slaughtering and conditioning which lead to variations in meat quality (Maltin *et al*., 2003).

2.4.2.1 Breed effects

Sanũdo *et al*. (2004) observed breed differences in carcass and meat quality when animals were subjected to the same conditions. According to Warriss (2000), muscle development is controlled by various genes and gene products. Various DNA markers have been linked to meat quality (Thaller *et al*., 2003; Barendse *et al*., 2007; Fortes *et al*., 2009). The various candidate genes affect muscle fibre type diversity, regulation of muscle mass and ultimately the yield and quality of meat in animals (Warriss, 2000), resulting in intra- and inter-muscular variations in meat quality (Warner *et al*., 2010). Both fibre type and muscle mass affect meat quality and quantity (Warner *et al*., 2010). Muscle type and site within the muscle influence the effect of genes on a trait (Warner *et al*., 2010).

Breed differences have been reported in meat colour, intramuscular fat content, water holding capacity and tenderness (Warriss, 2000; Barendse *et al*., 2007; Smith *et al*., 2009; Muchenje *et al*., 2009a). Intramuscular fat deposition has also been associated with genetic control of feed conversion efficiency (Barendse *et al*., 2007). Breed differences reflect underlying differences in gene expression or activities of enzymes involved in fatty acid synthesis,

desaturation or chain elongation (Smith *et al*., 2009). Differences in fatty acid composition among breeds result from variations in the proportion of intramuscular fat expressed as the ratio of polyunsaturated fatty acids to saturated fatty acids (PUFA:SFA) (Scollan *et al*., 2006; Wood *et al*., 2008). This ratio decreases with a decreasing level of fat in beef, although it is also affected by nutrition (Scollan *et al*., 2006; Dalley *et al*., 2010). Fatty acid composition is closely related to the level of fatness and is affected by genetics and diet (Scollan *et al*., 2006). Hence, breeds of cattle and the way they are managed affect fatty acid composition. Therefore, the properties of the final product and its acceptability can be improved through genetic selection within a breed and its production system, from an understanding of the relationships among production, carcass and meat quality variables (Sanũdo *et al*., 2004).

2.4.2.2 Environmental effects

Environmental effects that affect meat quality are those non-genetic factors such as on-farm conditions, animal handling, stress susceptibility during transportation and loading/unloading, heat stress during transportation, temperament, response to handling and towards the handlers at the abattoir and novelty of the abattoir environment (Warner *et al*., 2010). Furthermore, post-slaughter processing such as variation in electrical stimulation, response of the carcass to stimulation, rate of chilling and ageing affect meat quality (Daly *et al*., 1999; Immomen *et al*., 2000; Muchenje *et al*., 2009b; Bourguet *et al*., 2010; Warner *et al*., 2010).

Pre-slaughter handling may induce stress in animals, which in turn stimulate the release of stress hormones such as catecholamines and cortisol (Muchenje *et al*., 2009b). Pre-slaughter stress and the responsiveness of animals to stress affect meat quality (Muchenje *et al*., 2008). Physiological responses of animals to stress affect glycogen depletion in animals and meat quality parameters such as pH_u, colour, cooking losses and tenderness (Muchenje *et al*.,

2009b). Pre-slaughter glycogen depletion in muscle may result in meat with a higher ultimate pH (Immonen *et al*., 2000).

2.4.2.3 Nutrition

According to Priolo *et al*. (2001), how animals are fed significantly influences meat quality. Several studies have shown that different production systems, such as grassfed vs concentrate-fed systems, result in differences in meat quality. Beef from grassfed systems is darker than that from feedlot or concentrate-based systems (Daly *et al*., 1999; Mapiye *et al*., 2010b). Furthermore, beef from concentrate-fed cattle has lower ultimate pH than that from pasture-fed cattle (Daly *et al*., 1999; Mapiye *et al*., 2010b).

According to Warner *et al*. (2010), fluctuations in cattle nutrition towards slaughter can significantly affect beef quality, especially tenderness. Variations in nutrition and growth in the early life stages of animals may not necessarily affect the quality of meat at slaughter unlike in the finishing stage (Warner *et al*., 2010). However, if nutritional effects retard animal growth prior to the finishing period, animals may be older when they reach market weight. Consequently, tenderness will be reduced (Purchas *et al*., 2002).

The diet fed to beef cattle also has an effect on the fatty acid composition and lipid content of meat (Scollan *et al*., 2006; Wood *et al*., 2008). For example, forage-fed beef contains higher proportions of conjugated linoleic acid (CLA) which exhibits anti-carcinogenic properties and can immensely increase animal body protein than concentrate-fed beef (Wood *et al*., 2008). Forage feeding also improves the n-6 to n-3 fatty acid ratio which impacts positively on cardiovascular health (Daley *et al*., 2010). Pasture-fed beef has higher concentrations of PUFA, stearic (18:0), linoleic (18:2 n-6, LA), α-linolenic (18:3 n-3, LNA), arachidonic (20:4

n-6, AA), eicosapentaenoic (20:5 n-3, EPA), and docosapentaenoic (22:5 n-3, DPA) acids compared to those fed on concentrates (Scollan *et al*., 2006).

2.5 Climate

Beef cattle are kept in widely varying environments mostly under extensive conditions with minimum environmental modifications (Scholtz *et al*., 2013). Thus, cattle reared in diverse environments which vary in temperature, humidity and wind effects differ in their adaptive responses (Burrow and Prayaga, 2004; Henry *et al*., 2012). According to Burrow and Prayaga (2004) and Goddard (2013), cattle kept in extensive free-ranging systems are prone to the effects of adverse environmental conditions (Burrow and Prayaga, 2004; Goddard, 2013). Furthermore, Nardone *et al*. (2010) postulate that extensive grazing and mixed farming systems are at higher risks of the devastating effects of global warming and climate change.

The effects of climate change and water scarcity are already being experienced in South Africa (Blignaut, 2009; Fourie *et al*., 2013; Ndhleve *et al*., 2014). For example, Blignaut (2009) reported an increase of approximately 6 % in temperature and a decrease of about 6 % in rainfall in the Eastern Cape Province in the last two decades. The majority of smallholder farmers in South Africa rely on livestock farming for their livelihood (Musemwa *et al*., 2008; Ndhleve *et al*., 2013). Approximately 75 % of these farmers rear cattle in extensive, communally-managed grazing rangelands which are severely degraded (Scholtz *et al*., 2008; Mapiye *et al*., 2009b). Over 70% of these smallholder farmers are located in harsh, semi-arid agro-ecological regions of South Africa (Bester *et al*., 2003; Mapiye *et al*., 2009b). These semi-arid areas are characterised by high temperatures, long dry periods (Marufu *et al*., 2011) and frequent droughts (Collins-Lusweti, 2000; Mapiye *et al*., 2009a; Ndhleve *et al*., 2013) which make crop production unsuitable (Mapiye *et al*., 2009a; Ndhleve *et al*., 2013).

2.5.1 Effects of climate change on animal performance and meat quality

High ambient temperatures in conjunction with high relative humidity predispose cattle to development of heat stress (Burrow and Prayaga (2004). According to Burrow and Prayaga (2004), heat stress is one of the major challenges to livestock production in hot environments as it leads to poor animal welfare, reduced animal production and reproduction. Exposure of animals to high temperatures may lead to reduced ability to thermoregulate and therefore, affect normal animal behaviour, immunological and physiological functions of the animal (Henry *et al*., 2012; Scholtz *et al*., 2013). Futhermore, it affects energy and nutrient metabolism, animal growth rate and the quality of products such as carcass, meat and hides (Kadim *et al*., 2008; Leach and Wilson, 2009; Baumgard and Rhoads, 2012; Liu *et al*., 2012).

Variations have been observed in animal responses to thermal stress. Factors attributed to this variation include animal species, breed, previous exposure, health status, level of performance, body condition, age of the animal, whether an animal was sufficiently acclimatised to the environment or not and adaptation (Hansen, 2004; Henry *et al*., 2012). Metabolic and digestive functions of animals may be altered when animals are thermally stressed (Baumgard and Rhoads, 2012; Henry *et al*., 2012). Inability to regulate body temperature leads to decreases in biological efficiencies, such as a decline in feed efficiency due to more energy being diverted to thermoregulation (Baumgard and Rhoads, 2012). Reduction in overall growth rate results in more days on feed and tougher meat. The immune system is also compromised, resulting in increased susceptibility to diseases.

According to Gregory (2010), climate change could affect meat quality by direct effects on organ and muscle metabolism during heat exposure which can persist after slaughter,

resulting in darker cutting beef in cattle and dehydration. Chances of dark cutting beef increase when ambient temperature exceeds 35 ^{o}C (Kadim *et al*., 2004). Nardone *et al*. (2006) reported that hot environments may promote more deposition of fat in internal depots compared to the subcutaneous layer, resulting in higher marbling in beef.

2.5.2 Effects of climate on skin/hide quality

The skin is the major organ involved in thermoregulation, with its structure determining the efficiency of thermoregulation and heat tolerance status of cattle to high temperatures (Hansen, 2004). Heat tolerance has been reported to vary within – breed and among breeds (Hansen, 2004; Baumgard and Rhoads, 2012). Morphological and physiological adaptations of different livestock genotypes differ (Hansen, 2004). Examples of such adaptations include skin and hair-coat characteristics such as coat colour, coat score and hide thickness (Foster *et al*., 2009), skin pigmentation, skin thickness, hair length, hair colour and coat thickness (Darcan *et al*., 2009). Hair and skin pigmentation are under genetic control (Seo *et al*., 2007; Mohanty *et al*., 2008) and they are responsible for coat and skin colour variations (Darcan *et al*., 2009). Variations in hair pigments result in the different colour patterns on Nguni hides. Coat colour and colour patterns determine the grading and value of hair-on skins.

Coat scores differ among different cattle breeds (Hansen, 2004). In South Africa, Foster *et al*. (2009) reported variation in coat scores among six cattle breeds and the coat scores were correlated with rectal temperature in Charolais heifers (Foster *et al.* (2009). Nguni cattle have been reported to have low to moderate coat scores, i.e., fairly smooth, short hair coats (Marufu *et al*., 2011). All cattle breeds develop higher coat scores (thicker coats) in winter which they shed off in summer (Wright, 2002). Coat scores and type determine the quality of hair-on skins produced by different ecotypes of Nguni cattle in different environments and

seasons. They also determine the choice of processing methods used on the skins and hides. Hair removal during manufacturing of un-haired leather results in the characteristic grain pattern that is responsible for the natural beauty of leather from various animal species.

It appears that animals adapted to hot environments have thicker hides compared to temperate breeds (Foster *et al*. 2009). An indigenous breed in South Africa, the Afrikaner, had the thickest hide (14.1 ± 0.52 – 16.4 ± 0.16 mm) while an imported breed, the Charolais had the thinnest hide (8.0 ± 0.30 – 10.4 ± 0.4 mm) in a study involving six breeds (Foster *et al*., 2009). Variability in hide thickness among different breeds affects the choice of leather processing techniques and leather quality characteristics such as tensile strength and elongation at break. Hides are also split into the grain and flesh splits based on hide thickness.

Heat stress effects such as reduced feed intake and nutritional status of cattle can affect the condition of the skin (Mwinyihija, 2006). Nguni cattle are reported to maintain good to fair body condition in periods of feed scarcity such as droughts and cool dry season (Collins-Lusweti, 2000). Hides from animals in poor body condition lack substance and are of poor quality (Mwinyihija, 2006). Over-conditioned animals deposit too much fat in the flesh layer making the hides difficult to process (Leach and Wilson, 2009). The best leather quality is obtained from animals with optimum body condition (Leach and Wilson, 2009).

2.5.3 Adapting beef animals to global warming due to changing climatic conditions

The significant reduction in performance for beef cattle under thermal stress leads to significant economic losses. Minimising effects of high heat load on animal performance can be achieved through various ways including manipulation of the environment, e.g., provision of shade, sprinkling water on animals, manipulation of the diets of animals and feeding

patterns and selection of animals for high thresholds of thermo-tolerance (Renaudeau *et al*., 2010). Environmental manipulation and change in diet may be difficult to implement in extensive systems. Therefore, breeding for thermo-tolerant animals needs to be explored.

Thermo-tolerance is a quantitative trait, which is affected by genetic factors, environmental factors and genetic by environmental interactions (Webb and Casey, 2010). Mutations in the genes lead to polymorphism which affects the differential thermo-tolerance behaviour. These thermal differences enable the use of genetic tools such as molecular biotechnology to characterise gene expression, identify key cellular responses to heat stress and determine the relationship between adaptive and production traits (Renaudeau *et al*., 2012). Worldwide, both natural and artificial selection programmes have led to the development of cattle genotypes adapted to particular ecotones in their environments (Rege *et al*., 2011). Various cattle genotypes have been developed to meet the needs of livestock-keepers (Rege *et al*., 2011). In the smallholder farming systems of the tropics and sub-tropics, production systems evolve according to bio-physical characteristics of the environment and the socio-cultural environment of the farmers (Swanepoel and Setshwaelo, undated).

According to Renaudeau *et al*. (2012), strategies for mitigating challenges of heat stress include those that focus on increasing feed intake or decreasing metabolic heat production, those that enhance heat loss capacities and strategies involving genetic selection for heat tolerance. Mitigation strategies against the negative impact of heat stress would require identification and exploitation of heat tolerant germplasm/gene pool, DNA variation within a genome and an understanding and interpretation of genetic components which result in complex adaptive traits (Scholtz *et al*., 2013). This will also lead to development of novel indicator traits that can aid in selection for traits of economic importance such as disease

resistance and feed efficiency (Renaudeau *et al*., 2012). In addition, physiological indicator traits, such as hormone or heat shock protein response could be used for selection of economically important traits. Selection for individuals within a population with higher genetic thresholds for heat extremes would lead to reduced susceptibility at a faster rate than relying on breed differences alone. Identification of genes for cellular thermo-tolerance will lead to ease of transferring such genes to breeds that are prone to high heat loads, leading to improvement in physiological systems and reproduction and production traits of economic importance (Hansen, 2004).

2.6 Summary

Communal and small-scale emerging farmers in South Africa currently play a very insignificant role in the formal beef and leather markets despite the opportunities presented by the shortages in these sectors. The low input production systems and the type of breeds that are kept by the smallholder farmers create some disadvantages for participation in formal beef and hides markets. Livestock production potential is high but currently constrained by limited resource endowments, poor animal husbandry practices, lack of farming and value addition skills and inappropriate livestock breeds. Improvement in livestock production would lead to availability of more food of higher quality for family consumption for the resource-limited farmers and could offer them opportunities for improving income earning and enhance their capacity to access food. This will lead to an overall improvement in food security and standards of living. Furthermore, higher productivity of their livestock systems would enable them t participate in formal markets, improveing their income earnings.

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Chapter 3: Physiological responses of Nguni and non-descript crossbred cattle to environmental heat load in a semi-arid environment

Abstract

The objective of the study was to determine physiological responses of Nguni and non-descript crossbred cattle (NDCC) to environmental heat load on a sweetveld. Rectal and skin temperatures, cortisol and creatine kinase (CK) activity were determined over 16 weeks in 40 steers (20 Nguni and 20 NDCC) in a hot wet season. The steers were approximately 14 months of age at the beginning of the study. Ambient temperature, relative humidity, solar radiation and wind parameters were obtained from Honeydale research farm weather station. Temperature-humidity indices (THI) were computed. Hair-coat, skin traits, body condition and blood samples for cortisol and CK activity were analysed at two-week intervals. Coat scores ranged from extremely short (score 1) to very woolly (score 7). Results show that THI, wind speed and evaporation varied with week. Maximum THI was 92.3 ± 3.11 and minimum THI was 43.7 ±1.28. Environmental variables did not affect rectal temperature. Skin temperature was affected by week, maximum THI, solar radiation and wind parameters. Hair length varied across months. Five hair colours were observed (yellow-fawn, black, brown, red and white). Higher coat scores were observed in NDCC than in the Nguni cattle (2.1 ± 0.36 to 4.1 ± 4.20 and 1.6 ± 0.36 to 4.1 ± 0.36, respectively). Body condition, coat score, skin pigment and thickness were negatively correlated to skin and rectal temperatures. It was concluded that THI, body condition, hair and skin traits affect skin temperature, but not rectal temperature, cortisol and CK activity in Nguni and NDCC reared extensively.

Key words: adaptation, heat stress, skin colour, smallholder farmers, thermoregulation

3.1 Introduction

Various authors have indicated that global warming due to climate change will affect livestock production systems and livestock performance (Thornton *et al*., 2009; Thornton, 2010; Nardone *et al*., 2010; Scholtz *et al*., 2013). Variations in environmental factors due to climate change include lower rainfall, a higher frequency of occurrence of droughts and direct effects of high temperatures, solar radiation, relative humidity and wind speed on animals (Silanikove, 2000; Burrow and Prayaga, 2004; Nardone *et al.*, 2010; Scholtz *et al*., 2013).

According to Nardone *et al*. (2010), extensive grazing and mixed farming systems will be negatively affected by global warming and climate change. Cattle kept in extensive outdoor systems may suffer from exposure to adverse environmental conditions (Burrow and Prayaga, 2004; Goddard, 2013). In South Africa, Fourie *et al*. (2013) reported increasing evidence of climate change and water scarcity. Approximately 75 % of smallholder and emerging farmers in South Africa rear cattle in extensive grazing systems (Scholtz *et al*., 2008). They own approximately 40 % of the national cattle herd (Schotlz *et al*., 2008). Cattle genotypes reared in this sector are mainly non-descript crossbred and indigenous (Scholtz *et al*., 2008; Mapiye *et al.*, 2009). Non-descript crossbred cattle (NDCC) resulted from indiscriminate crosses between the indigenous cattle breeds such as the Nguni and imported improved breeds of cattle such as the Hereford, Aberdeen Angus and Jersey (Scholtz *et al*., 2008; Mapiye *et al*., 2009). Extensive systems in the arid and semi-arid regions are characterised by climatic extremes, large tracts of land that animals have to traverse in search of feed and are low input systems (Petherick, 2005).

Several authors (Petherick, 2005; McManus *et al*., 2009; Mirkena *et al*., 2010) suggested the

use of adapted animal genotypes in extensive, low input, harsh environments to mitigate some of the animal welfare issues and sustainable production. Improved cattle breeds and their crosses which are reared in the commercial sector due to desirable traits such as high growth rate, ability to reach market weight at an early age and good meat quality, have failed to perform in the smallholder emerging and communal sectors of South Africa (Bester *et al*., 2003). In addition, imported breeds are more prone to heat stress compared to indigenous breeds (Foster *et al.,* 2009; Fourie *et al*., 2013). Programmes to re-introduce indigenous breeds such as the Nguni cattle in most smallholder communities of South Africa are on the increase (Bester *et al.,* 2003; Raats *et al*., 2004).

In hot environments, heat stress is one of the major causes of poor animal welfare (Brown-Brandl *et al.,* 2006) which subsequently affects animal production and reproduction. Perano *et al*. (2015) defined heat stress as a condition that results from a failure to dissipate excess metabolic heat in animals subjected to high ambient temperature, high relative humidity or a combination of the two. Heat stress has been reported to have both direct and indirect effects on the animals and their physiology, energy and nutrient metabolism, growth rate, carcass and meat quality (Kadim *et al*., 2008; Baumgard and Rhoads, 2012; Liu *et al*., 2012). Physiological effects include changes in rectal temperature, skin temperature, respiration rate, heart rate (Ganaie *et al*., 2013), cortisol levels (du Preez, 2000; Trevisi and Bertoni, 2009) and creatine kinase activity (Rasooli *et al*., 2004; Srikandakumar and Johnson, 2004; Liu *et al*., 2012). Heat-stressed animals have reduced mobility, reduced appetite and poor health (Gray *et al*., 2011). They reduce metabolic heat production in an attempt to maintain core body temperature by decreasing feed intake.

Animals that have genetically adapted to hot environments can effectively regulate core body

temperature and will, therefore, not suffer huge declines in production due to heat stress. Coat and skin characteristics affect the response of livestock to environmental thermal conditions (McManus *et al*., 2011). These characteristics include coat thickness, structure, coat colour, hair length and type (Bertipaglia *et al*., 2007; Bernabucci *et al*., 2010; Fadare *et al*., 2013) skin thickness and colour (Foster *et al*., 2008; Darcan *et al*., 2009; Fourie *et al*., 2013; Cardoso *et al*. 2015). Furthermore, physiological responses to heat stress are affected by animal genotype, age of the animal, body condition, health status and nutritional status (Thornton *et al*., 2009).

Several studies have been conducted to establish the adaptability of Nguni cattle to various production environments (Mapiye *et al*., 2009; Mapiye *et al.,* 2010; Marufu *et al*., 2011; Katiyatiya *et al*., 2015; Mapfumo and Muchenje, 2015) and that of NDCC (Mapiye *et al.,* 2009; Mapiye *et al*., 2010). However, no comprehensive studies have been conducted to determine the simultaneous effects of multiple environmental factors, animal hair-coat, skin traits and body condition on animal welfare indicators such as rectal temperature, skin temperature, cortisol and CK activity in these cattle genotypes reared in the same environment in extensive grazing systems.

The objective of this study was, therefore, to determine the effects of environmental thermal load, body condition, coat characteristics and skin traits on rectal temperature, skin temperature, serum cortisol and creatine kinase activity as indicators of heat stress in Nguni and non-descript crossbred cattle.

3.2 Materials and methods

3.2.1 Study site

The study was carried out at Honeydale Research Farm, University of Fort Hare in Alice, Eastern Cape Province, South Africa. The farm is located at 32.8^{o} latitude and 26.9^{o} longitude and approximately 520 m above seas level. The mean annual rainfall is 480 mm received mainly in summer months of November to March (Acocks, 1988). Mean annual temperature of the farm is 18.7^{o}C, with a range of maximum temperatures of up to 24.6 ^{o}C and minimum 11.1 ^{o}C. The vegetation is known as the Bisho Thornveld (Mucina and Rutherfold, 2011). It is composed of several tree, shrub and grass species. *Acacia karroo* is the dominant woody species intermixed with other woody species such as *Scutia indica, Grewia occidentalis, Maytenus hetorophyla* and *Rhus longispina. Themeda triandra, Panicum maximum, Digitaria eriantha, Eragrostis spp, Cynodon dactylon* and *Pennisetum clandestinum* are the dominant grass species (Acocks, 1988). The farm is on a flat terrain with a few gentle slopes, on deep alluvial-derived soils.

3.2.2 Ethical clearance

Ethical clearance to conduct this research was granted by the University of Fort Hare's Research Ethics Committee (UFH/UREC) (Ethical clearance certificate number: MUC131SCHI01).

3.2.3 Environmental variables

Daily weather data was collected from a base station located on the University of Fort Hare Research Farm. It included ambient temperature (minimum, maximum, mean daily temperature averaged over 24 hours and averages of minimum and maximum temperatures), relative humidity, wind speed, direction and period, solar radiation, evaporation and amount of rainfall received. From the base station weather data, average, maximum and minimum temperature-humidity indices (THI) were calculated using the following formula:

THI = db – 0.55*(0.55*RH/100)*(db-58) (NRC, 1971)

Where bd = air temperature measured with a dry bulb;

RH= relative humidity of the air.

THI values of 70 or less are considered normal, 71 – 78 alert, 79 – 83 danger and 83 or above are considered as emergency.

3.2.4 Experimental animals and animal management

Forty steers (castrated male cattle) were used in this study. Twenty animals were of the Nguni breed and 20 were NDCC. They were approximately 14 months of age at the beginning of the study. The 40 steers were free-ranging together on the sweetveld located in the Bisho Thornveld. They were rotationally grazed on the paddocks and were moved to a new paddock every 21 days. Measurements of animal hair-coat characteristics and blood parameters were carried out at two-week intervals. The trial was conducted over a period of 16 weeks (February to May 2015), during the hot wet season (summer).

3.2.5 Data collection

3.2.5.1 Determination of body condition scores of Nguni and non-descript crossbred cattle

Body condition scores were determined at two-week intervals for the duration of the study by the same enumerator who was blinded to the treatments subjected to the cattle. Both visual appraisal and palpation were used. A 5-point scoring system was used according to the method by Osoro and Wright (1992) where a score of 1 is assigned to a very thin animal or emaciated and a score of 5 to a very fat (obese) animal.

3.2.5.2 Determination of hair-coat and skin characteristics of Nguni and non-descript

crossbred cattle

Coat colour groups were scored for different absorption rates according to Foster *et al*. (2009). Scores for coat colour groups were: white (score 0), grey (2), yellow-fawn (4), light-red (6), red (8), dark-red (10), brown (12), dark-brown (14) and black (16). Coat scores were assessed at two-week intervals for the duration of the trial. The hair coat scoring method of Turner and Schleger (1960) was used with the following scores: extremely short (score 1), very short (score 2), fairly short (score 3), fairly long (4), long (5), woolly (6), very woolly (7). Hair samples were shaved from an area measuring 1 cm^2 at the hair-skin interface once a month using a surgical blade, stored in ziplock plastics and sent to the laboratory for hair length measurement. A 30 cm ruler was used to measure hair length. The average of the 10 longest hairs of the sample was taken as the hair length (in millimetres) using the method of Foster *et al*. (2009) and Machado *et al*. (2010). Skin thickness was determined at two week intervals throughout the study period using a digital Vernier calliper (Reed DC515; U.S.A.) on the skin over the left mid-abdomenal side according to Tulloh (1961). The Vernier caliper was placed in an anterior to posterior direction on the animal body to measure skinfold thickness in millimetres according to Wesonga *et al*. (2006) and Foster *et al*. (2009). Skin pigment was determined by visual assessment of the colour of the skin under each colour patch and recorded.

3.2.5.3 Skin and rectal temperature determination

Skin surface temperature and rectal temperature measurements were carried out at two-week intervals prior to blood sampling. A non-contact infra-red thermometer (Nubee® NUB8380 Temperature Gun, California, USA) was used for determination of skin surface temperature. The infrared thermometer was held at a distance of approximately 30 cm from the animal to measure skin surface temperature as described by Scharf *et al*. (2012). Skin

temperature measurements were taken from the same position as skin thickness measurements. Rectal temperature and skin surface temperature were recorded at the same time as body condition score, coat scores and skin thickness just prior to blood sampling. Rectal temperature was recorded using a digital thermometer (Kruuse Digi-Vet SC 12, Denmark) inserted approximately 3 cm into the rectum for correlation with skin surface temperature. The sampling exercise was conducted between 10:00Hrs and 14:00Hrs.

3.2.5.4 Blood sampling and determination of cortisol and creatine kinase

Blood collection from experimental animals was done at two-week intervals by coccygeal venipuncture with 18 mm gauge needles into 5ml SST vacutainer tubes (BD Vacutainer®), Plymouth, UK) for determination of serum cortisol and creatine kinase. Vacutainers were kept on ice and centrifuged using a Model 5403 Centrifuge (Gatenbay Eppendorf, GmbH, Engelsdorp, Germany) at 3500 rpm at 10^{o}C for 15 minutes within two hours of collection for separation of serum and plasma. Blood serum for creatine kinase was immediately analysed for creatine kinase. For cortisol analysis, the serum was immediately transferred into red top evacuated vacutainers and frozen at -20^{o}C until analysis.

Creatine kinase activity was determined using the method described by Horder *et al*. (1991). The CK activity was analysed using a Model DXC machine (Beckman, Coulter, Ireland). The SYCHRON Systems reactivity ingredients were used. Serum CK activities were determined quantitatively in units per litre (U/L). Commercially available kits were used to determine the level of blood serum cortisol according to manufacturer's instructions. A chemiluminescent enzyme immunoassay was used for determination of serum cortisol on an Immulite® 1000 analyser (Siemens, U.S.A.). The *in-vitro* diagnostic quantitative determination of cortisol (Palme and Mostl, 1997) was used. Cortisol concentrations were expressed as nmol/L.

3.2.6 Data analysis

Square-root transformation was carried out on body condition scores to normalise the data. The square root transformed data was analysed for variance using PROC GLM of SAS (2003) for the effects of genotype, week of sampling and their interaction. Analysis of variance on environmental variables, hair-coat traits, skin traits, cortisol, creatine kinase, rectal and skin temperatures was done using PROC GLM of SAS (2003). Mean separation was done using the PDIFF option of SAS (2003). The following model was used for environmental variables:

$Y_{ij} = u + W_i + E_{ij}$

Where Y_{ij} = environmental variables (e.g. temperature, relative humidity)

μ = population mean

W_i = effect of the i^{th} week

E_{ij} = residual error.

For animal traits, the following model was used:

$Y_{ijk} = \mu + G_i + W_j + (G_i*W_j) + E_{ijk}$

Where:

Y_{ijk} = the response variables (e.g. coat score, square-root transformed BCS, skin)

μ = population mean

G_i = effect of the i^{th} genotype (i= 1, 2)

W_j = effect of the j^{th} week (where j = 2, 4, ….16)

$(G_i *W_j)$ = interaction between genotype and week

E_{ij} = residual error.

Pearson correlations were computed using PROC CORR of SAS (2003). Multivariate

analysis was carried out using Principal component analysis (PCA) in JMP 9.0 (SAS, 2010). The PCA was used to reduce the dimensionality of the data based on correlations of environmental, skin morphology and physiological variables. Proc FREQ of SAS (2003) was used to compute frequencies for skin pigment.

3.3 Results

3.3.1 Environmental Variables

The prevailing environmental factors during the study period are shown in Table 3.1 and Table 3.2. Generally, the mean maximum temperature increased from week 2 to week 6, with a peak of (27.7 ± 1.19 ^{o}C) and decreased to a low of 21.0 ± 1.19 ^{o}C in the 12th week increasing thereafter. Mean minimum temperatures generally decreased with week from 15.3 ± 0.62 to 7.8 ± 0.57 ^{o}C. Average temperatures had a peak of 20.7 ± 0.60 in week 6 and decreased thereafter.

Week of sampling significantly ($P < 0.05$) affected THI. The average, maximum and minimum THIs are presented in Figure 3.1. Week 6 had the highest maximum THI of 92.3 ± 3.11 while the lowest maximum THI was recorded in the 12th week. Both minimum THI and average THI were below 72, except in the second week for average THI. The most frequent winds were south easterly wind (43.5 %), followed by north westerly wind (29.4 %) and westerly wind (16.1 %). Other wind directions had a low frequency of occurrence (Figure 3.2)

Table 3.1: Temperature and humidity values (LSMean ± SE) at Honeydale Research Farm in Alice, Eastern Cape Province, South Africa from February to May 2015

Week	Tmean (oC)	Tx (oC)	Tn (oC)	RH (%)	RHx (%)	RHn (%)
2	$20.0^{c} \pm 0.58$	$25.6^{b} \pm 1.61$	$15.3^{c} \pm 0.62$	$76.7^{b} \pm 2.04$	$91.4^{b} \pm 0.83$	$55.7^{b} \pm 4.06$
4	$19.4^{c} \pm 0.56$	$25.9^{b} \pm 1.11$	$13.9^{c} \pm 0.60$	$72.1^{a,b} \pm 1.98$	$89.1^{a,b} \pm 0.82$	$48.5^{b} \pm 3.93$
6	$20.7^{c} \pm 0.60$	$27.7^{b} \pm 1.19$	$15.0^{c} \pm 0.65$	$71.0^{a,b} \pm 2.11$	$89.7^{a,b} \pm 0.87$	$45.0^{a,b} \pm 4.20$
8	$19.3^{c} \pm 0.58$	$25.6^{b} \pm 4.29$	$14.3^{c} \pm 0.62$	$76.2^{b} \pm 2.04$	$90.8^{b} \pm 0.84$	$53.2^{b} \pm 4.06$
10	$17.6^{b} \pm 0.48$	$23.6^{a,b} \pm 0.95$	$12.6^{b} \pm 0.51$	$76.4^{b} \pm 1.69$	$91.0^{a,b} \pm 0.70$	$53.1^{b} \pm 3.35$
12	$14.1^{a} \pm 0.60$	$21.0^{a} \pm 1.19$	$8.3^{a} \pm 0.65$	$76.9^{b} \pm 2.11$	$92.1^{b} \pm 0.87$	$50.7^{b} \pm 4.20$
14	$14.4^{a} \pm 0.60$	$22.2^{a} \pm 1.19$	$8.2^{a} \pm 0.65$	$72.6^{b} \pm 2.11$	$91.1^{b} \pm 0.87$	$41.4^{a,b} \pm 4.20$
16	$14.7^{a} \pm 0.53$	$23.6^{a} \pm 1.05$	$7.8^{a} \pm 0.57$	$66.7^{a} \pm 1.86$	$87.1^{a} \pm 0.77$	$36.0^{a} \pm 3.70$

Altitude = 520m above sea level, Latitude: 32.7803, Longitude: 26.84647

Tmean= is average temperature, Tx is mean maximum temperature and Tn is mean minimum temperature

^{a,b,c} Means with different superscripts within a column are different ($P < 0.05$)

Table 3.2: Environmental variables at Honeydale Research Farm in Alice, Eastern Cape Province , South Africa from February to May 2015

Week	Solar Radiation (MJ/M2)	Wind speed (m/s)	Evaporation	Rain (mm)
2	$23.1^{a,b} \pm 1.85$	$0.8^{b} \pm 0.09$	$4.4^{a,b} \pm 0.35$	$6.5^{b} \pm 1.29$
4	$23.7^{a,b} \pm 1.79$	$0.7^{b} \pm 0.09$	$4.4^{b} \pm 0.34$	$2.1^{a,b} \pm 1.24$
6	$21.6^{a,b} \pm 1.92$	$0.6^{a,b} \pm 0.09$	$4.2^{a,b} \pm 0.36$	$0.7^{a} \pm 1.35$
8	$19.4^{a} \pm 1.85$	$0.5^{a} \pm 0.09$	$3.6^{a,b} \pm 0.35$	$4.8^{b} \pm 1.29$
10	$21.8^{a,b} \pm 1.53$	$0.5a^{b} \pm 0.07$	$3.8^{a,b} \pm 0.29$	$2.7^{a,b} \pm 1.06$
12	$21.0^{a} \pm 1.92$	$0.4^{a} \pm 0.09$	$3.4^{a} \pm 0.36$	$0.7^{a} \pm 1.33$
14	$26.5^{b} \pm 1.92$	$0.5^{a} \pm 0.09$	$4.4^{b} \pm 0.36$	$0.1^{a} \pm 1.33$
16	$20.8^{a} \pm 1.70$	$0.4^{a} \pm 0.08$	$3.5^{a,b} \pm 0.32$	$0.2^{a} \pm 1.17$

Altitude = 520m above sea level, Latitude: 32.7803, Longitude: 26.84647

^{a,b} Means with different superscripts within a column are different ($P < 0.05$)

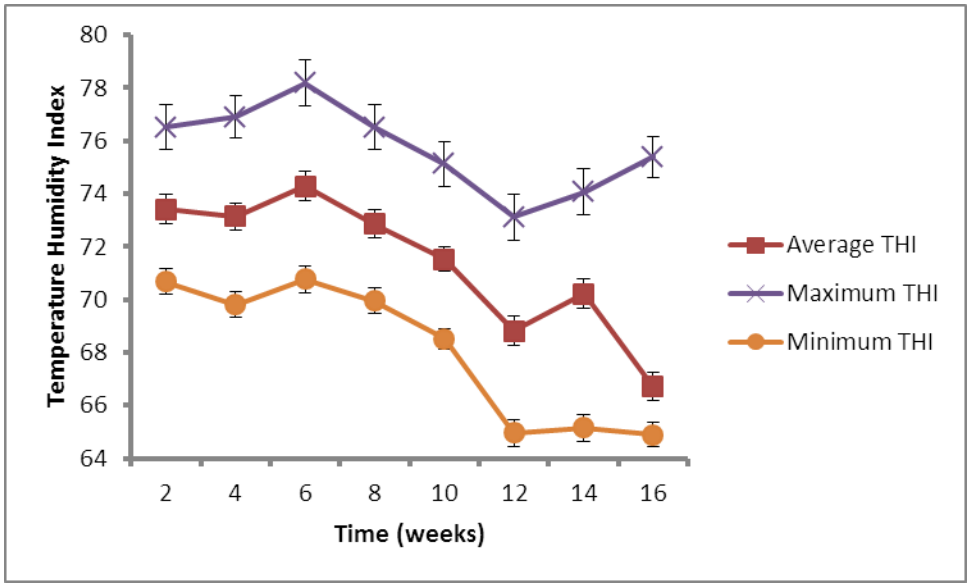

Figure 3.1: Temperature-humidity index (THI) at Honeydale Research Farm in Alice, Eastern Cape Province , South Africa from February to May 2015

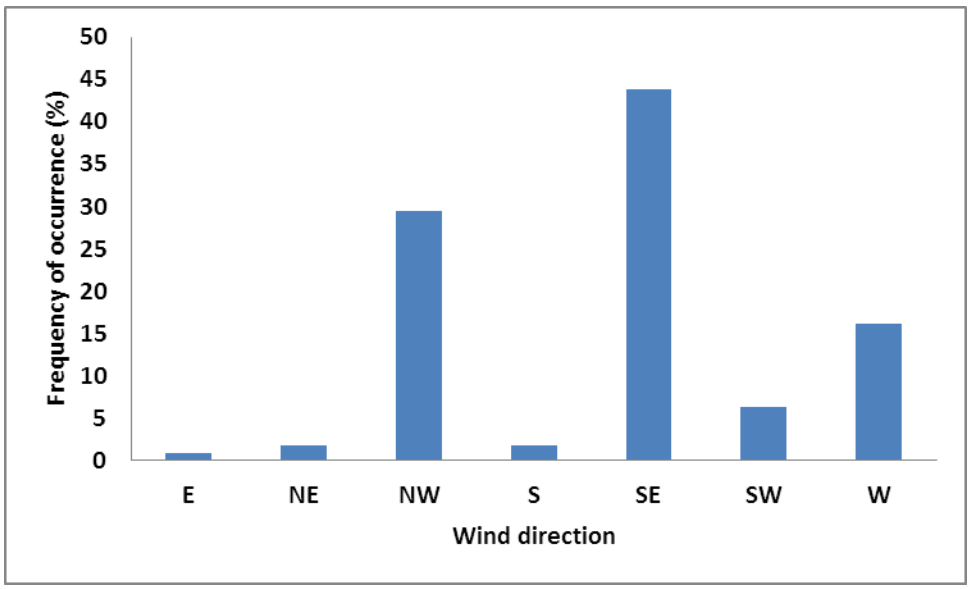

Figure 3.2: Frequency of occurrence of prevailing winds from different directions at the study site during the study period

3.3.2 Animal characteristics

3.3.2.1 Hair-coat and body condition scores

Genotype and week of sampling had significant ($P < 0.05$) effects on coat scores. Coat scores increased throughout the study period (February to May) in both genotypes (Figure 3.3). Non-descript crossbred cattle had higher coat scores than Nguni. Genotype and week of sampling had significant ($P < 0.05$) effects on body condition scores. Higher body condition scores were recorded in NDCC compared to Nguni cattle (Figure 3.4).

3.3.2.2 Hair colour, hair length, skin pigment and skin thickness

Table 3.3 shows the hair colours and changes in hair length in the two genotypes from March to May. Five hair colours were identified on both Nguni and NDCC. In both genotypes, the hair colours were either a single colour (black, white, yellow-fawn, brown and red) or a combination of any two or three colours in the hair coat. Among the Nguni cattle, the proportion of animals with a single colour, two colours and three colours in the hair-coat were 15, 25 and 10 %, respectively. The NDCC only had a single colour (7.5 %) or two colours (35%) in the hair-coat. Among the single colours, red-haired cattle were more dominant in the NDCC genotype, followed by black-haired cattle and the reverse was found in the Nguni genotype. Among cattle with two colours, the black and white combination was dominant in the non-descript genotype, especially the ones with more black than white, followed by those with a red coloured body and a white face, most likely crosses with Hereford cattle. The black and white Nguni cattle were also dominant among the cattle with two colours, followed by the red and white haired cattle. The tri-coloured Nguni cattle had red, brown and white hairs.

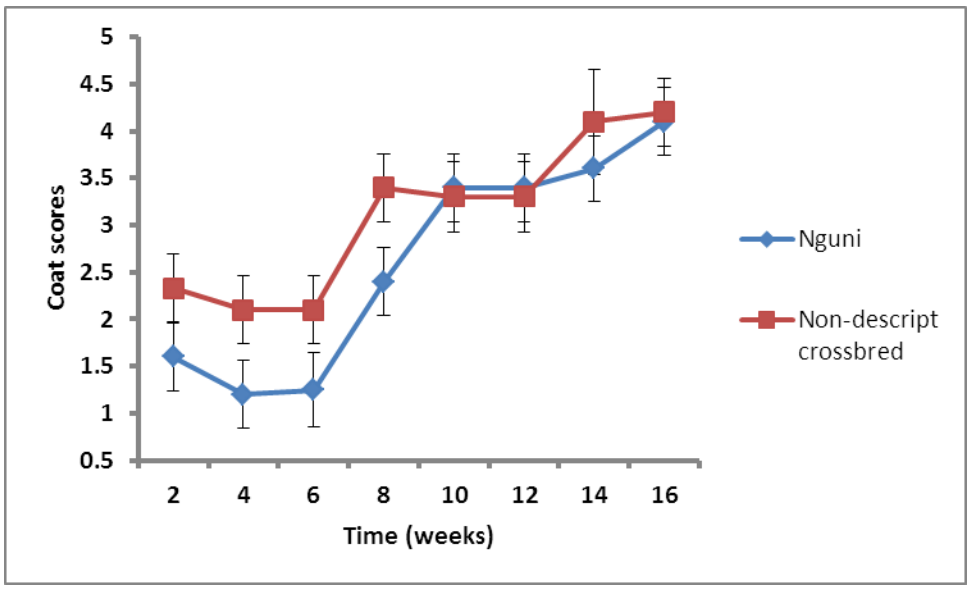

Figure 3.3: Changes in coat scores of Nguni and non-descript crossbred cattle over 16 weeks of sampling

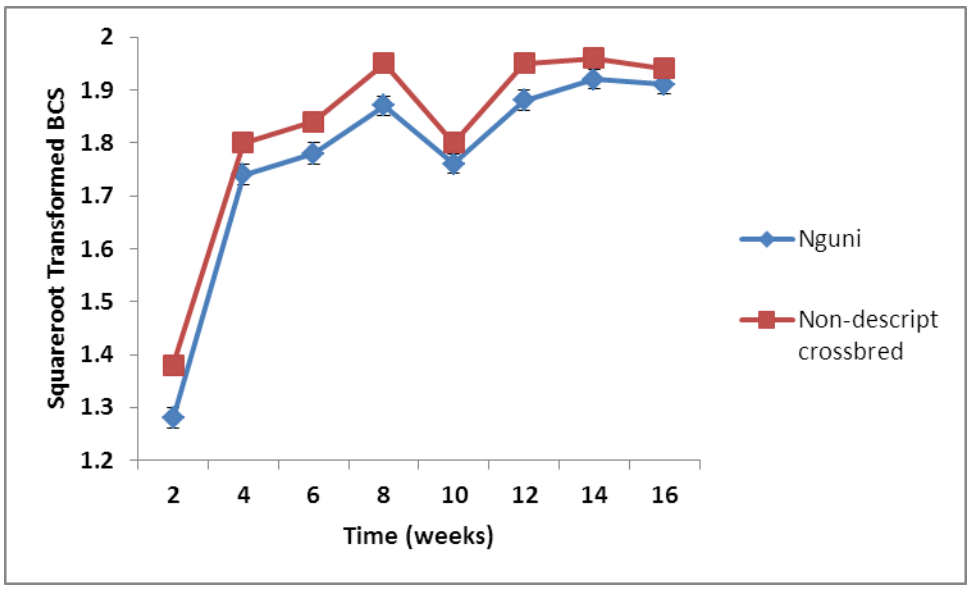

Figure 3.4: LSMeans ± SE of square root transformed body condition scores for the 16 weeks of sampling

Table 3.3: Variations in hair length in mm (LSMean ± SE) in different hair colours found in Nguni and non-descript crossbred cattle hair-coats from March to May

Breed	**Hair colour**	**Month**		
		March	**April**	**May**
Nguni	Yellow-fawn	11.3 ± 4.60	12.5 ± 4.64	14.9 ± 4.64
	Black	12.8 ± 1.64	16.5 ± 1.64	17.4 ± 1.55
	Brown	10.4 ± 2.32	12.5 ± 3.28	17.3 ± 4.64
	Red	11.4 ± 1.89	18.2 ± 1.64	20.8 ± 1.47
	White	12.4 ± 1.89	18.7 ± 2.07	18.3 ± 1.47
Non-descript	Yellow-fawn	13.0^{a} ± 3.28	$13.2^{a,b}$ ± 3.28	17.7 ± 3.28
	Black	$15.7^{a,b}$ ± 1.64	$18.5^{a,b}$ ± 1.89	19.3 ± 1.47
	Brown	$9.7^{a,A}$ ± 3.28	$12.3^{a,A}$ ± 2.67	26.2^{B} ± 4.64
	Red	19.6^{b} ± 2.07	20.1^{b} ±2.07	18.5 ± 1.63
	White	$10.8^{a,A}$ ± 2.07	$14.0^{a,b,A,B}$ ± 2.32	17.2^{B} ± 1.75

$^{A, B}$ Means with different superscripts within a row are different ($P < 0.05$)

$^{a, b}$ Means with different superscripts within a column are different ($P < 0.05$)

There were significant ($P < 0.05$) monthly variations in hair length. Only brown and white hair colour from the NDCC increased significantly ($P < 0.05$) in length over time, although all hair colours showed an increase in length. The shortest hair was recorded in March and the longest hair in May (Table 3.3). Across months, yellow-fawn hair was the shortest (16.3 ± 2.8), while brown hair was the longest (21.8 ± 3.28 mm) at the end of the study (Table 3.3).

The majority of Nguni cattle had black skin pigment (70 %), followed by 15 % with brown pigment and 15 % with non-pigmented skin. Among the NDCC, 65 % had black pigment, 15 % had brown pigment and 20 % had non-pigmented skin.

Week of sampling had a significant ($P < 0.05$) effect on skin thickness; skin thickness increased from 3.7 ± 0.18 mm to 5.3 ± 0.18 mm (Figure 3.5).

3.3.2.3 Blood serum cortisol and creatine kinase concentration

Genotype and week had no significant ($P > 0.05$) effect on creatine kinase activity. Creatine kinase activity, however, ranged from 278.4 ± 208.43 U/L to 910.0 ± 218.83 U/L in Nguni cattle and from 219.9 ± 208.43 U/L to 1037.3 ± 218.36 U/L in the nondescript crossbred cattle.

Cortisol concentrations over the 16 weeks of sampling are shown in Figure 3.6. Genotype had no significant ($P > 0.05$) effect on cortisol concentration, while week had a significant ($P < 0.05$) effect. Generally, cortisol levels decreased for six consecutive weeks, increased in the eighth week and decreased in the following six weeks in a regular pattern in both genotypes (Figure 3.6). Peak levels were recorded in the second, eighth and fourteenth weeks.

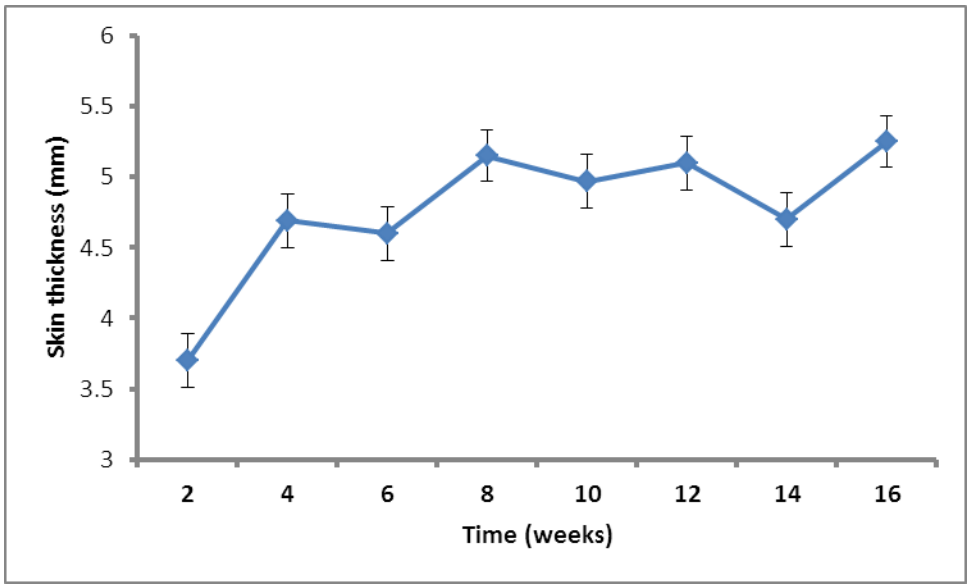

Figure 3.5: Variations in skin thickness (mm) in the Nguni and non-descript crossbred cattle during the 16 weeks of sampling

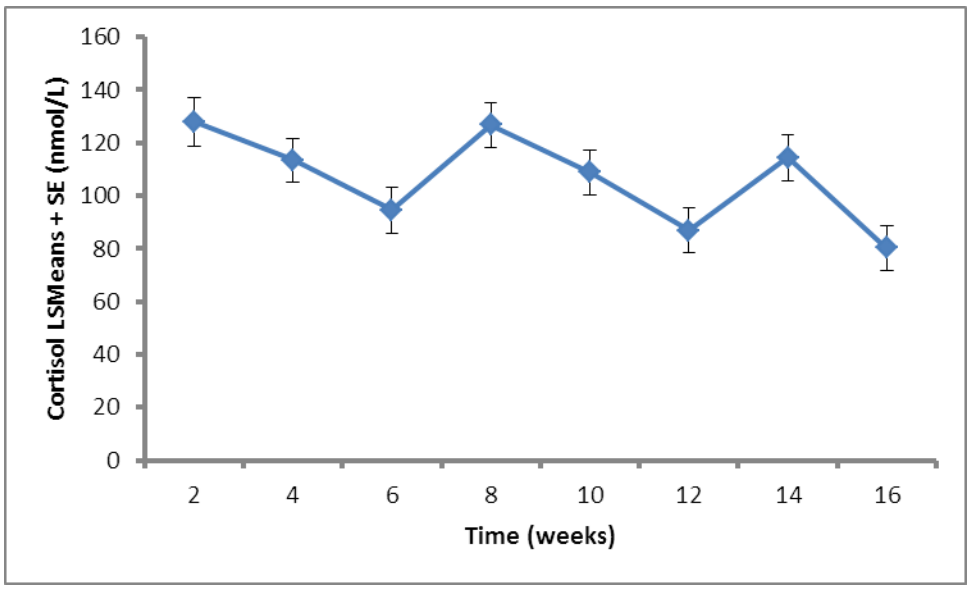

Figure 3.6: Variations in cortisol (nmols/L) concentrations (LS Mean ± SE) in the Nguni and non-descript crossbred cattle during the 16 weeks of sampling

3.3.2.4 Skin and rectal temperature of Nguni and non-descript crossbred cattle

Skin and rectal temperatures are shown in Figure 3. 7. Both genotypes maintained constant rectal temperature of 38.9 – 39.3 ^{o}C for Nguni and 38.4 – 39.3 ^{o}C for NDCC. Skin temperature was affected ($P < 0.05$) by week, while genotype had no effect ($P > 0.05$). Except in the 6th week which had a temperature of 35.4 ^{o}C and week 10 with 27.0 ^{o}C, skin temperature generally ranged between 31 and 33 ^{o}C. It was generally lower than rectal temperature.

3.3.3 Correlations among environmental variables, cattle skin morphological and physiological characteristics

Table 3.4 shows the correlations of environmental variable, skin morphological characteristics and physiological characteristics of the animals. There was no correlation ($P < 0.05$) between rectal temperature and any of the environmental variables (Table 3.4). While THI maximum and evaporation were positive correlated ($P < 0.05$) to skin temperature, wind parameters (speed, direction and period of day with prevailing wind) were negatively correlated to skin temperature (Table 3.4). Some skin morphological characteristics (thickness, coat score, skin pigment) were negatively correlated ($P < 0.05$) to rectal temperature, skin temperature and cortisol. Body condition scores were negative correlated with rectal temperature and skin temperature (Table 3.4). There was a positive correlation between skin temperature and rectal temperature ($r = 0.31$; $P < 0.05$). Creatine kinase was negatively correlated ($P < 0.05$) with solar radiation and evaporation. Cortisol and creatine kinase were positively correlated ($P < 0.05$).

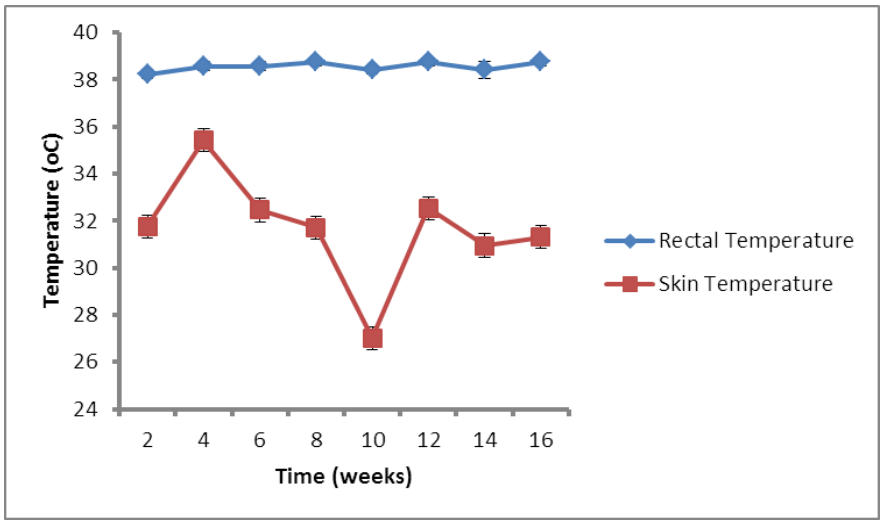

Figure 3.7: Changes in rectal and skin temperatures in the Nguni and non-descript crossbred cattle during the 16 weeks of sampling

Table 3.4: Correlations of environmental and animal characteristics to rectal and skin temperature, cortisol and creatine kinase

Parameter	Rectal Temperature	Skin Temperature	Cortisol	Creatine kinase
Week	NS	-0.15 ***	-0.19***	NS
THI average	NS	NS	0.17***	NS
THI maximum	NS	0.16 ***	NS	NS
THI minimum	NS	NS	0.19***	NS
Solar radiation	NS	NS	-0.14***	-0.16***
Wind speed	NS	-0.28 ***	NS	NS
Evaporation	NS	0.23 ***	NS	-0.13***
Prevailing wind direction	NS	-0.14 ***	NS	NS
Period of prevailing wind	NS	-0.13 ***	NS	NS
Genotype	NS	NS	NS	NS
Number of colours in coat	NS	NS	-0.17***	NS
Skin thickness	-0.70 ***	-0.48 ***	-0.15***	NS
Colour combinations	NS	NS	NS	-0.17***
Skin pigment	-0.22 ***	-0.17 ***	NS	NS
Cortisol	NS	-0.17 ***	-----	0.23***
Creatine kinase	NS	NS	0.23***	-----
Body condition	-0.87***	-0.68***	NS	NS
Coat score	-0.39***	-0.50***	-0.13***	NS

*** Means significant ($P < 0.05$)

NS- means not significant ($P > 0.05$)

3.3.4 Principal component analysis of environmental variables and animal factors

The first two principal components are shown on the bi-plot in Figure 3.8. Positive correlations were observed among rectal temperature, Temperature-humidity index (THI), skin temperature, skin thickness, creatine kinase, number of colours in hair-coat and evaporation (Figure 3.8). However, negative correlations were observed with coat score, BCS, solar radiation, skin pigment, hair colour combination and week (Figure 3.8).

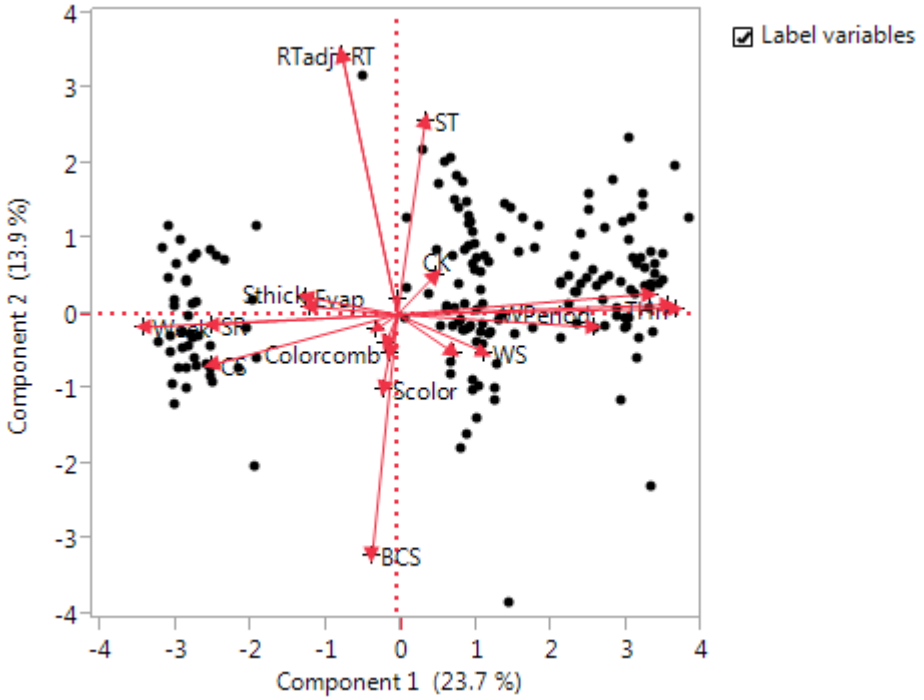

Figure 3.8: The relationships among environmental parameters, hair-coat traits, creatine kinase, cortisol, rectal and skin temperatures in principal components 1 and 2

Key: RTadj- adjusted rectal temperature, RT- rectal temperature as measured, ST– skin temperature, Sthick – skin thickness, Numcolors – number of colours in hair-coat, Colorcomb – combination of hair colours in the hair-coat, Evap – Evaporation, WS – Wind speed, SR- Solar radiation, WPeriod – Wind Period, Scolor- skin colour, WD- wind direction, CS – coat score

3.4 Discussion

Core body temperature is a very crucial index of adaptability to adverse environments (Spiers *et al*., 2004; McManus *et al*., 2009; Ganaie *et al*., 2013). The most frequently used proxy for core body temperature is rectal temperature as it is an indicator of heat stress (Scharf *et al*., 2010; Fadare *et al*., 2013). In this study, both Nguni and NDCC genotypes maintained normal rectal temperature under the prevailing climatic conditions for 16 weeks of the study. Rectal temperatures were within the normal range for cattle (McManus *et al*., 2009). Du Preez (2000) reported that under thermo-neutral conditions, the physiological reference of rectal temperature in cattle varies between 38 and 39.5 ^{o}C.

Cattle are homeotherms which maintain a high core body temperature by thermoregulatory mechanisms that balance metabolic heat production and heat loss (Brown-Brandl *et al*., 2003). Although, rectal temperature values obtained in this study were within the normal range, they were close to the upper limit of values expected under thermoneutrality. The implications are that a slight increase in the adversity of the environment beyond the current levels could lead to failure to maintain normal rectal temperature.

When animals are subjected to environmental conditions which induce heat stress, core body temperature increases (Brown-Brandl *et al*., 2003). An increase in rectal temperature indicates that heat dissipation through normal mechanisms of sensible and insensible heat loss are not adequate for maintenance of homeothermia (McManus *et al.*, 2009; Ganaie *et al*., 2013). Both cattle genotypes in this study were able to maintain a thermal steady state achieved at normal body temperature. This could be attribute to similar compensatory mechanisms for thermal balance in the two genotypes as reported by West (2003).

In this study, the average maximum temperature, humidity and solar radiation were very high (exceeding 25^{o}C, 90 % and 19 MJ/m^{2}, respectively) for the first 10 weeks of the study. Maximum THI values ranged between 74 and 93, while minimum and average THI values were below 70. Liu *et al.* (2008) reported that signs of heat stress in cattle commence at around 72 THI. According to Du Preez (2000), THI values between 71-78 are considered situations for alertness, 79-83 as dangerous while above 83 are considered emergency situations. In this study, some periods of the day in which THI was below 72 could have enabled dissipation of heat accumulated during heat stress-inducing periods, leading to recovery during cooler evenings and early morning (West *et al*., 1999). Heat stress in cattle has been reported to have a cyclic pattern, with peak heat stress and higher core body temperature in mid-afternoon (West *et al*., 1999). However, if the length of the period with THI of less then 72 is short, animals enter the next day with accumulated heat which predisposes them to heat stress (Liu *et al*., 2008).

In a study by Foster *et al.* (2009), rectal temperatures of 38.85 – 39.75 ^{o}C were recorded in six cattle genotypes reared in South Africa. Indigenous breeds, (Afrikaner and Drakensburger) and crossbreeds (Braford and Bonsmara) maintained normal rectal temperatures, even at THI values higher than 79. Charolais and Simmental breeds had rectal temperatures higher than 39 ^{o}C, surpassing normal temperature values (du Preez, 2000). Both Nguni and NDCC in this study managed to retain normal core body temperature under the prevailing THI range of values. Due to a wide thermal comfort zone, ruminants such as cattle are able to withstand exposure to high temperratures (Sejian and Srivastava, 2010).

During the day, heat stress in animals may be induced by exposure to intense solar radiation even at lower ambient temperatures (Van laer *et al.*, 2014; Kumar *et al*., 2015). In a study by

Tucker *et al*. (2008), lower minimum body temperatures (37.9 – 37.7) were recorded in cows that were shaded (25, 50, 99 %) from solar radiation compared to those with no shade (0%) during the day in a pasture-based system. Other authors reported similar findings in cattle (Brown-Brandl *et al*., 2005; Kendall *et al*., 2006; McManus, *et al.*, 2014), goats (Al-Tamimi, 2007) and sheep (Sevi *et al*., 2001). de Mira Geraldo *et al*. (2012) observed that when offered a choice under exposure to solar radiation, cattle preferred access to shade than immersion in water. In this study, solar radiation did not vary throughout the study period and had no correlation with rectal and skin temperatures. However, it was positively correlated to coat score, which in turn was negatively correlation to skin temperature and temperature-humidity index in this study. Coat characteristics, therefore, strongly affect the reaction of the skin when exposed to high temperature, high humidity and solar radiation.

Various factors such as animal breed, body condition, hair-coat characteristics (coat colour, hair length, coat thickness), skin thickness, animal sex and temperament (Foster *et al*., 2009; Fadare *et al*., 2013; Fourie *et al*., 2013) influence the response of animals to the environment. Heat exchange between the skin and its environment is affected by coat colour, hair type, hair thickness and hair length (Bertipaglia *et al*., 2007). In this study, hair colour was associated with hair length. Dark colours (black, brown and red) were longer than light colours (yellow-fawn and white) in both Nguni and NDCC. Hair length in March was similar to mean values reported in Brazil by Bertipaglia *et al*. (2005) for Holstein cows (12.60 ± 3.45 mm), for Braford cows (10.41± 3.91 mm) and in Venezuela for slick-haired (4.9 ± 0.12mm) and normal haired (10.9 ± 0.20 mm) Criollo Limonero cattle (Landaeta-Hernandez *et al*., 2011) reared under tropical conditions. Cardoso *et al.* (2015) reported shorter hair length (0.67 ± 0.023 to 0.99 ± 0.023 cm) for five breeds of cattle in Brazil. These cattle breeds were adapted to hot conditions. Nguni is also reported to be adapted to harsh tropical environments

(Collins-Lusweti, 2000). Similarly, NDCC in this study could possess some genes for heat tolerance as they are a result of non-controlled mating of indigenous cattle such as the Nguni with imported breeds such as Angus, Hereford and Jersey (Mapiye *et al*., 2009). Alternatively, they could have adapted over time through learning to survive in stressful environments as pointed out by Mirkena *et al*. (2010)

In the current study, there was an increase in hair length for all hair colours in both genotypes up to the end of the study period. Similar observations in hair length in Nguni cattle were reported by Katiyatiya *et al.* (2015) across different seasons in Nguni cows reared in Zazulwana, Komga and Honeydale Farm in South Africa. Hair length was shortest in autumn and longest in winter (Katiyatiya *et al*., 2015). Differences in environmental characteristics could have resulted in variations in hair length in Nguni cows (Katiyatiya *et al*., 2015). The three study sites are found at different altitudes with Honeydale Farm at an altitude of 520m, Komga at 647m and Zazulwana at 700-900 m above sea level (Mucina and Rutherford, 2011). Honeydale Farm is in a dry inland area, while Komga and Zazulwana are humid, coastal areas. Komga and Zazulwana are warmer than Honeydale Farm (Mucina and Rutherford, 2011). Seasonal changes in hair length have also been reported previously, with longer hairs in late autumn or early winter (Bertipaglia *et al*., 2007). The current study terminated as winter was approaching and this could have led to the observed increase in hair length. Furthermore, hair length varies due to breed, nutrition and age (Ferreira *et al*., 2009). Non-descript crossbred cattle and Nguni had similar hair length for all hair colours at the end of the study period probably due to similarity in genes controlling hair length. However, the number of hair colours in the coat and the combinations of colours were not associated with rectal or skin temperature in this study.

The slick hair gene controls hair length in cattle and has been linked to heat tolerance (Dikmen *et al.*, 2008). Short, sleek and glossy hair coats are a result of the presence of the dominant allele of the slick hair gene. Short hairs enable animals to maintain lower body temperature as less air is trapped within the animal's coat, thereby facilitating heat loss in hot environments. Both genotypes in this study had shorter hair and lower coat scores in March, a period characterised by high maximum THI values. Nguni cattle had lower coat scores compared to NDCC in this study. However, coat scores increased for both genotypes during the study period. Coat score was negatively correlated to THI. Similar results were obtained by Foster *et al*. (2009) and Fourie *et al*. (2013) in other indigenous breeds of South Africa, Afrikaner and Drakensberger which they compared to crossbreeds and exotic cattle breeds. Gray *et al*. (2011) indicated that in hot, humid environments, hair-coats which are dark, thick and woolly make cattle highly susceptible to heat stress and dehydration. Cattle with shorter hair, e.g., slick-haired types, channel excess heat from the body core to the skin more efficiently compared to non-slick-haired or wild type cattle (Dikmen *et al*., 2008).

The tropics and subtropics are characterised by an abundance of ultraviolet rays from solar radiation (Marai and Habeeb, 2010). Jablonski and Chaplin (2000) stated that photochemical effects of solar radiation are exerted upon absorption by the skin. The mammalian skin is, however, equipped with structures such as melanocytes, sweat and sebaceous glands, that help protect animals from devastating effects of solar radiation exposure (Seo *et al*., 2007; Darcan *et al*., 2009). Melanocytes produce melanin particles, responsible for highly pigmented dark skin, which trap ultra violet rays, thus protecting skin tissue below the dermis from harm (Seo *et al*., 2007). McManus *et al*. (2011) indicated that animal genotypes adapted to tropical environments should ideally possess a dark skin with a light hair-coat colour. Light coloured hair-coats reflect more light, unlike dark coats which absorb more light

(Bernabucci *et al*., 2010; McManus *et al.,* 2011; Fadare *et al*., 2013).

The majority of cattle in this study had black skin pigment. Brown pigment and non-pigmented skin were less prevalent. Furthermore, various pigments were also observed in the hair-coat as five different colours were identified (yellow-fawn, white, red, brown and black). These were observed as a single solid colour, two or more different mixtures of hair colours especially in the Nguni cattle. Pigmentation in the skin and hair-coat is under genetic control (Seo *et al*., 2007). Major pigments in the skin and hair are the haemes (red of haemoglobin), carotenes, melanin (brown and black) and guanine (white and iridescent) (Seo *et al*., 2007). Melanin has two components, black-to-brown eumelanin and yellow-to-reddish pheomelanin (Mohanty *et al*., 2008; Seo *et al*., 2007). Variations in the ratio of the two components result in differences in skin and hair colour (Mohanty *et al*., 2008).

Skin temperature changes due to vasodilation and vasoconstriction are employed in the control of core body temperature (West, 2003; Collier *et al*., 2006). During exposure to heat stress, skin temperature rises and this induces vasodilation of the capillaries in the skin. Blood flow is, therefore, increased to the skin (McManus *et al*., 2009), causing a rise in skin temperature, increasing the heat gradient with ambient temperature and enabling heat loss to the environment. In this study, ambient temperatures were consistently lower than skin temperature throughout the study period. According to Collier *et al*. (2008), skin temperatures in excess of 35 ^{o}C lead to heat storage in the animal thereby activating mechanisms for evaporative heat loss (EVHL). Collier *et al*. (2006) indicated that gradients large enough to promote use of conduction, convection, radiation and evaporation occur at skin surface temperatures below 35^{o}C. In this study, skin temperature varied with week but did not differ in the two genotypes for the duration of the study. Skin temperatures were

below 35 ^{o}C except in the fourth week (35.4 ± 0.48). Numerically, both skin and rectal temperature tended to be higher in NDCC compared to Nguni cattle.

During hot weather, cattle have a preference for areas with maximum exposure to the wind (Van laer *et al*., 2014). According to Mader *et al.* (2006), air movement can have beneficial effects in heat exchange, depending on air temperature and humidity. Elevated relative humidity, with restricted evaporative cooling could result in an increase in core body temperature (Collier *et al*., 2006). In this study, wind speed was low (0.4 – 0.8 m/s) and it generally decreased throughout the study period, while humidity was high.

Changes in hormone production in cattle subjected to heat stress have been reported (West, 2003). However, this occurs simultaneously with reduction in feed intake (West, 2003). Cortisol values obtained in this study were within the range obtained for Nguni cows by Katiyatiya *et al*. (2015). However, THI values reported for Honeydale Farm by Katiyatiya *et al*. (2015) in all four seasons were lower than maximum THI values reported in this study. Cortisol, a glucocorticoid, produced by the adrenal cortex in response to stress plays numerous physiological roles such as involvement in metabolism, distribution of body water and electrolyte balance (West *et al*., 1999). However, there are conflicting reports on the response of cortisol to heat stress (Dikmen *et al*., 2008; Trevisi and Bertoni, 2009).

Higher concentrations of plasma cortisol have been reported in cows subjected to acute heat stress compared to cows experiencing thermal comfort (Collier *et al.*, 2008). The increase in cortisol concentration is an adaptive mechanism employed to mobilise body reserves (Trevisi and Bertoni, 2009). Conversely, prolonged exposure to heat stress results in a decrease in the concentration of plasma cortisol (Du Preez, 2000; West, 2003; Collier *et al*., 2008). This

reduction is an adaptive mechanism employed by the animal to reduce heat production. In the current study, cattle could have been exposed to both acute and chronic levels of heat stress, resulting in the observed surges and troughs in cortisol concentration. However, physiological responses of the animals were able to restore core body temperature to normal levels in both cattle genotypes.

Both skin and rectal temperatures in this study were strongly negatively correlated to body condition score. Body condition scores were significantly higher for NDCC than Nguni cattle. However, the two genotypes had a constant body condition from the fourth week to the 16th week. Body condition scoring is based on the amount of body fat deposits in animals (Roche *et al*., 2004; Hussein *et al*., 2013). It is used as a subjective indicator of the nutritional status of livestock and animal welfare (Ayres *et al*., 2009; Roche *et al*. 2009). It is a good parameter for assessing the effects of exposure to harsh climatic environments such as heat stress. The constant body condition indicates that a certain level of subcutaneous fat was maintained by both genotypes probably to be able to thermoregulate under the prevailing enviornmental conditions.

Body condition is related to skin thickness. Brown *et al*. (2000) reported that the amount of subcutaneous fat on different sites of the animal body influences skin thickness. In this study, skin thickness followed the same pattern as body condition scores being higher for NDCC. Skin thickenss values recorded in this study are within the normal range for cattle (Foster *et al*., 2009). In their study, imported breeds (Simmentaler and Charolais) had lower BCS and skin thickness compared to crossbreds (Braford, Bonsmara) and indigenous breeds (Afrikaner and Drakensberger). Similarly, indigenous and crossbred cattle were reported to differ in skin thickeness by Verissimo *et al.* (2002). Cardoso *et al*. (2015) reported higher skin thickness

(0.73 – 0.83 cm) in 5 cattle breeds reared in Brazil with significant breed differences. In contrast, Marufu *et al.* (2011) did not find any differences in skin thickness between Nguni and Bonsmara breeds. In this study, both skin thickness and body condition score were negatively correlated to rectal and skin temperatures. However, in Foster *et al*. (2009), hide thickness affected rectal temperature in Afrikaner and Bonsmara breeds only out of the six breeds studied.

Measurements of rectal temperature and blood collection involve handling of animals. Cattle have to be restrained when measuring rectal temperature and collecting blood samples. The restraining exercises can be a source of stress to the animals (Petheric, 2005). Stressful handling of cattle has been reported to lead to elevated levels of CK in the blood (Mpakama *et al*., 2014). In this study, CK activity was used as an indicator of health status of the animals. Creatine kinase activity was not affected by week and genotype. However, it was higher in Nguni compared to NDCC. The normal range of CK activity in cattle is between 0 – 350 U/L (Merck's Veterinary manual, 2010). Except for two episodes (second and eighth weeks), most of the CK activity of NDCC was within normal range. Creatine kinase activity in Nguni cattle was much higher than the normal range except in weeek 16. The CK values in this study were much higher than those reported by Mapiye *et al*. (2010) for Nguni and NDCC. They were, however, within the range of values obtained by Mpakama *et al*. (2014) for Brahman, Beefmaster and Bonsmara cattle under stressful conditions of transportation and slaughter. Restraining for blood collection and rectal temperature collection was more strenous for Nguni compared to non-descript cattle. Stress leads to increased muscle permeability leading to higher CK activity (Totsuka *et al.,* 2002).

There are inconsistent reports on the effect of heat stress on creatine kinase activity in

livestock. Srikandakumar and Johnson (2004) reported a decrease in CK activity due to heat stress in Holstein, Jersey and Australian milking Zebu cows. Conversely, Rasooli *et al.* (2004) reported higher CK activities in summer compared to winter in cattle. Similar findings were reported in sheep by other authors (Nazifi *et al*., 2003; Liu *et al*., 2008; Miranda-de la Lama *et al*., 2010). Creatine kinase is mainly found in high energy production sites in muscles, where it plays a major role in energy homeostasis (Totsuka *et al*., 2002). Its presence and level in serum is linked to elevated cell membrane permeability and leakages from cells as a result of muscle cellular disruptions. Elevated serum CK levels are associated with tissue cell damage, disturbances in muscle cells or myopathy (Totsuka *et al*., 2002).

3.5 Conclusions and recommendations

Both Nguni and non-descript crossbred cattle maintained normal rectal temperatures. Rectal temperature in both genotypes was not affected by environmental heat load factors (ambient temperature, humidity, temperature-humidity index, solar radiation, windspeed, wind direction and evaporation). Most environmental factors affected skin temperature, except THI average and THI minimum. Evaporation and solar radiation affected cortisol and CK activity. Skin traits, hair-coat traits and body condition affected rectal temperature, skin temperature and cortisol. Creatine kinase activity was affected by colour combination only among animal traits. Both genotypes were able to cope with the prevailing environmental conditions. However, non-descript crossbred cattle have characteristics such as higher body condition, higher coat scores and thicker skins that can predispose them to heat stress compared to Nguni cattle. Animals with shorter, sleek hair, thinner skins and optimum body condition had more desirable welfare indicators. Smallholder farmers rearing the Nguni and NDCC genotypes need to monitor the two genotypes in the hot season for maintenance of good animal welfare.

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Chapter 4: Nutritionally-related blood metabolites, growth performance, carcass characteristics and hide weights of Nguni and non-descript crossbred cattle reared on a sweet veld

Abstract

The objective of the study was to determine changes in blood metabolite concentrations, growth performance, hides weights and carcass characteristics of Nguni and non-descript crossbred cattle (NDCC) raised on a sweetveld. Forty steers (20 Nguni and 20 NDCC) were studied over a period of 16 weeks in a hot wet season. The ages of steers were approximately 14 months at the beginning of the study. Liveweights ranged between 152.74 ± 1.83 kg and 203.17 ± 1.88 kg for Nguni and NDCC, respectively. Blood collection was done at two week intervals and analysed for blood metabolites. At the end trial, the steers were slaughtered at a commercial abattoir. The results showed that body condition scores, total protein (TP), creatinine, urea, albumin and globulin were affected by week of sampling and genotype. Glucose concentration varied with week of sampling. Genotype affected slaughter and hide weights. Nguni cattle had lower slaughter and hide weights (232.6 ± 6.5 kg and 14.71 ± 0.54 kg) than NDCC (285.85 ± 6.52 kg and 18.43 ± 0.54 kg). Carcass characteristics were affected by genotype. Subcutaneous fat levels ranged from nil to very lean in both Nguni and NDCC. A higher proportion of NDCC (73.7 %) had fatness level score 1, compared to Nguni cattle (50 %). It was concluded that Nguni and NDCC differ in nutritionally-related blood metabolites, growth performance, hide weights and carcass traits. Furthermore, week of sampling affects blood metabolite concentrations in both genotypes.

Keywords: carcass classification, energy, liveweight, protein metabolites

4.1 Introduction

Despite owning over 40 % of the national cattle herd, communal farmers in South Africa contribute very little to formal agricultural output (Palmer and Ainslie, 2006). Currently, the participation in formal beef markets is very low (DAFF, 2014; Soji *et al*., 2015), with an annual offtake of between 2.5-10 % (Nkhori, 2004; Scholtz *et al*., 2008). There is need to improve the participation of these farmers in formal beef market in view of market opportunities that are available locally (Taljaard *et al*., 2006) and internationally (Thornton *et al*., 2009; Rege *et al.,* 2011; Rewe *et al*., 2011) due to the rising demand for meat and other livestock products. While the smallholder farmers have livestock resources which are not used in formal meat production, South Africa faces a 15 % annual deficit in beef supply which is catered for through imports (DAFF, 2014). The leather industry is also importing hides due to shortages of supply from the beef sector.

Livestock are a source of products such as meat, milk and hides (Musemwa *et al*., 2008; Scholtz *et al*., 2008; Mapiye *et al*., 2009; Tada *et al*., 2013). While small-scale farmers in South Africa have an interest in generating income from livestock (Musemwa *et al*., 2008; Mapiye *et al*., 2010), they tend to shun the formal markets (Soji *et al*., 2015). The quality and value of carcasses from the animals which are reared in communal production systems do not always meet the specifications of the South African Carcass Classification system. Class classification in red meat species such as cattle is based on five physical characteristics which are age of the animal, sex (gender), level of fatness, conformation and bruising (damage) (RMIF, 2013). Meeting the standards expected in the carcass classification would require addressing some of the challenges faced by smallholder farmers (Soji *et al*., 2015).

At slaughter, hides are co-produced with meat and farmers are paid for the hides by the

abattoir based on the weight of hides and production system (veld vs feedlot) (RMAA, 2015). These hides enter into the hides, skins and leather value chain as the major raw material (DAFF, 2012). The leather industry, however, requires good quality hides and skins for production of good quality leather. Such hides are obtained from animals that have been raised under good husbandry conditions to attain optimum body condition (Leach and Wilson, 2009).

Most of the livestock in smallholder communal production systems are reared on communal rangelands (Mapiye *et al*., 2009). The performance of these animals on communal rangelands is severely affected by challenges such as shortage of feed (Mapiye *et al*. 2009). Under free-ranging extensive grazing systems, livestock are subjected to spatial and temporal heterogeneity in the quantity and quality of available nutrients (Pambu-Gollah *et al*., 2000). Nutritional requirements of cattle are often not met, affecting animal body condition, liveweights and product quality (Mapiye *et al*., 2009; Damptey *et al*., 2014). Often, such animals have reduced growth rates, attain slaughter weights at old age and have reduced saleable meat yield (du Plessis and Hoffman, 2004). Furthermore, beef toughness, decreased beef colour and flavour acceptability have been reported in cattle finished on natural rangelands. Since smallholder farmers are resource-poor and cannot afford to purchase supplementary feeds for their livestock due to financial constraints (Mapiye *et al*., 2009), it is imperative that animal breeds kept by such farmers be highly adapted to the low-input farming systems.

In addition to the shortage of feed, other production challenges hamper the productivity of livestock (Mapiye *et al*., 2009; Soji *et al*., 2015). These include among others, diseases and parasites, poor breeding practices, lack of production skills (Mapiye *et al*., 2009).

Furthermore, production challenges are aggravated by the high feed maintenance costs of large-framed non-descript crossbreds reared in the communal areas of South Africa. Indiscriminate cross-breeding, non-controlled mating and poor breeding practices led to the proliferation of non-descript crossbreds in the smallholder sector (Scholtz *et al*., 2008; Tada *et al*., 2012). Besides, the non-descript crossbreds, other cattle breeds kept by the small-scale farmers are the indigenous breeds such as the Nguni (Scholtz *et al*., 2008). Nguni cattle have been reported to cope with the harsh environment and low input systems found in the smallholder sector and are now widely promoted as a breed suitable for such production systems. Ndlovu *et al.* (2009) pointed out that adapted animal genotypes are expected to be raised with very little need for external feed supplementary and veterinary inputs. They are expected to be efficient in utilising available feed resources (Mapekula *et al.*, 2011). Furthermore, the immune systems of adapted genotypes are expected to guard against endemic diseases and parasites (Mapekula *et al*., 2011). Knowledge of nutrient demands and efficiency of feed utilisation assists in the choice of appropriate cattle breeds for rearing in a specific environment (Mapiye *et al*., 2010).

The nutritional status of animals can be evaluated by monitoring changes in body weight, body condition and nutritionally-related blood metabolites (Ndlovu *et al*., 2007; Damptey *et al*., 2014). However, factors such as physiological status of the animal, genotype, season, nutrition and age need to be taken into account as they affect the metabolite concentrations in the blood (Ndlovu *et al*., 2007). Determination of the nutritionally-related blood metabolites provides an understanding of the effect of nutritional status on product quality under free-ranging systems, leading to formulation of management intervention strategies. The objective of this study was, therefore, to evaluate changes in blood metabolite concentrations and their relationship to growth performance, carcass characteristics and weights of hides of Nguni and

non-descript crossbred cattle raised on a sweetveld during a hot wet season.

4.2 Materials and methods

4.2.1 Study site

As described in section 3.2.1

4.2.2 Ethical clearance

As described in section 3.2.2

4.2.3 Experimental design and animal management

As described in section 3.2.

4.2.4 Environmental variables

As described in section 3.2.4

4.2.5 Determination of liveweights and body condition scores of Nguni and non-descript crossbred cattle

Body condition scoring was carried out at two-week intervals prior to weighing the animals. A 5-point scoring system as described Osoro and Wright (1992) was used to determine body condition scores, a score of 1 being assigned to a very thin or emaciated animal and a score of 5 to a very fat (obese) animal. Both visual appraisal and palpation were done by the same enumerator who was blinded to the treatments subjected to the animals. Body weights were measured at two-week intervals using a digital cattle scale (Waikato, New Zealand).

4.2.6 Blood sample collection

Blood collection was done at two-week intervals by coccygeal venipuncture with 18 mm

gauge needles. Blood was collected into 4ml vacutainer tubes (BD Vacutainer®, Plymouth, UK) with sodium fluoride and 5ml SST vacutainer tubes (BD Vacutainer®), Plymouth, UK) for glucose and serum metabolites, respectively. Vacutainers were kept on ice and centrifuged using Model 5403 Centrifuge (Gatenbay Eppendorf, GmbH, Engelsdorp, Germany) at 3500 rpm at 10 ºC for 15 minutes within two hours of collection for separation of serum and plasma. Blood plasma was immediately analysed for glucose using enzymatic methods (Gotchman and Schmitc, 1972). Blood serum was analysed for urea, creatinine, albumin and total protein (TP). Colorimetric methods were used to spectrophotometrically analyse serum using a Chexcks machine (Nxt/Vetex Alfa Wasseman Analyser) and commercially purchased kits (Siemens) for the determination of total proteins (Wichselbaum, 1946), albumin (Doumas and Biggs, 1972) and creatinine (Tietz, 1995). Enzymatic methods were used for the determination of urea (Tietz, 1995). Globulin concentrations were calculated as the difference between TP and albumin. The albumin:globulin ratio was also calculated.

4.2.7 Animal liveweights at slaughter

At the end of May, the steers were slaughtered at a commercial abattoir using approved slaughter and flaying procedures. They were weighed individually at the abattoir prior to slaughter, to determine liveweights at slaughter. The order of the steers during slaughter was recorded for identification of hides during flaying and weighing.

4.2.8 Hide identification and weights

For identification and traceability purposes, a plastic disc labelled with the steer's ear tag number was attached to each hide prior to complete removal of the hide from the carcass. Hides were weighed individually as green hides soon after flaying. Relative hide weights

were determined by expressing hide weights as a proportion of slaughter weights.

4.2.9 Warm carcass mass and cold carcass mass

The carcasses were weighed after dressing and evisceration to determine warm carcass mass. Three percent (3 %) of warm carcass mass was calculated and deducted from the warm carcass mass to estimate cold carcass mass. Dressing percentage was determined by dividing cold carcass mass with liveweight taken just before slaughter. Thereafter, the carcasses were placed in chiller rooms set at 7 ^{o}C for 24 hours.

4.2.10 Blood sampling at slaughter

Blood samples were collected during exsanguination for plasma glucose analysis using 4ml vacutainer tubes (BD Vacutainer®, Plymouth, UK) with sodium fluoride. For serum metabolites (total protein, creatinine, urea, albumin, creatine kinase and cortisol), 5ml SST vacutainer tubes (BD Vacutainer®), Plymouth, UK) were used. Vacutainer tubes were kept on ice and centrifuged using Model 5403 Centrifuge (Gatenbay Eppendorf, GmbH, Engelsdorp, Germany) at 3500 rpm at 10^{o}C for 15 minutes within two hours of collection. Glucose and protein metabolites were analysed as described above. Blood serum cortisol was analysed using commercially available kits according to the manufacturer's instructions. An Immulite® 1000 analyser (Siemens, U.S.A.) was used for determination of serum cortisol on using a chemiluminescent enzyme immunoassay. An *in-vitro* diagnostic quantitative determination of cortisol (Palme and Mostl, 1997) was done. Cortisol concentrations were expressed as nmol/L. A Model DXC machine (Beckman, Coulter, Ireland) was used for creatine kinase activity determination. SYCHRON Systems reactivity ingredients were used. Serum CK activities were determined quantitatively in units per litre (U/L).

4.2.11 Carcass classification

Carcass classification was conducted using the South African Carcass Classification System by the abattoir personnel (SAMIC, 2006). The Carcasses were classified based on a 5 criteria namely; age, sex, conformation, fatness level and damage (bruising).

4.2.12 Statistical Analysis

Body condition score were square-root transformed to normalise the data. PROC GLM of SAS (2003) was used to analyse the square root transformed data for the effects of genotype and week of sampling. Analysis of variance was performed on weekly liveweights and blood metabolite concentrations data using PROC GLM of SAS (2003). Blood metabolites at slaughter, slaughter weights, hide weights and carcass weights were analysed for the effects of genotype using PROC GLM of SAS (2003). Significant means were separated using the PDIFF option. For hide weights, analysis of co-variance was performed using PROC GLM with slaughter liveweight as a covariate. Principal component analysis was performed based on correlations to determine the relationships between THI and blood metabolite concentrations over the 16 week period using JMP 9.0 (SAS, 2010).

4.3 Results

4.3.1 Temperature humidity index (THI) values

Maximum, minimum and average Temperature-humidity index values are shown in Figure 3.1.

4.3.2 Cattle liveweights and body condition scores

Genotype and week of sampling had significant ($P < 0.05$) effects on cattle liveweights. Generally, liveweights increased throughout the study period for both genotypes (Table 4.1). Non-descript crossbred cattle had higher liveweights than Nguni cattle throughout the study period. Genotype and week of sampling had significant ($P < 0.05$) effects on square-root transformed body condition scores. Generally, body condition scores for both genotypes increased up to 8^{th} week, dropped slightly in week 10 and rose to a constant level until week 16 (Figure 4.1).

4.3.3 Blood serum energy and protein metabolites

Over the 16 weeks, glucose concentration ranged between 3.7 ± 0.08 and 4.91 ± 0.09 mmol/L (Figure 4.2). Week of sampling had a significant ($P < 0.05$) effect on glucose while genotype had no effect ($P > 0.05$). Glucose levels generally declined from week 2 to week 16.

Generally, Nguni cattle had higher concentrations of total proteins compared to NDCC over the 16 weeks (Figure 4.3). Total protein concentrations were significantly ($P < 0.05$) affected by genotype and week of sampling ($P < 0.05$).

Table 4.1: Liveweights (kg) and average daily gain (ADG) (kg) of Nguni and non-descript crossbred cattle over the 16 weeks of the trial

Week	**Genotype**	
	Nguni	**Non-descript crossbred**
2	$152.1^{a, A} \pm 5.73$	$203.2^{a, B} \pm 5.88$
4	$169.9^{b, A} \pm 5.76$	$219.2^{a, B} \pm 6.21$
6	$180.4^{b, A} \pm 6.04$	$221.1^{c, B} \pm 5.73$
8	-	-
10	$204.2^{c, A} \pm 5.73$	$255.14^{d, B} \pm 5.73$
12	$213.8^{c, A} \pm 5.73$	$261.7^{d, B} \pm 5.88$
14	$216.3^{c, A} \pm 5.73$	$267.1^{d, B} \pm 6.04$
16	$232.6^{d, A} \pm 5.73$	$285.9^{e, B} \pm 5.73$
Average daily gain (kg/day)	0.7 ± 0.04	0.7 ± 0.04

$^{a,b, c,d}$ Means with different superscripts within a column are different ($P < 0.05$)

^{A,B} Means with different superscripts within a row are different ($P < 0.05$)

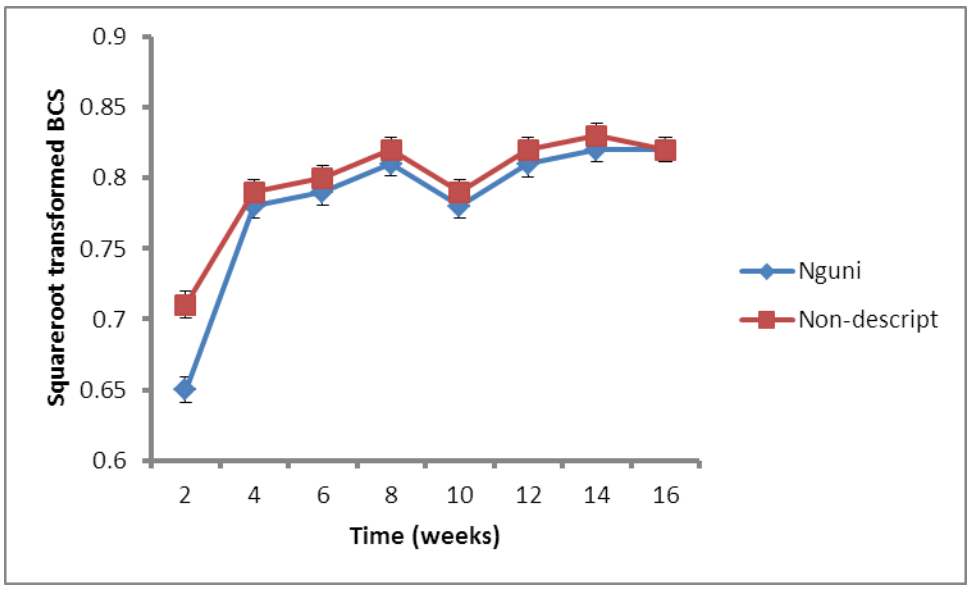

Figure 4.1: LSMeans ± SE of square root transformed condition scores of Nguni and non-descript crossbred cattle over 16 weeks of the trial

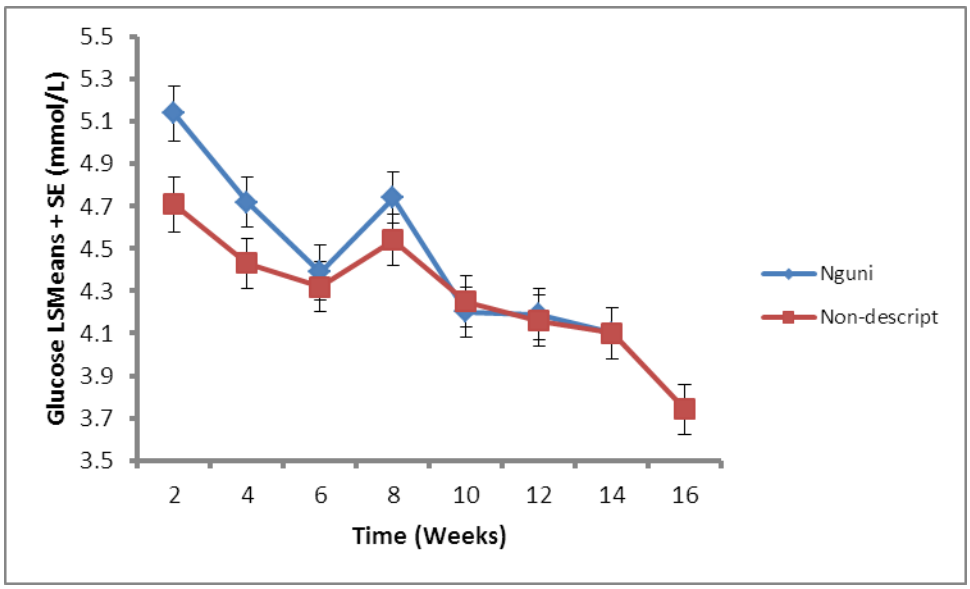

Figure 4.2: Changes in serum glucose (mmol/L) (LSMeans ± SE) in Nguni and non-descript crossbred cattle over 16 weeks of sampling

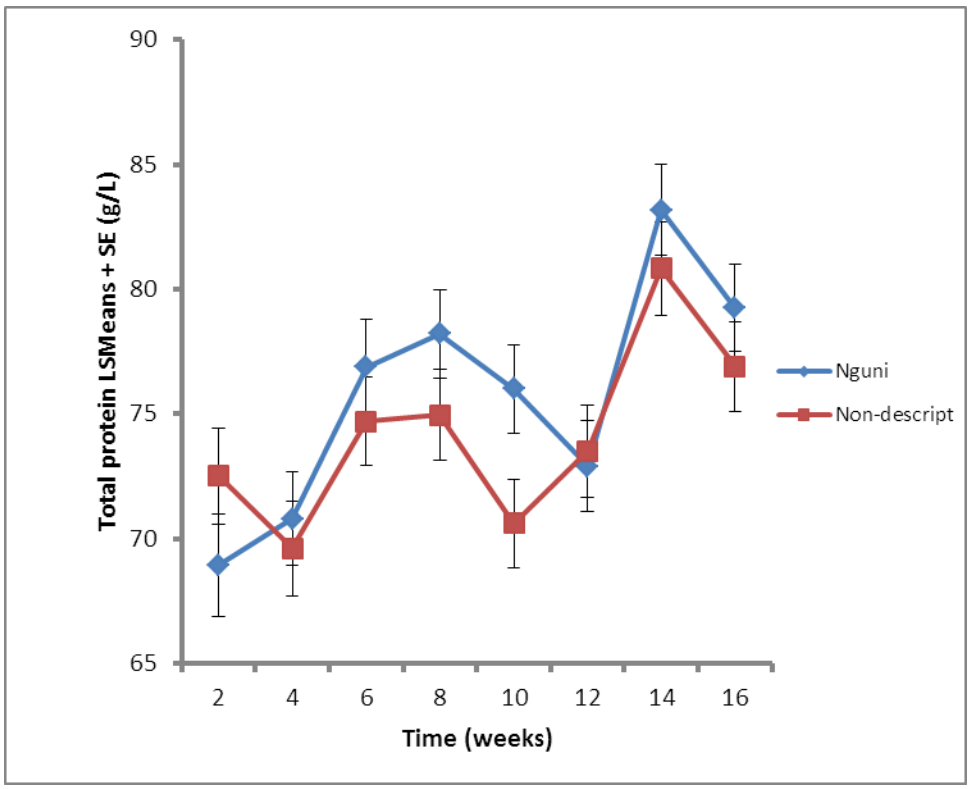

Figure 4.3: Variation in the concentration of total protein (g/L) (LSmean ± SE) over 16 weeks for Nguni and non-descript crossbred cattle.

Creatinine concentrations increased over the 16 weeks of the study period (Figure 4.4). Genotype and week of sampling significantly ($P < 0.05$) affected creatinine concentrations. Nguni cattle had lower creatinine levels compared to NDCC throughout the study period (Figure 4.4).

Nguni cattle had higher concentrations of urea compared to NDCC throughout the 16 weeks (Figure 4.5). There were significant ($P < 0.05$) variations in urea concentrations due to genotype and week of sampling effects.

Figure 4.6 shows changes in concentrations of albumin over the study period. Genotype and week of sampling had significant ($P < 0.05$) effects on albumin concentration. Generally, albumin concentrations were lower in Nguni cattle compared to NDCC in the first 8 weeks. Between weeks 10 and 14, Nguni cattle had higher albumin concentrations compared to NDCC (Figure 4.6). Globulin concentrations were higher in Nguni than NDCC over 16 weeks (Figure 4.7). Genotype had significant ($P > 0.05$) effects on globulin concentration.

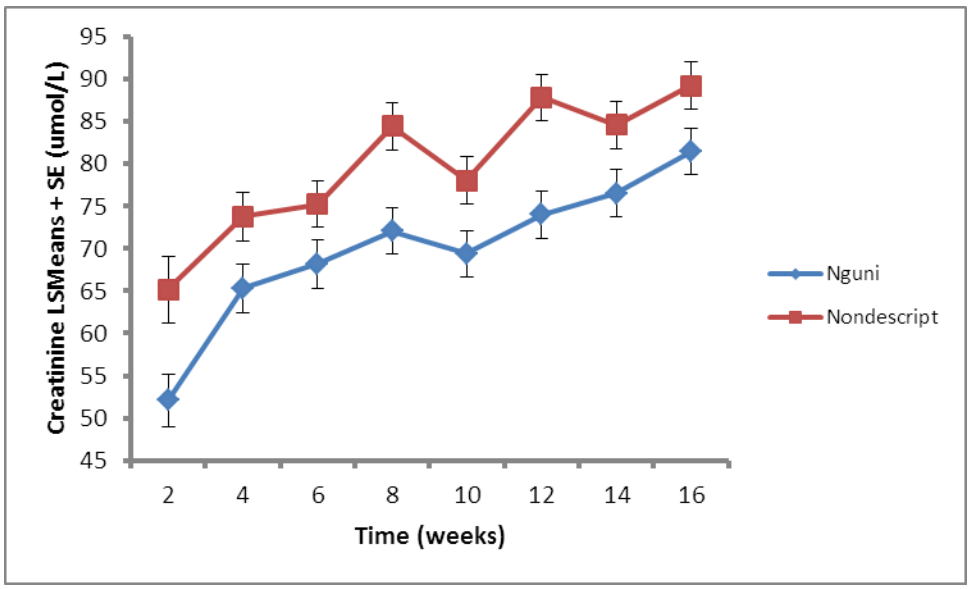

Figure 4.4: Changes in creatinine concentrations (umol/L) (LSmean ± SE) in Nguni and non-descript crossbred cattle over the 16 weeks of study

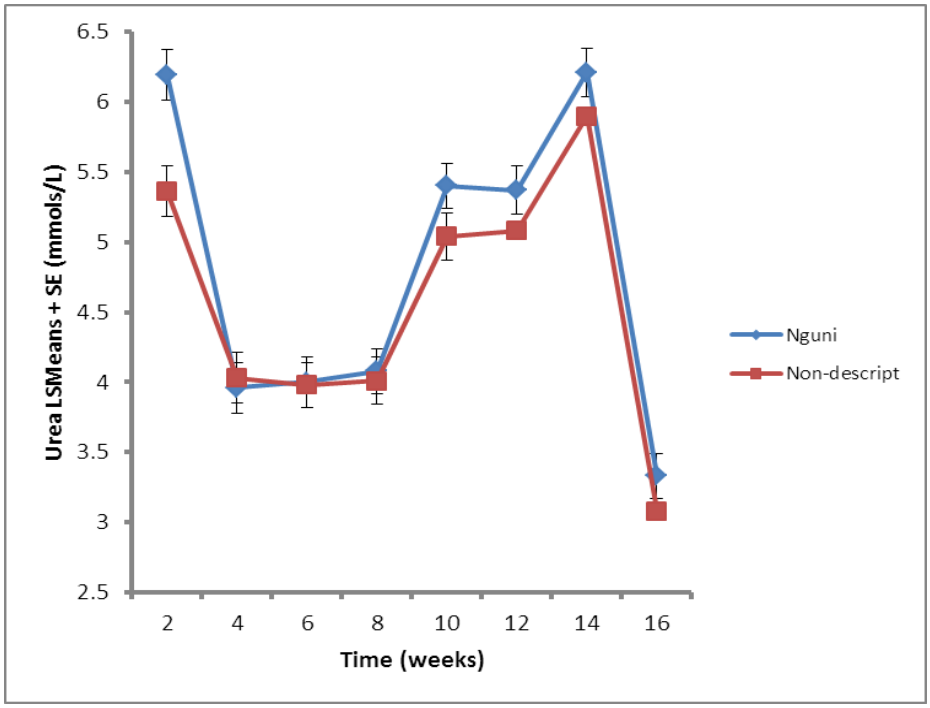

Figure 4.5: Variations in urea concentration (mmols/L) (LSmean ± SE) over the 16 weeks of the trial

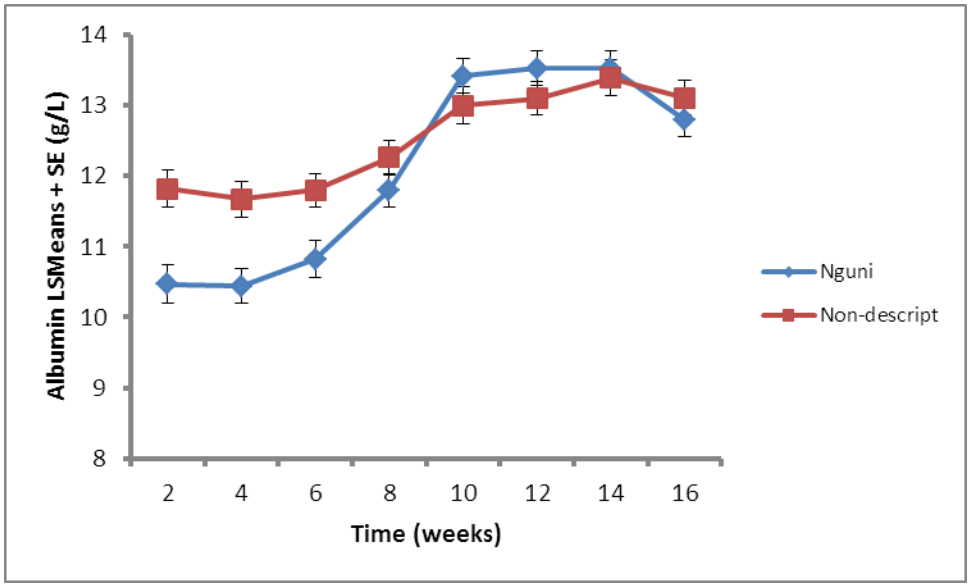

Figure 4.6: Variations in albumin concentration (mmols/L) (LSmean ± SE) over the 16 weeks of the trial

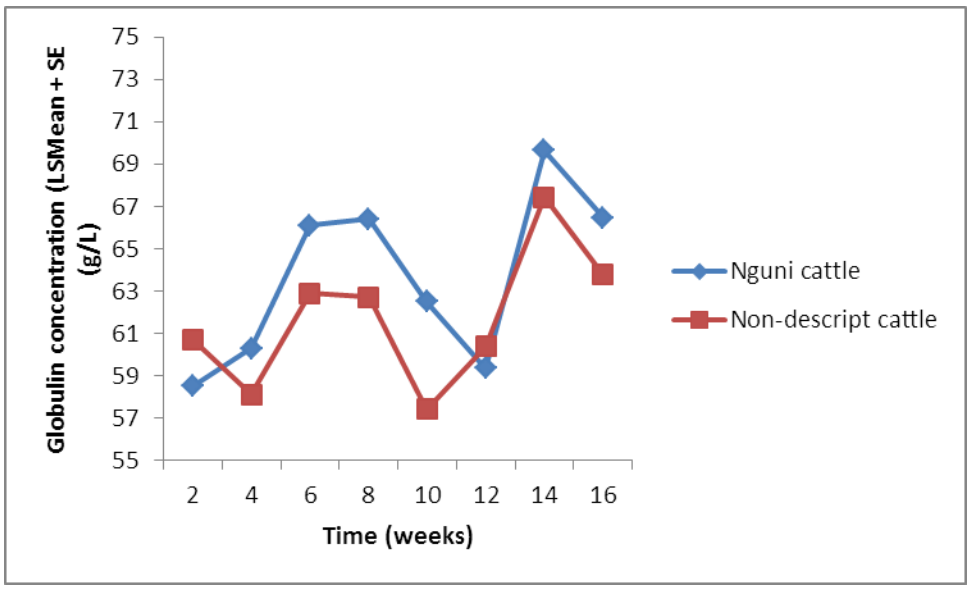

Figure 4.7: Variations in globulin concentration (mmols/L) (LSmean ± SE) in Nguni and non-descript crossbred cattle over the 16 weeks of the trial.

Table 4.2 shows the albumin:globulin ratio by genotype across the 16 weeks of sampling. Genotype had significant ($P > 0.05$) effects on the albumin:globulin ratio. However, week of sampling had no significant ($P > 0.05$) effect. The albumin:globulin ratio tended to be lower in Nguni cattle compared to NDCC (Table 4.2).

The correlations of Temperature-humidity index values and blood metabolites is shown in Figure 4.8. Principal components 1 and 2 show that glucose concentration was negatively correlated with THI indices.

There were no significant ($P > 0.05$) genotype effects on glucose, total protein, creatinine, urea, globulin, albumin, albumin:globulin ratio, creatine kinase activity and cortisol at slaughter.

4.3.4 Slaughter weights, hide weights and carcass classification

Genotype had a significant ($P < 0.05$) effect on slaughter and hide weights. Nguni cattle had lower slaughter and hide weights (232.6 ± 6.5 kg and 14.7 ± 0.54 kg) than NDCC (285.85 ± 6.52 kg and 18.4 ± 0.54 kg) as shown in Table 4.3. Using slaughter liveweight as a covariate, genotype had a significant ($P < 0.05$) effect on hide weights. Slaughter liveweight was significant ($P < 0.05$) as a covariate. Hideweights from covariate analysis were significantly ($P < 0.05$) lower (15.5 ± 0.55 kg) for Nguni than NDCC (17.7 ± 0.55 kg). However, genotype had no significant ($P > 0.05$) effect on relative hide weights. Based on age and fatness scores, the A1 class was more dominant than A0 in NDCC, while half of Nguni cattle were in either class A0 or A1 (Figure 4.9). All animals in this study were castrated male (i.e. steers), were in the A age category (0 tooth) and had a carcass conformation of 3. A higher proportion of non-descript crossbred steers had subcutaneous fatness scores of 1 (73.7 %), compared to those in

Table 4.2:Changes in the albumin:globulin ratio in Nguni and non-descript crossbred cattle over 16 weeks of sampling

	Albumin:globulin ratio	
Week	**Nguni**	**Non-descript crossbreed**
2	0.2 ± 0.08	0.2^{a} ± 0.08
4	0.2 ± 0.08	0.2^{a} ± 0.08
6	0.2 ± 0.08	0.2^{a} ± 0.07
8	0.2 ± 0.07	0.2^{a} ± 0.07
10	0.2^{A} ± 0.07	$0.5^{b,B}$ ± 0.08
12	0.1 ± 0.07	0.2^{a} ± 0.08
14	0.2 ± 0.07	0.2^{a} ± 0.08
16	0.2 ± 0.07	0.2^{a} ± 0.07

$^{a,b,\ c,d}$ Means with different superscripts within a column are different ($P < 0.05$)

^{A,B} Means with different superscripts within a row are different ($P < 0.05$)

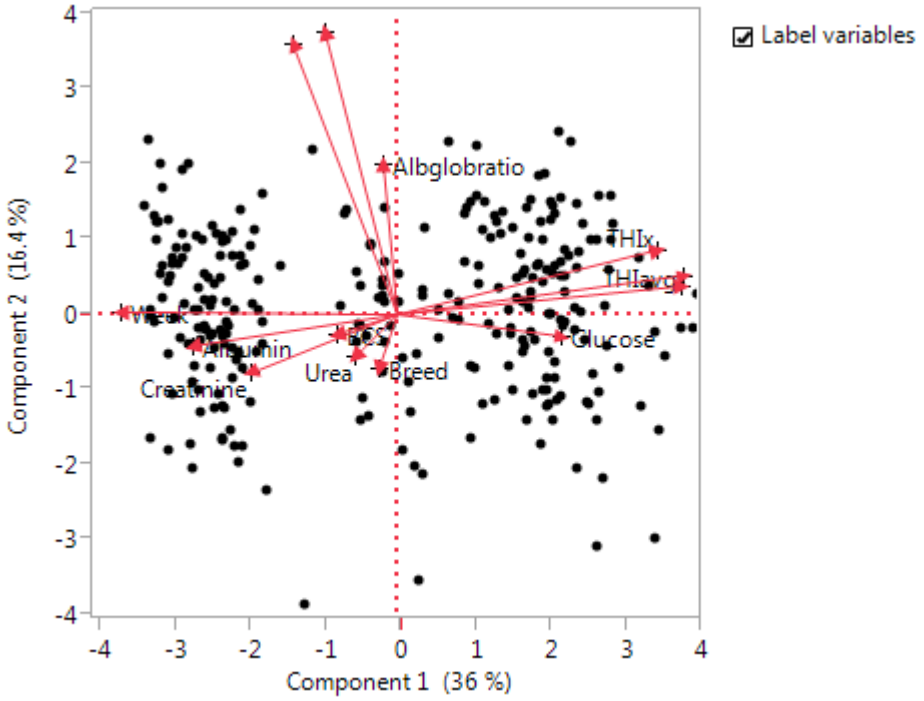

Figure 4.8: Principal components of correlations among blood metabolites and THI over the 16 week study period.

Albglobratio- albumin:globulin ratio. THIx – maximum temperature humidity index, THIn – minimum temperature humidity index, THIav – average temperature humidity index

Table 4.3: LSMeans ± SE for slaughter weights (kg), carcass weight (kg), hide weights (kg) and relative hide weight (%) of Nguni and non-descript crossbred cattle reared on a sweet veld

Parameter	**Genotype**	
	Nguni	**Non-descript crossbreed**
Slaughter weight	$209.8^{a} \pm 7.39$	$254.8^{b} \pm 7.39$
Warm carcass mass	$105.0^{a} \pm 3.13$	$131.4^{b} \pm 3.13$
Cold carcass mass	$101.8^{a} \pm 3.04$	$127.5^{b} \pm 3.04$
Dressing percentage	50.1 ± 0.84	51.9 ± 0.84
Green hide weight	$14.7^{a} \pm 0.54$	$18.4^{b} \pm 0.54$
Relative hide weight	7.0 ± 0.18	7.5 ± 0.19

$^{a, b}$ means within a row with the different superscripts are different ($P < 0.05$)

N. S.- not significant

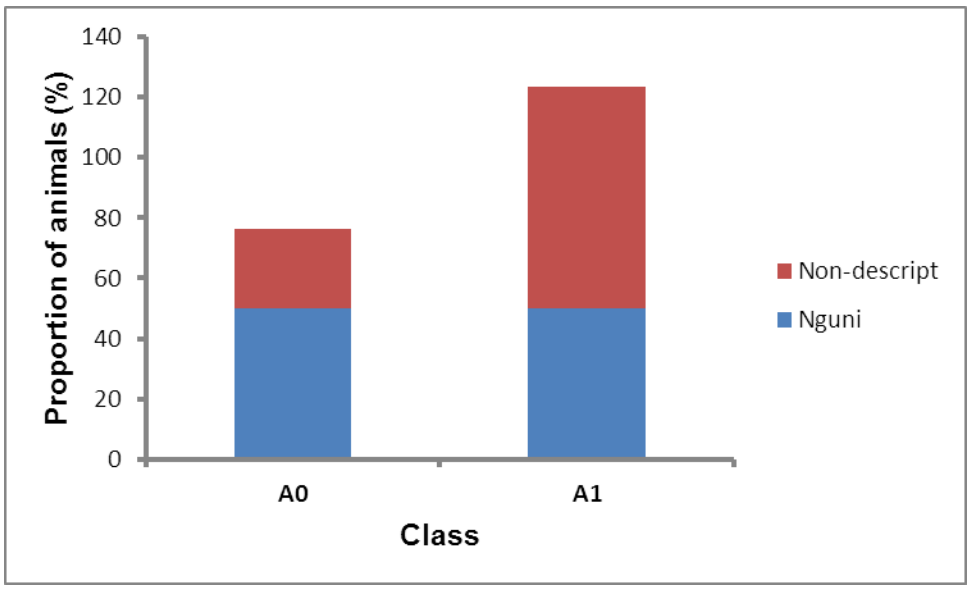

Figure 4.9: Carcass classes for Nguni and non-descript crossbred cattle at slaughter based on age and fatness score

the 0 fatness score class, while 50 % of Nguni cattle were either in fatness score 0 or 1. None of the animals had fatness scores above 1. Over 80 % of the animals in both genotypes had no bruises, while the rest had slight bruises.

4.4 Discussion

In this study, non-descript crossbred cattle had higher weekly liveweights compared to Nguni cattle. Generally, NDCC are heavier and bigger framed than Nguni cattle (Mapiye *et al*., 2009). The findings in this study are similar to findings by du Plessis and Hoffman (2007), who reported lowest liveweights for Nguni cattle and highest weights for Simmentaler cattle when finished on natural pasture. In this study, liveweights increased throughout the study period for both genotypes. This shows that both genotypes were able to satisfy maintenance and growth requirements from the natural forage. These results concur with Muchenje *et al*. (2008) who obtained similar liveweights for Nguni cattle reared on a natural pasture. The hot wet season is characterised by an abundance of natural forage as the grasses will be actively growing. The sweet veld in particular, is characterised by grasses that maintain their palatability and relatively high nutritive value well into the dry season (Ellery *et al*., 1995; Tainton, 1999; Palmer and Ainslie, 2006). Sweetveld grasses, however, are not bulky and not as vigorously growing as sourveld grasses due to low and unpredictable rainfall patterns. Most sweet rangelands are dominated by annual species. They need to be lightly stocked and/or rested to prevent overgrazing and loss of veld condition (Barnes, 1979; Danckwerts and Tainton, 1996). Crude protein content can be as low as 2 % in the sweet rangelands during the winter season (Lesoli, 2008).

In this study, significantly higher body condition scores in NDCC reflect better capacity to store fat reserves. Breed differences in subcutaneous fat deposition have been reported

(Ermias *et al*., 2002; McLellan *et al*., 2009; Van Laer *et al*., 2014). However, in both genotypes, body condition scores only increased up to the fourth week and were maintained throughout the study period, unlike weekly liveweights which continued to increase throughout the study period. The similarity in body condition between the Nguni and NDCC at the end of the 16 week trial could be attributed to the lower maintenance requirements and efficiency of utilising the veld forages in Nguni cattle compared to NDCC. As animal liveweight increases, maintenance requirements also increase (Stobbs, 1975). This would place a larger demand on the available nutrients, leaving lesser nutrients for storage as body reserves in larger NDCC. Generally, different breeds have different nutrient requirements (Stobb, 1975). The nutritive value of the forage, the amount of herbage available for foraging and the genetic potential of the animals will determine the performance of the animals. According to Ermias *et al*. (2002) tropically- adapted animals use survival mechanisms such as storing energy in adipose tissues when forage quality and quantity are high and when all the requirements of the animals are being met. They are normally faced with fluctuations in forage availability and nutritive value. These reserves will be used later during periods of energy deficits (Ermias *et al*., 2002).

The maintenance of a constant body condition could also be indicative of a limit that was reached by the veld forages in their ability to support animal production. However, other factors such as the genetic potential of the animal to convert nutrients in feed to body mass also affect the overall performance (Barendse *et al*., 2007). In semi-arid areas, the seasonality in precipitation, coupled with variations in topography result in spatial heterogeneity in forage quality and quantity (Palmer and Ainslie, 2006). Furthermore, within-season variations in environmental conditions result in a fluctuating feed resource base that consequently affects animal performance (Scoones, 1995; Boone and Wang, 2007). Cattle

production efficiency has been reported to be affected by feed shortages, low quality of feed, diseases and parasites (Mapiye *et al*., 2009). These challenges affect the nutritional status, welfare and performance of livestock (Rumosa-Gwaze *et al*., 2010).

Veld forages generally increase in crude protein content and available energy early in the rainy season, increase to a peak and then decline as the dry season approaches (Tainton, 1999). However, forage biomass production also increases up to the end of the rainy season, with carryover forage into the dry season (Ellery *et al*., 1995). Therefore, the increase in forage biomass may be compensating for the declining nutritive value to sustain the increases in liveweight and a constant body condition.

Although both liveweights and body condition are generally used as indicators of animal wellbeing, body condition scores are considered the better predictors of nutritional status of the animals compared to animal liveweight (Corbet *et al.* 2005). Besides being used for immediate management purposes, body condition during rearing can also be used to predict subcutaneous fat level in carcasses at slaughter (Ayres *et al*., 2009).This can assist livestock managers in targeting a certain finishing level that will ensure optimal fatness level at slaughter. In contrast, Ndlovu *et al*. (2007; 2009) and Damptey *et al*. (2014) indicated that both liveweight and body condition score are not very good indicators of nutritional status. Ndlovu *et al*. (2009) further reported that changes in the scale used for body condition and liveweights respond too slowly to short-term changes in diet and feeding management making them unreliable. Smallholder cattle production heavily relies on extensive grazing which is affected by seasonality of precipitation and other environmental conditions (Angassa and Oba, 2007). Ndlovu *et al*. (2009) however, indicated that instead of relying on body weight changes and body condition scores, blood metabolites can be used as an immediate indicator of nutritional and health status of cattle at that point in time. In the short to medium

term, blood metabolites have been recommended in evaluation of dietary effects on cattle performance. Blood metabolites are sensitive to changes in nutrient intake (Pambu-Gollah *et al*., 2000).

In this study, the lack of genotype effects on plasma glucose concentration could be a reflection of similar energy requirements in the two genotypes during the study period. It also reflects that the energy requirements of both genotypes were being met as the glucose concentrations were within normal range (Merck Veterinary Manual, 2010). In this study, however, week of sampling affected glucose concentrations. Plasma concentration of glucose is an important indicator of the adequacy of dietary energy intake (Whitaker *et al*., 1999). The normal range of glucose concentration obtained in this study therefore, indicates that the steers had adequate energy supply (Boonprong *et al*., 2007) and were able to maintain glucose homeostasis. Weekly fluctuations in blood glucose could be a result of the changes in nutritive value of natural rangeland forages which are generally affected by within-season and seasonal variations. As pointed out by Mapiye *et al.* (2010), energy metabolite profiles could be used in evaluating animal ability to cope with fluctuations in quality and quantity of the available feed resources. The two genotypes in this study responded in a similar way to weekly changes throughout the study period, probably indicating similarity in nutrient harvesting from the forages. Glucose levels in this study concur with earlier findings on Nguni and non-descript cattle (Mapiye *et al*., 2009; Ndlovu *et al*., 2009). Damptey *et al*. (2014) also reported similar glucose levels in Sanga cattle reared on natural pasture. Similar to findings in the current study, Mapiye *et al.* (2009) did not find any significant breed differences in blood plasma glucose concentration between Nguni and NDCC. In contrast, Ndlovu *et al*. (2009) found significant differences between Nguni and Bonsmara breeds in glucose concentrations.

Generally, glucose levels in this study were higher at the beginning of the study and declined from the 2nd week to the end of the study period (week 16). Mapekula *et al*. (2011) reported similar findings. Pambu-Gollah *et al*. (2000) attributed this decline in glucose concentration to a simultaneous impact of an increase in glucose utilisation by the animal and a decline in the intake of glucose progenitors as the advancing growing season slowed down forage growth. Mapiye *et al*. (2009) reported lowest glucose concentrations during the hot-wet season and approximately 78 % of cattle had blood glucose levels below the normal expected range in this season.

In addition to energy profiles, protein profiles are a reflection of the nutritional wellbeing of an animal (Mapiye *et al*., 2010). The higher total protein observed in the Nguni compared to the NDCC throughout the study suggest that Nguni cattle were more efficient at digesting the veld forages. Total plasma concentrations are an indicator of long-term body protein status (Pambu-Gollah *et al*., 2000). The total proteins are usually maintained until body proteins reserves are significantly depleted (Pambu-Gollah *et al*., 2000). In this study, total protein concentrations increase until the end of the trial, with higher concentrations in the Nguni cattle compared to NDCC. This finding could be attributed to the adaptation observed in the Nguni breed to the harsh conditions in South Africa (Collins-Lusweti, 2000). Both genotypes were however, able to meet expected total protein concentrations (68.4 ± 1.64 to 82.0 ± 1.57 g/L). The total protein concentrations were within the normal range (Farver, 1997; Otto *et al*., 2000; Merck Veterinary Manual, 2010). The results obtained in this study concur with findings by Mapiye *et al*. (2010). Ndlovu *et al*. (2009) and Mapfumo and Muchenje (2015) observed similar TP concentrations in Nguni cattle grazing on natural rangelands.

Creatinine concentrations increased over the 16 weeks of the study period for both genotypes. However, Nguni cattle had significantly lower creatinine levels compared to NDCC throughout the study period. Creatinine is a product of muscle metabolism and its excretion is influenced by muscle mass (Pambu-Gollah *et al*., 2000). According to Caldeira *et al.* (2007), the formation of creatinine from creatine phosphate in the muscles is affected by two factors. These include: (i) the amount of creatine that is directly related to musle mass and (ii) the proteolysis and rate of use of N compounds derived from the body tissue (Caldeira *et al*., 2007). Furthermore, Whittet *et al*. (2004) reported that creatinine levels are correlated to liveweight and correlate strongly to muscle mass. The lower level of creatinine in Nguni cattle is, therefore, consistent with the lower liveweight compared to NDCC. In this study, NDCC had higher liveweights compared to the Nguni cattle throughout the 16 weeks. Creatinine concentrations from both genotypes were within normal range (Merck Veterinary Manual, 2010).

Genotype and week of sampling had significant effects on urea concentrations. Generally, Nguni cattle had slightly higher levels of urea compared to NDCC. According to Greenwood *et al*. (2002), urea concentrations are associated with catabolism of body proteins when animals experience energy restrictions. This is done to counter shortfalls in energy supply. Urea concentrations (3.2 ± 0.12 to 5.2 ± 0.12 mmol/L) in the current study were within the normal range for cattle (Farver, 1997; Merck Veterinary Manual, 2010). Mapiye *et al*. (2009), Ndlovu *et al*. (2009) and Mapfumo and Muchenje (2015) reported similar ranges of urea concentrations for Nguni cattle. In Mapiye *et al*. (2009), NDCC had normal urea concentrations. The huge drop in urea levels from 2nd week to 8th week shows an improvement in the nutritional status of both genotypes. However, the increase in urea concentrations from week 10 to week 14 shows a decline in nutritional status. This decline in

nutritional status could be attributed to the onset of the winter season as the study was terminated at the beginning of June. The nutritional status and growth patterns of veld forages in the sweetveld is heavily dependent on climate (rainfall and temperature) and soil parent material (Ellery *et al*., 1995). Although it was not merasured in this study, it would be helpful in future studies to correlate the blood parameters with the nutritional value of the forage. The decline in plasma glucose concentration throughout the study might have led to the decreased energy supply which could have consequently led to muscle catabolism leading to higher urea concentrations (Damptey *et al*., 2014). When diets containing sufficient energy are fed, urea concentrations are positively correlated to crude protein intake. However, energy-deficient diets result in high urea concentrations (Damptey *et al*., 2014).

Albumin concentrations obtained in this study were much lower than the expected normal range of 25-38 g/L (Merck Veterinary Manual, 2010). Generally, albumin concentrations were lower in Nguni cattle compared to NDCC in the first 8 weeks. Between weeks 10 and 14, Nguni cattle had higher albumin concentrations compared to NDCC. Albumin concentrations are an indication of the protein status of animals. Reductions in albumin levels indicate protein deficiencies (Agenas *et al*., 2006). According to Kaneko *et al.* (1997) normal albumin concentrations are associated with good nutritional status and good body condition in cattle. Nguni cattle appeared to be more nutritionally stressed than NDCC in the first 10 weeks, as reflected by lower body conditions compared to NDCC, thereafter improving in nutritional status as evidenced by an increase in albumin concentrations after week 10.

Nguni cattle had higher concentrations of globulin compared to NDCC throughout the 16 weeks. Standard reference range for globulin concentration in cattle is between 28-42 g/L (Farver, 1997; Merck Veterinary Manual, 2010). High globulin concentrations indicate high

infection levels (Whitaker *et al*., 1999) and therefore, an indication of the immune status of an animal (Kapele *et al*., 2008). Circulating globulin concentrations increase as a response to diseases and infections (Marufu *et al*., 2010). Breed differences in globulin concentrations are attributed to differences in resistance or tolerance to endemic diseases and parasites (Marufu *et al*., 2010). The higher globulin concentrations in Nguni cattle could be a reflection of their natural resistance to diseases and parasites compared to NDCC. During the rainy season, there is a high prevalence of tick-borne diseases and internal parasite challenge (Marufu *et al*., 2009; Ndlovu *et al*., 2009; Marufu *et al*., 2011).

Genotype had significant effects on the albumin:globulin ratio. The normal range for albumin:globulin ratio is 0.9-1.4 (Farver, 1997). The albumin:globulin ratios obtained in this study, for both genotypes, were lower than the normal range. Nguni cattle had lower albumin:globulin ratios compared to non-descript cattle. This could be explained by the lower albumin and higher globulin observed in this study (Figures 4.6 and 4.7). Mapiye *et al.* (2009) and Ndlovu *et al*., 2009) reported much higher albumin:globulin ratios than that obtained in this study.

Various authors (Bernabucci *et al*., 2010; Baumgard and Rhoads, 2012; Ganaie *et al*. 2013) have reported changes in blood metabolites due to heat stress during the hot wet season. Heat stress has been reported to depress feed intake, feed utilisation efficiency, nutritional status of the animals and consequently affect carcass and meat characteristics (Baumgaurd and Rhoads, 2012). Ganaie *et al*. (2013) reported inconsistent changes in plasma protein and albumin during heat stress in various animal species. Bernabucci *et al*. (2010) and Baumgard and Rhoads (2012) indicated that heat stress increases maintenance requirements of animals and may lead to hypoglycaemia. Furthermore, Baumgaurd *et al*. (2012) reported increased

skeletal catabolism in most species during heat stress, increasing plasma markers of muscle catabolism, consequently affecting carcass traits. The first 10 weeks of this study had very high maximum THI values which could have potentially affected some blood metabolites in these two genotypes. The principal component analysis showed a negative correlation between THI values and glucose in this study. Effects of heat stress on cattle nutritional status need further investigation.

Blood concentrations of glucose, creatinine, total protein and blood urea at slaughter were within the normal range, albumin was lower than normal, while globulin was higher than normal ranges (Merck Veterinary Manual, 2010). Creatine kinase activity was higher than the normal range of 0-350 U/L (Merck Veterinary Manual, 2010). However, the CK activity values obtained in this study are similar to values obtained by Mpakama *et al*. (2014) for other cattle breeds at slaughter. The lack of differences between the two genotypes in metabolite concentrations at slaughter, probably reflect a similar response to pre-slaughter stress and fasting.

Nguni cattle had lower slaughter and hide weights compared to NDCC in this study. This could be explained by the small frame size and lower liveweights of Nguni cattle throughout the study period. This observation could also be attributed to inherently lower growth rate of Nguni cattle (Strydom, 2008; Frylinck *et al*., 2013). The higher total protein concentration observed in contrast to the NDCC did not translate to better muscle deposition in the Nguni cattle. However, relative hide weights were not different across the two genotypes. Abattoirs pay farmers for hides on weight basis and also sell to tanneries on the same basis (RMAA, 2015). Non-descript crossbred cattle hides from this study would therefore, fetch more income for the farmers compared to Nguni cattle hides. Warm carcass mass and cold carcass

mass were significantly lower in Nguni compared to NDCC. However, dressing percentage was not different although it tended to be higher for NDCC. Non-descript crossbred cattle are bigger framed compared to Nguni cattle (Mapiye *et al*., 2009) and it therefore follows that as a result of the normal nutritional status observed in this study through metabolic profiles, they finished off at higher carcass weights than Nguni cattle.

All the steers in this study finished off at a medium carcass conformation score (3). Carcasses that are too flat tend to have a low meat to bone ratio. Carcass conformation is used as an indicator of potential saleable meat yield and conformation scoring is based on visual assessment (Conroy *et al*., 2010). In this study, there was similar carcass conformation in the two genotypes. In contrast, Muchenje *et al*. (2008) reported that carcasses from indigenous breeds such as the Nguni do not have excellent conformation, resulting in Nguni farmers not getting premiums on carcass conformation. Soji *et al*. (2015) also pointed out that due to poor conformation, indigenous cattle breeds reared by smallholder farmers would be out-competed by improved breeds. The similarity in conformation could be a result of the young age at slaughter. Most Nguni cattle are sold at old ages and would have gone through cycles of weight gain in the rainy season and weight loss in the dry season.

The majority of the steers from both genotypes finished at a very lean carcass class (class A1), while the rest had no visible subcutaneous fat (class A0). Half of the Nguni had no visible subcutaneous fat (A0; 50 %) while the other half were very lean (A1; 50 %). This finding could be related to the observed differences in body condition scores in the two genotypes at the beginning of the study. At the end of the study however, body condition scores were similar in the two genotypes. The similarity in body condition scores, however, does not seem to be reflected in the fatness level at slaughter in the two genotypes. Non-

descript crossbred cattle being crosses of both *Bos indicus* and *Bos taurus* may be more inclined to deposit subcutaneous fat. Fatness score 0 has no visible subcutaneous fat, while score 1 is for subcutaneous fat less than 1 mm thick (Red Meat Industry Forum (RMIF), 2006; South African Meat Industry Company (SAMIC), 2006). Fat cover is considered one of the important attributes of meat affecting consumer purchase decisions, with consumers preferring lean meat to overfat meat or very lean meat (Morales *et al*., 2013). Besides the quantity of fat, fat quality is also of consumer concern as they are interested in health promoting food products (Daley *et al*., 2010). Lean carcasses fetch higher premiums compared to overfat or over lean carcasses (Sanúdo *et al*., 2000). Carcasses from both genotypes in this study finished off below the optimum fatness score of 2 desired by consumers.

4.5 Conclusions

It was concluded that nutritionally-related blood metabolites vary with genotype and week of sampling. Furthermore, growth performance, hide weights and carcass weights varied between the two genotypes. Nguni and NDCC had similar conformation but different fatness levels which ranged from nil to very lean. However, relative hide weights were similar. Further research is required to determine if the differences in blood metabolite profiles and body condition translate into differences in meat quality. Evaluation of physico-chemical quality and fatty acid composition of beef from these two genotypes is recommended. Furthermore, physico-mechanical evaluations are recommended to determine if there are differences in the quality of leather manufactured from Nguni and NDCC hides.

4.6 References

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Chapter 5: Fatty acid profiles and some physico-chemical quality traits of beef from 18-month old Nguni and non-descript crossbred steers reared on a sweetveld

Abstract

The objective of the study was to determine the fatty acid profiles and physico-chemical quality of beef from Nguni and non-descript crossbred cattle (NDCC) reared extensively on a sweetveld. Furthermore, physico-chemical quality characteristics of two beef muscle types from the two genotypes were compared. Forty steers (20 Nguni and 20 NDCC) were reared from the age of 14 months for 16 weeks on a sweetveld. The steers were slaughtered at the end of the trial, at a commercial abattoir. Slaughter liveweights were 209.8 ± 7.39 kg and 254.8 ± 7.39 kg for Nguni and NDCC, respectively. After chilling the carcasses for 24 hrs, meat samples were collected from the right *longissimus thoracis et lumborum* (LTL) and *Triceps brachii* (TB) muscles for physico-chemical quality tests. Fatty acid profiles were determined on the LTL. Ultimate pH (pH24), temperature, colour (L*, a*, b*), thawing loss, cooking loss and Warner Bratzler shear force (WBSF) tenderness were determined on the LTL and TB. Results indicated that intramuscular fat was higher ($P < 0.05$) in beef from Nguni than NDCC. Nguni steers had darker ($P < 0.05$) coloured beef (L*=33.6 ± 0.01) than that from NDCC (L*= 35.7 ± 0.54). There were no significant ($P > 0.05$) genotype effects on thawing loss, cooking loss, WBSF tenderness, fat-free dry matter, moisture content, fatty acid profiles and health-related lipid indices. It was concluded that beef from Nguni and NDCC differs in the IMF and meat lightness but is similar in fatty acid composition and some physico-chemical quality parameters.

Keywords: lipid, colour, farmers, meat, oleic, tenderness

5.1 Introduction

In South Africa, there are efforts to restore adapted breeds in smallholder low-input, extensive cattle production systems in order to promote participation of smallholder farmers in formal beef markets (Bester *et al*., 2004; Mapiye *et al*., 2009; Tada, 2013). Presently, the majority of cattle owned by the smallholder farmers are non-descript crossbreed cattle (NDCC) which resulted from uncontrolled and indiscriminate mating of indigenous cattle such as the Nguni with improved imported cattle breeds such as the Jersey, Angus, Bonsmara, Brahman and Friesian (Bester *et al*., 2003; Mapiye *et al*., 2009). Small-scale farmers own approximately 40 % of the national cattle herd (Scholtz *et al*., 2008). They, however, currently have a low offtake into the formal beef sector, ranging between 2.5-10 % (Scholtz *et al*., 2008; Mapiye *et al*., 2009).

For smallholder farmers to be competitive in the formal beef sector, they need to produce good quality beef which meets the nutritional and health requirements demanded by modern day consumers. Although various authors have highlighted a number of challenges faced by smallholder farming systems in South Africa (Musemwa *et al*., 2008; Mapiye *et al*., 2009; Soji *et al*., 2015), they possess certain characteristics that could make beef produced in this sector attractive in natural beef niche markets. For example, cattle in this sector are reared in extensive production systems with little or no veterinary inputs (Mapiye *et al*., 2007; Scholtz *et al*., 2008; Musemwa *et al.*, 2010).

Beef consumers are increasingly demanding natural beef from locally adapted genotypes, reared in free-range systems due to its perceived eating quality experience (De Smet *et al*., 2004; Wood *et al*., 2008; Scollan *et al*., 2014) and health-promoting attributes (Verbeke *et al*., 2010; Xue *et al*., 2012; Font-i-Furnols and Guerrero, 2014; Scollan *et al*., 2014). Beef

contains variable types and amounts of fats and fatty acids which may be beneficial to consumer health or may predispose consumers to health risks such as cardiovascular diseases, diabetes and cancer (Wood *et al*., 2008; Daley *et al*., 2010; Gogus and Smith, 2010; Brugiapaglia *et al.*, 2014). High associations between increased health risks and consumption of foodstuffs such as beef which contain high amounts of saturated fatty acids have been reported (Schaefer, 2002; Purchas *et al*., 2005; Gogus and Smith, 2010). Certain saturated fatty acids result in elevated levels of serum low-density lipoprotein cholesterol (Realini *et al*., 2004; Gogus and Smith, 2010).

Several authors pointed out that dietary factors and genotype significantly influence the overall fat content and fatty acid composition, thereby affecting the nutritive value of the meat (De Smet *et al*., 2004; Wood *et al*., 2008; Scollan *et al*., 2014). Concentrate-fed cattle have been reported to produce fatter carcasses with a higher level of saturated fatty acids, while grass-fed cattle tend to produce leaner carcasses with a higher degree of unsaturated fatty acids and anti-oxidant properties (Daley *et al*., 2010). In addition to the production system and genotype, the fat content and fatty acid composition vary among meat cuts. Rani *et al*. (2014) reported significant variations in intramuscular fat content, fatty acid profiles and other physico-chemical quality attributes in different portions of mutton. Not many studies have been carried out comparing fatty acid profiles of different meat cuts.

Other than fat content and fatty acid profiles, beef quality intrinsic attributes valued by consumers include colour, taste (flavour), aroma, tenderness, juiciness, freshness, leanness, healthiness and nutritional value (Realini *et al*., 2004; Nuernberg *et al*., 2005; Kraus, 2015). While grass-fed beef has some desirable health and eating quality attributes, it has unfortunately been associated with a darker colour compared to that from feedlot systems and

is therefore perceived to be less favourable to consumers at retail point (Roosevelt *et al*., 2011). Meat colour is used by consumers as an indicator of freshness (Font-i-Furnols and Guerrero, 2014). Furthermore, meat colour is related to pH which affects shelf life and cooking properties of meat.

Several factors affecting beef quality include intrinsic factors such as genotype, sex and extrinsic factors such as animal diet, production system and pre-slaughter handling (Maltin *et al*., 2003; Scollan *et al*., 2006; Mach *et al*., 2008; Daley *et al*., 2010). Cattle in smallholder systems of South Africa graze on communally-owned rangelands which are commonly found in poor condition due to institutional complexities of simultaneous communal ownership of rangelands but individual ownership of cattle (Moyo *et al.*, 2008). Beef cattle reared in these systems are exposed to feed resources that fluctuate in quality and quantity leading to high variability in their nutritional status in both sweet and sour rangelands and in different seasons (Mapiye *et al*., 2009; Ndlovu *et al*., 2009; Mapiye *et al*., 2010a; Mapiye *et al*., 2010b; Mapekula *et al*., 2011). The variation in rangeland forage quality and biomass has been reported to affect numbers of marketable cattle, beef yield and quality in unadapted breeds (Coetzee *et al*., 2005; Mirkena *et al*., 2010).

Adapted breeds such as the Nguni have been reported to perform well under harsh conditions (Collins-Lusweti, 2000). They, however, have a small frame size which does not normally compete well against improved breeds in commercial feedlots and abattoirs (Muchenje *et al*., 2008a; Muchenje *et al*., 2008c; Strydom *et al*., 2008; Soji *et al*., 2015). Nevertheless, Nguni cattle produce good quality beef which is comparable to that from improved breeds under natural rangelands (Muchenje *et al.*, 2008a; Muchenje *et al*., 2008b). There is very little information on the quality of beef from non-descript crossbred cattle reared under natural

conditions. Very few studies have been conducted comparing the quality of beef from Nguni and non-descript crossbred cattle reared under similar conditions.

The objective of this study was to determine the fatty acid profiles and physico-chemical quality of beef from 18-month old Nguni and non-descript crossbred steers reared under ecologically-controlled sweet rangelands. Furthermore, the study sought to determine differences in physico-chemical quality of beef from the *Longissimus thoracis et lumborum* and *Triceps brachii* muscles. It was hypothesised that there is no difference in fatty acid profiles and physico-chemical quality of beef from 18-month old Nguni and NDCC reared under similar ecologically-controlled conditions on a sweetveld. It was further hypothesised that the physico-chemical quality of *Longissimus thoracis et lumborum* and *Triceps brachii* muscles from the 18-month old Nguni and non-descript crossbred steers is similar.

5.2 Materials and methods

5.2.1 Study site

As described in section 3.2.1

5.2.2 Ethical clearance

As described in section 3.2.2

5.2.3 Animal management

As described in section 3.2.3

5.2.4 Animal liveweights at slaughter, slaughter procedure and carcass chilling

At the end of May, the steers were slaughtered at a commercial abattoir using approved

slaughter and dressing procedures. They were weighed individually at the abattoir prior to slaughter, to determine liveweights at slaughter. The animals were stunned using the captive bolt method. Carcasses were electrically stimulated using a voltage of 300 V, a frequency of 50 Hz, a current of 5 A in 40 to 45 seconds at a pulse of 12/s, to control the effect of rapid chilling on cold shortening of muscles. The dressed carcass consisted of the body after removal of the fifth quarter, i.e., the skin, head at the occipito-atlantal joint, the fore feet, the hind feet and the viscera. The carcasses were split and weighed. Carcass classification was done using the South African Carcass Classification System. The carcasses were then chilled at 7 °C for 24 hours before meat sampling. Representative samples of the *muscularis longissimuss thoracis et. lumborum* (LTL) and *Triceps brachii* (TB; shoulder muscles) on the right side were sampled 24 hours after slaughter. The LTL was sampled from the 10^{th} rib to the third lumber vertebra in the direction of the rump. The thickness of the steaks for Warner-Bratzler test and Commission International De I' Eclairage (CIE) lab colour measurements were 100 mm and 20 mm, respectively. Meat samples for fatty acid analysis were cut after chilling for 24 hours, vacuum-packed and immediately frozen until analysis.

5.2.5 Meat quality measurements

5.2.5.1 Fatty acid profile determination

Total lipid from LTL samples from Nguni and non-descript crossbred cattle was quantitatively extracted, according to the method of Folch *et al*. (1957) using chloroform and methanol in a ratio of 2:1. An antioxidant, butylated hydroxytoluene was added at a concentration of 0.001 % to the chloroform: methanol mixture. A rotary evaporator was used to dry the fat extracts under vacuum and the extracts were dried overnight in a vacuum oven at 50°C, using phosphorus pentoxide as moisture adsorbent. Total extractable intramuscular fat was determined gravimetrically from the extracted fat and expressed as % fat (w/w) per

100 g tissue. The fat free dry matter (FFDM) content was determined by weighing the residue on a pre-weighed filter paper, used for Folch extraction, after drying. By determining the difference in weight, the FFDM could be expressed as % FFDM (w/w) per 100 g tissue. The moisture content of the muscle was determined by subtraction (100% - % lipid - % FFDM) and expressed as % moisture (w/w) per 100 g tissue.

The extracted fat from muscle was stored in a polytop (glass vial, with push-in top) under a blanket of nitrogen and frozen at –20°C pending fatty acid analyses. A lipid aliquot (20 mg) of muscle lipid were converted to methyl esters by base-catalysed transesterification, in order to avoid CLA isomerisation, with sodium methoxide (0.5 M solution in anhydrous methanol) during 2 h at 30 °C, as proposed by Park *et al*. (2001), Kramer *et al*. (2002) and Alfaia *et al*. (2007). Fatty acid methyl esters (FAMEs) from muscle were quantified using a Varian 430 flame ionization GC, with a fused silica capillary column, Chrompack CPSIL 88 (100 m length, 0.25 mm ID, 0.2 μm film thicknesses). Analysis was performed using an initial isothermic period (40 °C for 2 minutes). Thereafter, temperature was increased at a rate of 4 °C/minute to 230 °C. Finally an isothermic period of 230 °C for 10 minutes followed. FAMEs *n*-hexane (1μl) were injected into the column using a Varian CP 8400 Autosampler. The injection port and detector were both maintained at 250 °C. Hydrogen, at 45 psi, functioned as the carrier gas, while nitrogen was employed as the makeup gas. Galaxy Chromatography Software recorded the chromatograms. Fatty acid methyl ester samples were identified by comparing the retention times of FAME peaks from samples with those of standards obtained from Supelco (Supelco 37 Component Fame Mix 47885-U, Sigma-Aldrich Aston Manor, Pretoria, South Africa). Conjugated linoleic acid (CLA) standards were obtained from Matreya Inc. (Pleasant Gap, Unites States). These standards included: *cis*-9, *trans*-11; *cis*-9, *cis*-11, *trans*-9, *trans*-11 and *trans*-10, *cis*-12-18:2 isomers. All other

reagents and solvents were of analytical grade and obtained from Merck Chemicals (Pty Ltd, Halfway House, Johannesburg, South Africa). Fatty acids were expressed as the proportion of each individual fatty acid to the total of all fatty acids present in the sample. The following fatty acid combinations were calculated: omega-3 (*n*-3) fatty acids, omega-6 (*n*-6) fatty acids, total saturated fatty acids (SFA), total monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), PUFA/SFA ratio (P/S) and *n*-6/*n*-3 ratio. Thrombogenicity index (TI) and atherogenicity index (AI) were calculated using the following formulae by Ulbritch and Southgate (1991):

1. AI = [(4*C14:0) + C16:0 + C18:0)] / ∑MUFA + ∑PUFA-n6 + ∑PUFA-n3

2. TI = [C14:0 + C16:0 + C18:0] / [(0.5*MUFA) + (0.5* PUFA) + (3*PUFA-n3) + (PUFA-n3/PUFA-n6)]

5.2.5.2 Ultimate pH of meat

Ultimate muscle pH (pHu) was determined on the LTL and TB muscles using a portable fibre-optic pH and temperature (Tm) meter probe (CRISON pH 25 Instruments, S. A., Alella, Spain) with a sharp metal sheath to prevent damage of the glass bulb from the raw meat 30 hours post mortem. Calibration of the pH meter was done prior to taking measurements using pH 4, pH 7, and pH 9 standard solutions (CRISON Instruments, SA, Alella, Spain).

5.2.5.3 Meat colour

The Commission International De I' Eclairage (CIE) lab colour space was used on the LTL and TB muscles. A Minolta colour guide 45/0 BYK-Gardner GmbH machine with a 20 mm diameter measurement area and illuminant D65-day light, 10^{o} standard observer was used for

determination of the colour of the meat colour. Instrumental colour measurements were carried out 48 hours post-mortem for L* (lightness; 0: black, 100: white), a* (redness/greenness; positive values: red, negative values: green) and b* (yellowness/blueness; positive values: yellow, negative values: blue) after allowing a blooming period of 30 mins. Green, black and white colour standard tiles were used to calibrate the colour guide machine each day before taking measurements. Three readings were taken per meat sample by rotating the colour guide 90^{o} between measurements in order to obtain an average value for the colour. Colour values for each meat sample were recorded. Colour saturation was calculated as the square root of the sum of a^{*2} and b^{*2} (Brewer *et al*., 2001).

5.2.5.4 Thawing loss, cooking loss and Warner Bratzler (WB) Shear Force tenderness

The LTL samples were weighed after being frozen for 2 weeks. They were thawed for 10 hours at room temperature and re-weighed. The thawed samples were placed in ziplock plastic bags and cooked using a water bath at 72 ^{o}C until the core temperature reached 72^{o}C. Thawing and cooking losses were determined using the following equations:

$$\text{Thawing loss (TL) \%} = \frac{\text{(weight from freezer – weight after thawing)}}{\text{(weight from freezer)}} * 100\%$$

$$\text{Cooking loss (CL) \%} = \frac{\text{(weight before cooking – weight after cooking)}}{\text{(weight before cooking)}} * 100\%$$

Beef tenderness was determined using the Instron Warner-Braztler Shear Force (WBSF) machine. Following cooking, meat samples were allowed to cool to room temperature for 6 hours. Three sub-samples of specified core diameter (10mm) were cored parallel to the grain of the meat using a coring device. The samples were sheared perpendicular to the direction of

the fibres using a Warner-Bratzler (WB) shear device mounted on an Instron 3344 Universal Testing (cross head speed at 400 mm/min, one shear in the centre of each core). The mean maximum load recorded for the three cores represented the peak force in Newtons (N) for each sample.

5.2.6 Statistical analysis

Data on ultimate pH (pH_u), temperature, colour (L*, a* and b*), colour saturation were analysed using PROC GLM procedure of SAS (2003). The following model was used :

$Y_{ijk} = \mu + G_i + M_j + (G_i * M_j) + E_{ijk}$

where Y_{ijk}= response variable (pH_u, temperature, colour (L*, a* and b*), and colour saturation)

μ = overall mean

G_i = Effect of genotype

M_j = Effect of muscle type (j=loin or shoulder)

$G_i * M_j$ = interaction between genotype and muscle type

E_{ijk} = residual error

Significant differences in means were separated using Fisher's LSD.

Thawing loss, cooking loss, WBSF tenderness, proximate composition, fat acid ratios and fatty acid profiles were analysed using PROC GLM of SAS (2003). Fisher's LSD was used for separation of means. The following model was used:

$Y_{ij} = \mu + G_i + E_{ij}$

where Y_{ij} = response variable (thawing loss, cooking loss, WBSF tenderness, proximate composition, fat acid ratios and fatty acid profiles)

μ= overall mean

G_i = Effect of genotype (i= 1, 2 i.e., Nguni and non-descript crossbred cattle)

E_{ij} = residual error

Principal component analysis (PCA) was carried out using JMP of SAS (2010) to determine correlations among the meat quality variables.

5.3 Results

5.3.1 Intramuscular fat content, fat-free dry matter and moisture content of beef from 18 –month old Nguni and non-descript crossbred cattle

Genotype had a significant ($P < 0.05$) effect on intramuscular fat content (i.e., marbling). Nguni beef had higher IMF content (1.81 ± 0.092) compared to beef from NDCC (1.52 ± 0.092) as shown in Table 5.1. However, there was no significant ($P > 0.05$) genotype effect on fat-free dry matter and moisture content.

5.3.2 Fatty acid profiles of beef from 18 –month old Nguni and non-descript crossbred steers

Table 5.2 shows the fatty acids found in beef from Nguni and NDCC. Fatty acid profiles were not significantly ($P > 0.05$) affected by genotype.

5.3.3 Fatty acid ratios, atherogenicity index and thrombogenic index of beef from Nguni and non-descript crossbred cattle

Total SFAs, PUFAs, MUFAs, PUFA/MUFA ratio, n-6, n-3, n-6:n-3 ratio are shown in Table 5.2. Genotype had no significant ($P > 0.05$) effect on total saturated fatty acids (SFAs), total

Table 5.1: Marbling percentage, fat-free dry matter and moisture content of beef from 18-month old Nguni and non-descript crossbred steers reared on a sweetveld

Parameter	Genotype		Standard Error	P- value
	Nguni	Non-descript crossbred		
Intramuscular fat (marbling)	1.81[b]	1.52[a]	0.092	0.038
Fat- free dry matter	21.82	21.88	0.023	0.849
Moisture	76.38	76.60	0.260	0.356

[a] Means with different superscripts in the same row are significantly different ($P < 0.05$)

Table 5.2: Fatty acids (LSmean ± SE) and fatty acid ratios (LSmean ± SE) in beef from 18-month old Nguni and non-descript crossbred steers reared on a sweetveld

Abbreviation	Genotype			
	Nguni	Non-descript crossbred	Standard error	P- value
C12:0	0.02	0.02	0.005	0.785
C14:0	2.16	1.79	0.152	0.093
C14:1c9	0.26	0.18	0.034	0.104
C15:0	1.48	1.63	0.072	0.162
C15:1c10	0.12	0.16	0.013	0.103
C16:0	24.40	23.07	0.631	0.140
C16:1c9	1.92	1.58	0.144	0.105
C17:0	0.92	0.91	0.031	0.759
C17:1c10	0.23	0.24	0.044	0.907
C18:0	19.93	19.96	0.593	0.974
C18:1t9	0.13	0.10	0.041	0.549
C18:1c9	29.51	29.13	0.577	0.645
C18:1c7	1.69	2.41	0.288	0.083
C18:2c9,12 (n-6)	6.751	7.23	0.463	0.467
C20:0	0.16	0.14	0.009	0.071
C18:3c9,12,15 (n-3)	2.32	2.50	0.143	0.375
C18:2c9,t11(n-6)	0.39	0.35	0.018	0.090
C20:3c8,11,14(n-6)	0.03	0.02	0.008	0.414
C22:1c13	0.50	0.57	0.042	0.234
C20:4c5,8,11,14(n-6)	3.18	3.18	0.275	0.143
C23:0	0.04	0.05	0.018	0.638
C20:5c5,8,11,14,17(n-3)	1.54	1.66	0.117	0.415
C22:5c7,10,13,16,19(n-3)	2.24	2.45	0.158	0.350
C22:6c4,7,10,13,16,19(n-3)	0.08	0.12	0.020	0.149
Total SFAs[a]	49.1	47.55	1.054	0.299
Total MUFAs[b]	34.36	34.37	0.718	0.997
Total PUFAs[c]	16.52	18.09	1.047	0.297
n-6[d]	10.32	11.33	0.682	0.298
n-3[e]	6.17	6.73	0.407	0.338
PUFA/SFA[f]	0.35	0.39	0.028	0.279
n-6 – n-3[g]	1.74	1.70	0.106	0.797
AI[h]	1.07	0.97	0.052	0.195
TI[i]	1.17	1.05	0.067	0.237

[a] Saturated fatty acids.
[b] Monounsaturated fatty acids.
[c] Polyunsaturated fatty acids.
[d] Omega-6 fatty acids.
[e] Omega-3 fatty acids.
[f] Ratio of polyunsaturated fatty acids and saturated fatty acids.
[g] Ratio of n-6 and n-3 fatty acids.
[h] Atherogenicity index
[i] Thrombogenicity index

polyunsaturated fatty acids (PUFAs), total monounsaturated fatty acids (MUFAs) and PUFA/MUFA ratio. The n-6, n-3, n-6:n-3 ratio were not significantly ($P > 0.05$) affected by genotype. Genotype effects did not significantly ($P > 0.05$) affect atherogenicity and thrombogenicity indices. Athrogenicity index (AI) and thrombogenicity index (TI) are shown in Table 5.2.

5.3.4 Physico-chemical quality of *m.* L*ongissimus thoracis et lumborum* and *Triceps brachii* muscles from 18-month old Nguni and non-descript crossbred steers

Ultimate pH, meat colour redness (a*), yellowness (b*), thawing loss, cooking loss and tenderness of beef loin and shoulder muscles are shown in Table 5.3. Genotype and muscle type had no significant ($P > 0.05$) effects on ultimate pH, meat colour redness (a*), yellowness (b*), thawing loss, cooking loss and Warner Bratzler shear force tenderness. However, genotype had a significant ($P < 0.05$) effect on meat lightness (L*). Muscle type had no significant ($P < 0.05$) effect on L* and there was no significant ($P > 0.05$) interaction of genotype by muscle type on L*. Non-decript crossbred cattle beef was lighter (L* = 35.8 ± 0.77) coloured compared to beef from Nguni cattle (33.7 ± 0.54) (Table 5.3) There was however, no significant correlation between meat lightness (L*) and any of the meat quality parameters tested in this study, including IMF content (Figure 5.1).

Table 5.3: Physico-chemical quality characteristics of beef loin *(longissimus thoracis et lumborum)* from 18-month old Nguni and non-descript crossbred steers reared on a sweetveld

Parameter	**Genotype**		**SE**
	Nguni cattle	**Non-descript crossbred**	
pHu	5.82	5.82	0.017
Temperature	10.29	10.86	0.362
L*	33.56[a]	35.70[b]	0.544
a*	13.83	14.4	0.723
b*	11.58	11.5	0.339
Chroma	18.06	18.47	0.470
Thawing loss	6.55	4.56	1.067
Cooking loss	23.72	24.25	0.554
WBSF	38.47	36.38	2.883

[a] Means with different superscripts in the same row are significantly different ($P < 0.05$)

L* - lightness, a*- redness, b*- yellowness and WBSF- Warner-Bratzler shear force. Temperature and pHu were measured 30hrs post mortem.

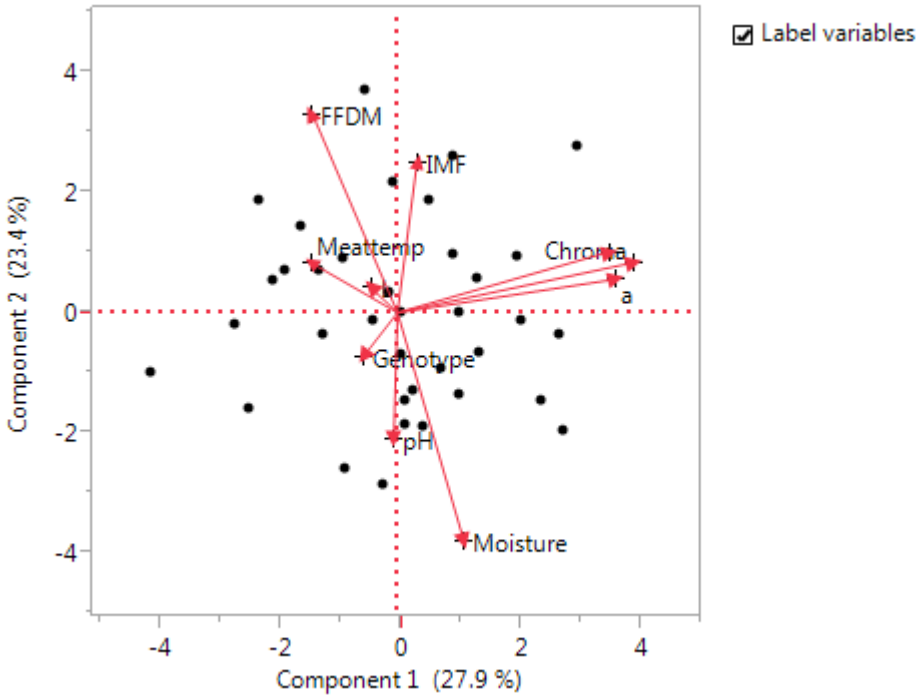

Figure 5.1: Principal components 1 and 2 showing correlations of meat colour and proximate composition variables of beef from the shoulder muscle of Nguni and non-descript crossbred cattle

FFDM- fat free dry matter; IMF – intramuscular fat; Meattemp – meat temperature; a- redness; L- lightness; pH- meat pH; chroma – meat chroma

5.4 Discussion

Consumers are concerned about fat content and the health risk posed by some fatty acids found in beef. As a result, fat is currently being regarded by consumers as an unpopular component of meat (Wood *et al*., 2008). Consumers are demanding functional foods of high nutritional value which promote their health and reduce chances of dietary-related illnesses and conditions (Brugiapaglia *et al*., 2014; Kraus, 2015). They demand much leaner beef with little or no visible subcutaneous fat, high intramuscular fat (marbling) and high amounts of unsaturated fatty acids as a way of reducing risk of dietary lipid-related health problems (Calder, 2007; Farrow *et al.*, 2009; Morales *et al*., 2013). In this study, Nguni cattle had higher intramuscular fat content (i.e., higher marbling) compared to NDCC. Breed differences in intramuscular fat deposition have been reported and linked to various gene markers (Thaller *et al*., 2003; Ceasar *et al*., 2014; Guo *et al*., 2014).

IMF deposition has been associated with genetic control of feed conversion efficiency (Barendse *et al*., 2007). Barendse *et al*. (2007) further attributed the differences in IMF deposition and feed conversion efficiency to the origin of the breeds. *Bos indicus* breeds, which are small in size, are reported to be more efficient in feed conversion efficiency and IMF deposition compared to *Bos taurus* breeds (Barendse *et al*., 2007). In this study, the higher IMF content of beef from Nguni cattle, which are *Bos taurus-africanus,* can be attributed to more efficient feed conversion compared to NDCC which are an indiscriminate crossbreed. Non-descript crossbred cattle resulted from uncontrolled mating of indigenous breeds such as the Nguni and imported taurine breeds such as Angus, Jersey and Simmental (Mapiye *et al*., 2009). Results from this study are however, in contrast to a report by Muchenje *et al*. (2009a) who found no breed differences in intramuscular fat content among Nguni, Bonsmara and Angus breeds. They were, however, consistent with findings by

Strydom *et al*. (2000) who reported breed differences in Nguni, Bonsmara, Santa Gertrudis, Pinzgauer, Brown Swiss and Afrikaner cattle. The IMF values obtained by Muchenje *et al*. (2009a), Strydom *et al*. (2000) and Mapiye *et al.* (2011) were lower than the ones obtained in this study.

Besides genotype, diet or feeding system, age (Smith *et al*., 2009), gender and muscle type within the same breed (Hocquette *et al.*, 2010) can lead to variations in intramuscular fat content. Smith *et al*. (2009) attributed the increase in intramuscular fat to marbling adipocyte hypertrophy. Furthermore, Strydom *et al*. (2008) stated that the expression of IMF commences as the animal approaches its maximum potential for muscle fat growth. Nguni cattle being a small-framed breed could have an earlier initiation of adipocyte maturation compared to the non-descript crossbred cattle.

In this study genotype differences could have resulted from efficiency of use of pasture forages. Generally, pasture- fed beef cattle have been reported to have a strongly reduced stearoyl-coA desaturase (SCD) activity, leading to the generally observed low IMF content of beef (Smith *et al*., 2009). However, Smith *et al*. (2009) further stated that breeds that are less sensitive to the pasture depressing effect on SCD activity, adipogenesis and mono-unsaturated fatty acid synthesis tend to deposit more IMF. In this study, Nguni cattle could therefore be considered less sensitive to depressing effects of the pasture compared to NDCC. Generally, Nguni cattle have been reported to perform better under harsh conditions on extensive systems (Gertenbach and Kars, 1999; Collins-Lusweti, 2000).

The similarity in the moisture content and fat free dry matter of beef from Nguni and NDCC cattle in this study could be attributed to the similarity in age and diets consumed by these

two genotypes. According to Hocquette *et al*. (2010), the water, protein, mineral and glycogen contents of muscles are fairly constant at 75 %, 19-25 %, and 1-2 %, respectively. However, findings from Muchenje *et al*. (2009a) were in contrast to the results in this study as Nguni beef had lower moisture content compared to Bonsmara and Angus beef.

In this study, although the IMF content was different between the Nguni and non-descript crossbred beef, there were no differences in total saturated fatty acids (SFAs), total polyunsaturated fatty acids (PUFAs), total monounsaturated fatty acids (MUFAs) and PUFA/MUFA ratio. Garcia *et al*. (2008) reported breed effects on SFAs and MUFAs in Holstein Argentine, Angus and Charolaise-Angus crosses. Mazzucco *et al*. (2016) reported of genotype effects on C16:0, and some MUFAs in Angus, Hereford and crossbreed steers that were grazing on pastures. This was attributed to possibility of certain genes that could influence fatty acid composition and IMF through metabolism. Some dietary fatty acids escape unchanged in the rumen or are precursors of fatty acids that could be synthesised *in vivo*. Latimori *et al.* (2008) reported of breed effects on marbling and subcutaneous fat thickness or fatty acid composition. De Smet *et al*. (2004) and Smith *et al*. (2009) reported that genotype effects generally have a small influence on total fat and fatty acid composition compared to the effects of diet and age. It is possible that the diet and age similarities in this study resulted in similarities in fatty acid composition between the two genotypes. In this study, the steers were slaughtered at a young age of 18 months. In addition, muscle fatty acid composition generally reflects the fatty acid composition of the diet (Wood *et al*. 2008; Scollan *et al*., 2014). The results in this study are consistent with Muchenje *et al*. (2009a) who found no breed effects on most fatty acid ratios and individual fatty acid concentrations. Similarly, n-6, n-3 and n-6:n-3 ratio were not affected by genotype in this study and in Muchenje *et al*. (2009). However, total SFA, total MUFAs, and total PUFAs in this study are

consistent with values obtained for grass-fed beef in other studies (De Smet *et al*., 2004; Mapiye *et al*. 2011). Lipid profiles and ratios are affected by various factors which include genetics, age, gender, production system and diet (De Smet *et al*., 2004; Aldai *et al*., 2005). Among these factors, production system (e.g. grass-fed vs feedlot) and nutrition significantly influence the fatty acid composition and anti-oxidant content of the various fat depots and body tissues (De Smet *et al*., 2004; Scollan *et al*., 2006).

In this study, the PUFA/SFA ratio for both genotypes was reasonably high. Most beef cattle have a PUFA/SFA ratio of around 0.1 (Scollan *et al*., 2006). The optimal PUFA:SFA ratio is 0.4 or above (Schaefer, 2002; Wood *et al*., 2008). It is generally lower in beef due to bio-hydrogenation of PUFAs in the rumen. The optimal n-6:n-3 ratio for beef is 4:1 (Raes *et al*., 2004; Calder, 2007; Daley *et al*., 2010). In this study, the n-6:n-3 ratio for beef from both Nguni and NDCC genotypes was 1.74 ± 0.104, signifying a much higher and more favourable n-3 omega fatty acid content in relation to the n-6 omega content. This shows that the beef produced in this study had a healthy fatty acid composition. Consumption of more unsaturated fatty acid especially n-3 omega fatty acids in the diet compared to n-6 omega 6 fatty acids is being encouraged to reduce the risk of cardiovascular diseases (Raes *et al*., 2004).

Saturated fatty acids (SFAs) were the most dominant in beef from both genotypes in this study, followed by mono-unsaturated fatty acids (MUFAs) and PUFAs respectively. This is consistent with other reports on beef (Scollan *et al*., 2006; Muchenje *et al*., 2009; Mapiye *et al*., 2011). In order to reduce the chance of developing cardiovascular diseases (CVD), atherosclerosis and dietary-related cancer, the World Health Organisation (WHO, 2003) recommends an intake of SFAs of not more than 10 % of the total energy intake. SFAs are

reported to be the chief cause of CVD and atherosclerosis. Various authors (Scollan *et al*., 2006; Wood *et al*., 2008; Daley *et al*., 2010), however, reported that different types of saturated fatty acids do not have similar effects on serum cholesterol. As such, provision of information on individual fatty acids in beef from various production and dietary systems is more informative to meat consumers than aggregate lipid composition. For instance, while stearic acid, palmitic acid and myristic acid tend to have the highest proportions and contribution to total SFAs in beef (Scollan *et al*., 2006; Daley *et al*., 2010), their effect on serum cholesterol are not similar. The effects of stearic acid and palmitic acid are not as adverse as those of lauric and myristic acids (Schaefer, 2002). Stearic acid (C18:0) has no net contribution on serum cholesterol and no apparent effect on both LDL and HDL cholesterol (Schaefer, 2002). Palmitic acid leads to an elevation of serum low density lipoprotein cholesterol in the blood but not as adversely as lauric acid (Temme *et al*., 1996). On the other hand, lauric acid has both positive and negative effects. It results in the elevation of total serum cholesterol, while simultaneously reducing the ratio of total cholesterol to HDL as it preferentially elevates HDL cholesterol in serum (Schaefer, 2002). Similarly, myristic acid, which is the most potent of the saturated acids, elevates serum low density lipoprotein cholesterol (Schaefer, 2002). Beef from both genotypes in this study could be considered as possessing health beneficial properties as it had very low concentrations of lauric and myristic acids, even though stearic and palmitic acid concentrations were high. Stearic acid and oleic acid are generally the most abundant fatty acids in all fat depots in livestock (Webb *et al*. 1998; Pavan and Duckett, 2013).

There is inconclusive information on the effect of n-6 PUFAs on human health. WHO (2003) recommends an increase in the intake of MUFAs, PUFAs and a reduction in the trans-fatty acid. Similarly, FAO (2010) encourages replacement of SFAs with both n-3 and n-6 PUFA

and a reduction of SFA in the diet to not more than 10 % of total energy as a way of reducing the risk of cononary heart diseases. The MUFAs and PUFAs are reported to possess health-promoting properties (Scollan *et al*., 2006; Daley *et al*., 2010). It has been reported that some n-6 PUFAs such as arachidonic acid have detrimental effects on meat consumers (Calder, 2007). FAO (2010) reported a possibility of alterations of indices of metabolic syndrome, inconclusive links of PUFA intake to cancer, body weight and adiposity. In this study, the most abundant fatty acid was oleic acid, a mono-unsaturated fatty acid in both genotypes. This is consistent with reports on grass-fed beef (Webb *et al*., 1998). However, while oleic acid is beneficial to consumer health, it is unfortunately the chief contributor to the grassy-odour in grass-fed beef, a characteristic which makes grass-fed beef unattractive to some consumers. The grassy-odour results from compounds such as hexanals which are derived from oleic acid and α-linoleic acid (Priolo *et al*., 2001).

Linoleic , linoleic acid and α-linolenic acids are the most abundant PUFAs of beef and are beneficial to human health (Gogus and Smith, 2010). Results from this study are consistent with this observation. Other PUFAs such as arachidonic acid (n-6 PUFA), docosapentaenoic and eicosapentaenoic acids were also found in appreciable amounts in beef from both genotypes in this study. Although an intake of up to 1.5g/day of arachidonic acid by healthy individuals has been reported to be harmless (Calder, 2007), a caution is given for intakes of more than 1.5g/day. The effects of the apparently harmful n-6 PUFAs is countered by the presence of health-beneficial n-3 PUFAs (Schaefer, 2000; Scollan, *et al*., 2006). The presence of conjugated linoleic acid in beef examined in this study confirms the health benefits of grass-fed beef (O'Quinn *et al*., 2000; Lorenzen *et al*., 2007).

The pHu values obtained in this study for beef from Nguni and NDCC concur with those

obtained by others (Daly *et al*., 1999; Muchenje *et al*. 2008a; Mapiye *et al*., 2010c; Chulayo, 2015). The lack of genotype differences in ultimate pH could be a reflection of adequate glycogen reserves at slaughter in both Nguni and NDCC. The concentration of muscle glycogen at slaughter influences the rate of pH decline due to anaerobic lactate production post-mortem (Immonen *et al*., 2002). Insufficient glycogen levels are attributed to insufficient glucose absorption from the diets, pre-slaughter stress due to transportation, poor animal handling during slaughter and novelty of the abattoir environment (Daly *et al*., 1999; Immomen *et al*., 2002; Muchenje *et al*., 2008; Bourguet *et al*., 2010). Although the two genotypes in this study did not differ in ultimate pH, genetic differences in hormonal receptors for glucocorticoids and mineralocorticoids linked to plasma cortisol concentrations have been reported (Poleti *et al*., 2015). Glycogenolysis and gluconeogenesis are some of the energy mobilisation pathways that are influenced by the secretion of cortisol in response stress in preparation for the fight or flight response (Poleti *et al*., 2015). The two genotypes in this study could have, therefore, responded similarly to the stress during transportation, slaughter and post mortem lactate production. The perception of pre-slaughter stress in the two genotypes could have been similar as they were raised under similar conditions, transported together and slaughtered together.

Meat colour is affected by the presence of pigments, tissue composition and meat structure (Weglarz, 2010). A red-purple colour is associated with freshness while brown colour is association with lack of freshness (Carpenter *et al*., 2001). Meat lightness (L*) values obtained in this study for Nguni cattle (33.56 ± 0.544) are similar to those reported by Muchenje *et al*. (2008a) and Mapiye *et al*. (2010c). However, unlike in Muchenje *et al*. (2008a), significant breed differences in meat lightness were observed in this study. The observed differences could stem from the genetic background of the two genotypes, with the

Nguni being a *Bos taurus-africanus* and non-descript cattle an indeterminate crossbreed between Nguni and the Jersey, Angus, Hereford or other imported Bos *taurus* breeds. Breed effects on meat quality have been reported and several genetic markers for some quality parameters have been identified through single nucleotide polymorphism (Hopkin *et al*., 2011; Melucci *et al*., 2012). According to Hopkin *et al*. (2011), cross-breeding can lead to genetic changes that affect colour stability such as the darker colour observed in Merino sheep and their crossbreds. Non-descript crossbred cattle had higher lightness values (L* = 35.70 ± 0.544) therefore, slightly lighter meat than Nguni cattle (33.56 ± 0.544). Baublits *et al*. (2006) attributed differences in meat colour lightness to intramuscular fat content. In this study, NDCC had lower IMF content compared to Nguni cattle. However, principal component analysis showed no correlation between intramuscular fat content and meat lightness. However, lighter coloured meat is more acceptable to consumers than dark-coloured meat at the point of purchase (Carpenter *et al*., 2001).

Redness (a*) and yellowness (b*) values obtained in this study were not different between the two genotypes. Redness values in Nguni cattle were consistent with those reported by Muchenje *et al*. (2008a) and Mapiye *et al*. (2010c). Yellowness values obtained in this study were, however, higher than those reported by the same authors (Muchenje *et al*., 2008a; Mapiye *et al*., 2010). There were no breed differences in chroma (colour saturation) in this study and this is consistent with Muchenje *et al*. (2008a). The chroma values were similar to those reported for Nguni cattle by Muchenje *et al*. (2008a) and Mapiye *et al.* (2010c). In this study, loin and shoulder muscles did not differ in colour saturation.

Thawing loss, cooking loss and Warner Bratzler Shear Force (WBSF) values for tenderness were not different in beef from Nguni and NDCC. Steers from both genotypes were

slaughtered at a young age. Young animals are reported to produce tender meat as there is less connective tissues and crosslinking in the meat compared to meat from adult animals. These results are consistent with Muchenje *et al*. (2008a) who found no significant differences in Nguni, Bonsmara and Aberdeen Angus cattle slaughtered at the age of 18 months.

Meat ultimate pH, colour, and chroma were not different between LTL and TB muscles in this study. Meat colour and pH in different muscles are related to muscle fibre type, capillary density and muscle fibre composition (Klont *et al*., 1998). These properties influence biochemical processes in the muscles post slaughter (Klont *et al.*, 1998). Muscle fibre types ware not determined in this study. However, the lack of significant differences could probably point towards a similarity in both muscle fibre type and muscle fiber composition and therefore needs further investigation.

5.5 Conclusions

Beef from Nguni and non-descript crossbred cattle reared under similar conditions on sweetveld did not differ in most physico-mechanical properties and fatty acid profiles. However, Nguni cattle had higher intramuscular fat content than NDCC. Furthermore, Nguni beef was darker than beef from non-descript crossbred cattle. Other meat colour space values (a*, b*), pHu, cooking parameters (thawing loss, cooking loss and tenderness) were similar. Fatty acid profiles, fatty acid ratios, concentrations of individual fatty acids, atherogenicity index and thrombogenicity index were similar in the two genotypes. Both genotypes had favourable proportions of mono-unsaturated fatty acids, poly-unsaturated fatty acids and n3:n6 ratio. Ultimate pH, meat colour and chroma were similar in LTL and *Triceps brachii* muscles from Nguni and non-descript crossbred cattle.

5.6 References

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Chapter 6: Some physico-mechanical characteristics of automotive upholstery crust leather from Nguni and non-descript crossbred cattle hides and the associated architecture of the collagen fibres

Abstract

The objective of the study was to determine some physico-mechanical characteristics of automotive upholstery leather from Nguni and non-descript crossbred cattle (NDCC) and the associated collagen fibre architecture of leather from various body regions. Fifty-four hides (27 Nguni and 27 NDCC), were obtained from a commercial abattoir at slaughter, weighed, labelled and preserved using wet salting method. Specimens were collected from the neck, belly and butt regions before and after tanning for fibre architecture. Crust leather area was estimated. Physico-mechanical tests were done on butt samples cut perpendicular and parallel to the backbone. Results showed that breaking load and tensile strength were higher (1257.1 ± 70.72 N and 28.3 ± 1.23 MPa, respectively) in specimens taken parallel than perpendicular to the backbone (979.5 ± 70.72 N and 23.6 ±1.23 MPa, respectively) across genotypes. In NDCC, breaking load and tensile strength were affected by sampling direction, being higher ($P<0.05$) in samples taken parallel (1208.2 ± 90.10 N and 28.4 ± 1.46 MPa, respectively) than perpendicular (885.0 ± 90.10 and 21.4 ± 1.46 MPa, respectively) to the backbone. Collagen fibre orientation and diameter differed in longitudinal and cross-sections of the three body regions. Nguni hides had similar ($P > 0.05$) fibre diameters in longitudinal (3.4 ± 0.12 µm) and cross-sections (3.2 ± 0.11 µm). It was concluded that automotive crust leathers from Nguni and NDCC were similar in some physico-mechanical properties but varied in collagen architecture in different body regions. Leathers from both genotypes can be considered for use as automotive upholstery leather.

Keywords: collagen, elongation, fibril, quality, rawhide, tensile

6.1 Introduction

Leather is an intermediate product with many industrial uses. It is used in the manufacture of boots, shoes, handbags, automotive upholstery and furniture leather and other leather artefacts (Luong, 2007). Although leather can be made from any type of animal skin, the major raw materials in the leather industry are hides and skins from cattle. Leather is made by tanning the hides and skins (Covington, 2009; Leach and Wilson, 2009) to stabilise collagen, the main protein found in animal skins, against putrefaction or drying out to an inflexible mass (Umney and Rivers, 2003; Orlita, 2004; Luong, 2007).

Generally, leather is expected to have good physico-mechanical properties that meet the requirements for use in the manufacture of various leather products (Bitlisli *et al*., 2004). The physical, mechanical and chemical characteristics of leather are used to determine its value (Bitlisli *et al*., 2004; Basil-Jones *et al.*, 2010) against the intended application or use (Li *et al*., 2009). The application, in turn, has specific quality standards in terms of desired physico-mechanical properties (BASF, 2009). The properties, however, vary widely as hides and skins used are obtained from animals reared in various environments and production systems (Musa and Gasmelseed, 2013). The quality of leather, therefore, depends on the quality of the hide or skin that it is manufactured from (Rehbein *et al.*, 2000; Tolossa, 2013). Factors affecting the intrinsic quality of hides and leather include animal intrinsic factors such as breed, sex and slaughter age (Jacinto *et al*., 2004; Engelbrecht *et al*., 2009; Salehi and Bitaraf, 2013; Tolossa; 2013), nutrition (Jacinto *et al*., 2004; Engelbrecht *et al*., 2009), animal husbandry, slaughter methods, preservation methods, storage conditions (FAO, 2010) and processing methods (Jacinto *et al*., 2004; Engelbrecht *et al*., 2009). Furthermore, the properties of leather are influenced by its physical structure and chemical composition (Bitlisli *et al*., 2004).

The skin, being part of the extracellular matrix (ECM) of mammals, is mainly composed of connective tissue such as those found in structures which undergo mechanical deformation (Liao, *et al*., 2005). Mechanical properties are derived from the dermis (papillary and reticular layers) which is the main matrix of the skin. The major macromolecule found in the dermis layer of the skin is collagen type I, a fibrillary protein (Hagisawa and Shimada, 2005; Asano *et al*., 2009). Collagen fibres aggregate to form a natural, three-dimensional weave in the dermis of the skin which further aggregate to higher organisations of collagen. These various hierarchical levels of collagen aggregation contribute to tissue and structural integrity under loading (Hagisawa and Shimada, 2005; Wess, 2008). Collagen type 1 is responsible for the mechanical properties of the skin such as strength and resiliency (Christensen *et al*., 2000; Liao *et al*., 2005; Asano *et al*., 2009; Basil-Jones *et al*., 2010; Bail-Jones *et al*., 2012).

Mechanical properties of connective tissue are affected by factors such as collagen content, collagen fibril and fibre size (i.e., mass-average diameter and fibril diameter distribution) and fibril orientation (Basil-Jones *et al*., 2013). These factors vary due to age and the amount of strain the tissue is exposed to (Parry and Craig, 1984; Kobayashi *et al*., 1999; Starborg *et al*., 2008; Basil-Jones *et al*., 2010). Tissues which require high tensile strength contain the highest collagen content and thick fibres (Parry and Craig, 1984). Strong leather is sought after for many high value commercial purposes of leather such as automotive upholstery leather (BASF, 2009).

In South Africa, the demand for good quality hides is increasing as a result of the orientation of the leather sector from manufacturing of footwear and general leather goods to automotive leather upholstery (DAFF, 2012). This change is due to industry support policies meant to stimulate the growth of the automotive industry and component manufacturers, such as

stitched car seats, to cater for the growing demand in Europe (DAFF. 2012). Examples of such export-incentive support schemes are the Motor Industry Development Programme and Automotive Production (MIDP) and Development Programme (APDP) (ECDC, 2005; DTI, 2008; Bronkhorst *et al*., 2013). Car seats made from hides sourced locally or from indigenous breeds are among the auto components considered in this incentive support scheme under the vulnerable sub-sector. In this regard, car manufacturers have expressed an interest in using Nguni hides (Brits, 2014; Koro, 2015). Besides automotive upholstery, the leather industry in South Africa also manufactures footwear, general leather goods and hair-on skins (Brits, 2014). The aesthetic, multi-coloured Nguni hides and hair-on skins are used in the manufacture of handbags, floor rugs, carpets, wall hangings, ottomans, lounge furniture and other small items (Ramsay *et al*., 2000; Brits, 2014; Koro; 2015).

While the demand for leather in the export market is increasing, the supply of hides in South Africa, however, falls short of the leather industry requirements, particularly the automotive upholstery leather sector. The shortage of hides locally has led to importation of large volumes of hides from various parts of the world (DAFF, 2011). This is despite that fact that South Africa has a large herd of unutilised livestock resources, such as those found in the smallholder communal and emerging sectors that need to be tapped into. The emerging and communal farmers contribute very little due to a low offtake rate of between 2-5 % (Mapiye *et al*., 2009), unlike the commercial sector which is the main supplier. Emerging and smallholder communal farmers mainly keep non-descript crossbred cattle (NDCC) and indigenous Sanga cattle such as the Nguni (Scholtz *et al*., 2008) which are generally discriminated against in formal markets due to perceived poor quality. Improvement in the production, processing and marketing of hides in the smallholder sector has a potential to boost industry leather productivity while simultaneously benefiting smallholder by generating

income (Jordaan and Eita, 2012). However, there is a paucity of information on mechanical properties and the associated architecture of leather from cattle breeds reared in South Africa, including the Nguni and non-descript crossbred cattle genotypes. This information is crucial in determining the appropriate industrial application of leather and will be especially useful in ascertaining the usability of hides from the smallholder farming sector.

The objective of this study was, therefore, to determine the physico-mechanical characteristics of automotive upholstery leather from Nguni and non-descript crossbred cattle hides. Furthermore, the study sought to determine the architecture of Nguni and non-descriptcrossbred cattle raw hides and automotive upholstery leather sampled from various regions (neck, belly and butt) using scanning electron microscopy.

6.2 Materials and Methods

6.2.1 Study site

The study was carried out at the University of Fort Hare in Alice, Eastern Cape Province. Hides were obtained from Buffalo City Municipality of Eastern Cape Province of South Africa. A high throughput abattoir in East London, which periodically slaughtered Nguni cattle, was selected in the Eastern Cape Province. The abattoir is situated 120 km South East of the University of Fort Hare, Alice Campus. The operations of the abattoir are governed by the Meat Safety Act of 2002 and SAMIC (2006). The application to conduct the study was reviewed and approved by The Research Ethics Committee of the University of Fort Hare, South Africa (UFH/UREC, MUC131SCHI01).

6.2.2 Sampling of hides from the abattoir

Although smallholder famers have a high proportion of Nguni and non-descript crossbred

cattle, their slaughter rates are low. Occasionally, a small proportion of the Nguni cattle are sold through auctions or to abattoirs. Emerging farmers, however, regularly send non-descript crossbred cattle for slaughter in abattoirs. In addition, formal abattoirs use modern slaughter facilities which allow complete bleeding of the carcass unlike incomplete bleeding which is prevalent in slaughters conducted in the small-scale farmers' homesteads. A decision was made to sample hides from Nguni and NDCC that would have been sent to the formal abattoir for slaughter and preserve the hides through wet salting as sufficient numbers of hides were being accumulated. Arrangements were made with the abattoir managers of the East London Abattoir for notification of delivery of Nguni cattle since they were not slaughtered on daily basis.

6.2.3 Animal identification, information and records

Prior to slaughter, *ante-mortem* inspection of animals was carried out to determine if the animals were fit for meat for human consumption. Information, such as farm of origin, age, gender, number of animals, distance travelled, was collected on the animals from the documents submitted to the abattoir manager by the transporters. Animals were weighed and put in holding pens waiting for slaughter.

6.2.4 Hides collection and traceability

Upon slaughter of Nguni and non-descript cattle, hides were immediately labelled by means of a disc attached with a cable tie. The label on the hide corresponded with the information on the animal collected before slaughter. Fifty-four hides (27 Nguni and 27 NDCC) were collected. The carcass number assigned by the abattoir was also recorded for later reference. Hides were weighed individually immediately after flaying. Washing was done to remove blood, dung and other dirt. Water was drained off and the hides were immediately transported

to Alice, University of Fort Hare Research Farm for curing.

6.2.5 Hide preservation

Upon arrival at University of Fort Hare Honeydale Research Farm, hides were spread on the shed floor with the flesh side up and cured with medium coarse salt. Medium coarse salt was appied at the rate of 0.87 kg/kg of fresh hideweight (w/w). After 24 hours, the hides were folded and placed on pallets. They were left to cure for 7 days until they were transported to the International School of Tanning Technology in Grahamstown for tanning into automotive upholstery leather.

6.2.6 Sampling of hide specimens for scanning electron microscopy

Prior to tanning of each batch of salted hides, hide pieces for scanning electron microscopy were sampled from the butt, belly and neck region and placed in labelled ziplock plastic bags. The specimens were taken to the laboratory for scanning electron microscopy.

6.2.7 Tanning of hides

The tanning drums could only accommodate 6 hides at a time. The processing of the hides was carried out as follows:

1. three Nguni and three non-descript hides were processed at a time into wet blue using the process outlined in Appendix 1.
2. after processing into wet blue, the hides were shaved and then processed further into black dyed crust leather as outlined in Appendix 2.

6.2.8 Sampling of leather specimens for scanning electron microscopy

After processing of the hides into dyed automotive crust leathers, specimens were collected

from the same positions (butt, belly and neck). The specimens were placed in labelled ziplock plastic bags and taken to the laboratory for scanning electron microscopy.

6.2.9 Tissue preparation for scanning electron microscopy and imaging of Nguni and non-descript hides and automotive crust leathers

Twenty hides (10 Nguni and 10 NDCC) were used in the determination of fibre architecture. The Nguni hides were all from mature cows while the non-descript hides comprised of 4 cows, 3 heifers and 3 oxen. Samples were collected from three different parts of the salted hides (i.e., neck belly and butt) just prior to soaking of the salted hides for processing into leather at the tannery processing. Salted samples were taken to the laboratory in preparation for scanning electron microscopy.

Specimens for SEM analysis ($0.5cm^2$) were cut from three different parts of the hide (i.e., neck belly and butt), one in the cross-section and the other in the longitudinal section of the hide. The two specimens from each hide were put in a clean glass tube labelled with the hide's identity and washed three times with distilled water to remove the salt and other dirt materials. The specimens were then soaked for 8-12 hours to re-hydrate them as is done during the soaking stage in the tannery. The soaking water was decanted and the rehydrated specimens were washed with distilled water, fixed with 2.5 % glutaraldehyde and stored at 4 °C for 24 hours. Cold phosphate buffer was used to wash the samples 4 times. After washing, the samples were treated with cold Osmium Tetroxide in buffer for 24 hours. Distilled water was used to wash the samples three times, to remove the Osmium Tetroxide. Graded concentrations of ethanol (30-100 %) were then used to dehydrate the samples for 20 mins each for each concentration.

Samples were dried using the critical-point drying method with liquid carbon dioxide (CO^2). The dried fixed sections were mounted vertically and horizontally on aluminium stubs to view the cross-section and longitudinal sections for surface details. They were coated with gold palladium using a sputter-coater. Examination was carried out using a JEOL JSM 6390 LV scanning electron microscope (JEOL, USA) operated at an accelerating voltage of 15KV at magnification ranging from X400 to X2700.

Dyed crust leather specimens were directly taken for gold coating as described above and subsequent SEM analysis was done thereafter (Sivasubramanian *et al*., 2008).

6.2.10 Determination of leather area

Determination of leather area was done manually on 54 crust leathers (27 Nguni and 27 NDCC) using the method for determining the arithmetic mean for irregular shapes (Appendix 3). Each piece of automotive crust leather was spread as flatly as possible on a floor with cream-coloured tiles of known area (dimensions were 30cm*30cm). The shape of each leather piece was traced on the floor tiles using an erasable whiteboard marker. The full number of tiles covered by the leather were counted and multiplied by the area of each full tile. The area of the partially covered tiles was determined using a transparent plastic tile with outer dimensions similar to the floor tiles (30cm*30cm) but subdivided into smaller squares (2cm*2cm). The transparent plastic tile was superimposed onto each partially covered tile and full small squares were counted and multiplied by the area of each full small square (2cm*2cm). Lastly, all partly covered small squares were taken as half squares, counted and multiplied by half of the small square tile. The total area covered by each leather piece was computed as follows:

Leather area per piece = ∑[(number of full big floor tiles * area of each big tile) + (number of small squares on plastic tile grid * area of small square on the plastic tile grid) + number of half squares on plastic tile grid * ½(area of small square on the plastic tile grid)].

6.2.11 Crust leather quality assessment

6.2.11.1 Sampling of leather specimens for the determination of tensile strength elongation at break and break load.

Thirty leather pieces (15 Nguni and 15 NDCC) were used for determining tensile strength, elongation at break and break load. Five batches of crust leathers were selected. Each batch was composed of three Nguni and three non-descript hides. Non-descript crust leathers comprised of five leathers for each of the classes of cows, heifers, oxen while all Nguni crusts were from cows. Sampling of the crust leather, from the official sampling position of the 30 leathers for physico-mechanical testing, was done according to SLP2 (IUP/2) (IUP, 2000).

6.2.11.2 Conditioning of leather pieces

Conditioning of the leather test specimens was carried out prior to physical testing according to SLP (IUP/3) (IUP, 2000). Briefly, leather test pieces were kept in a standard atmosphere of temperature 20 ± 2^{o}C and relative humidity 65 ± 2 % for a period of 48 hours.

6.2.11.3 Determination of leather thickness, tensile strength and elongation at break

An Instron machine (model 3345) was used for measurement of tensile strength and percent elongation. The load cell was 5kN, gauge length of 50mm and speed of jaw separation was 100mm/min). Determination of tensile strength, breaking load and percentage elongation was done according to SLP 6 (IUP/6) (IUP, 2000). Leather thickness was determined using the Elastocon EV 06B type with a 50mm foot pressure.

6.2.12 Data analysis

Data on leather area was analysed for the effect of genotype using the Proc GLM procedure of SAS (2003). Analysis of variance was performed using Proc GLM of SAS (2003) with slaughter liveweight as a covariate. Mean separation was done using the PDIFF option at 5 % level of significance.

Data on mechanical properties of automotive upholstery leather (i.e ultimate tensile strength, elongation at break and break load) from specimens taken from the official sampling position of the right butt region of female cattle only (cows and heifers) were analysed for the effects of genotype and direction of sampling (parallel or perpendicular to the backbone) using PROC GLM procedure of SAS (2003). Significant means were separated using the PDIFF option at 5 % level of significance. The following model was used:

$Y_{ijkl} = \mu + G_i + S_j + (GS)_{ij} + E_{ijkl}$

Where Y_{ijkl} = The independent variable (break load, tensile strength or elongation at break)

μ= overall mean

G_i = gender (sex) of the animal

S_j = direction of sampling of leather specimen (perpendicular or parallel to backbone)

$(GS)_{ij}$ = interaction between gender and sampling direction

E_{ijkl} = random error

PROC GLM of SAS (2003) was used to compare the effects of gender (sex) and direction of sampling (parallel or perpendicular to the backbone) on mechanical properties (break load, tensile strength and percentage elongation) of automotive upholstery crust leather from non-descript cattle genotype only where three gender classes were represented. Means separation was done using the Pdiff option. The following model was used:

$Y_{ijkl} = u + G_i + S_j + P_k + (GD)_{ij} + (GP)_{ik} + (SP)_{jk} + (GSP)_{ijk} + E_{ijkl}$

Where Y_{ijkl} = The independent variable (break load, tensile strength or elongation at break)

μ= overall mean

Gi = gender (sex) of the animal

Sj = direction of sampling of leather specimen (perpendicular or parallel to backbone)

Pk = crust leather region of specimen sampling (butt, belly or neck)

(GS)ij = interaction between gender and sampling direction

(GP)ik = interaction between gender and crust leather region of specimen sampling

(SP)jk = sampling direction and crust leather region of specimen sampling

(GSP)ijk = three way interaction among gender, sampling direction and crust leather region of specimen sampling

Eijkl = random residual

Analysis of variance for the data on fibre diameters from scanning electron microscopy was carried out for the effects of breed, sectioning direction (transverse or longitudinal) and hide or automotive crust leather part from which the specimen sampling was done (butt, neck and belly) using PROC GLM of SAS (2003). Breed differences were computed from same sex animals (cows and heifers). The following model was used:

$Y_{ijkl} = \mu + G_i + D_j + P_k + (GD)_{ij} + (GP)_{ik} + (DP)_{jk} + (GDP)_{ijk} + E_{ijkl}$

Where Y_{ijkl} = The independent variable (fibre diameter)

μ= overall mean

G_i = effect of genotype (Nguni or non-descript)

D_j = Direction of sectioning of specimen (transverse or longitudinal)

P_k = hide or crust leather region of specimen sampling

$(GD)_{ij}$ = interaction between genotype and direction of sectioning of specimen

$(GP)_{ik}$ = interaction between genotype and hide or crust leather region of specimen sampling

$(DP)_{jk}$ = interaction between direction of specimen sectioning and hide or crust leather region of sampling

$(GDP)_{ijk}$ = three way interaction among genotype, direction of specimen sectioning and hide or crust leather region of sampling

E_{ijkl} = random error

Within-breed analysis of variance was carried out on fibre diameter data from hides and automotive crust leathers using data from non-descript cattle genotype only since it had both genders represented (male and female). Hide and crust leather fibre diameter data were analysed for variance using Proc GLM (SAS, 2003) for the effects of gender, crust leather or hide region of specimen sampling and sectioning direction (transverse and longitudinal). Significant differences of means were separated using the PDIFF option at 5 % significance level. The following model was used:

$Y_{ijkl} = \mu + S_i + D_j + P_k + (GD)_{ij} + (GP)_{ik} + (DP)_{jk} + (GDP)_{ijk} + E_{ijkl}$

Where:

Y_{ijkl} = The independent variable (fibre diameter)

μ= overall mean

S_i = effect of gender (sex) of animal (male or female)

D_j = Direction of sectioning of specimen (transverse or longitudinal)

P_k = hide or crust leather region of specimen sampling

$(SD)_{ij}$ = interaction between gender and direction of sectioning of specimen

$(SP)_{ik}$ = interaction between gender and hide or crust leather region of specimen sampling

$(DP)_{jk}$ = interaction between direction of specimen sectioning and hide or crust leather region of sampling

$(SDP)_{ijk}$ = three way interaction among gender, direction of specimen sectioning and hide or crust leather region of sampling

E_{ijkl} = random error

6.3 Results

6.3.1 Physico-mechanical properties of automotive crust leather

Physico-mechanical properties of automotive crust leather evaluated include leather area, breaking force, tensile strength and elongation at break.

6.3.1.1 Leather area

There were no significant ($P > 0.05$) genotype effects on the area of the crust leathers. The mean areas (LSmean ± SE) were 3.5 ± 0.07 m^2 and 3.4 ± 0.07 m^2 for Nguni and NDCC automotive crust leathers, respectively. There were no significant ($P > 0.05$) genotype effects in the leather area when controlling for liveweight (i.e., using slaughter liveweight as a covariate).

6.3.1.2 Effects of genotype and sampling direction on breaking load, tensile strength and elongation at break in automotive crust leathers from Nguni and non-descript automotive crust leather

Tables 6.1 and 6.2 show the variations in breaking load, tensile strength and elongation at break in automotive crust leathers from Nguni and non-descript cows and heifers (females) in different directions of sampling. Direction of sampling had a significant ($P < 0.05$) effect on breaking load and tensile strength. Elongation at break was, however, not significantly ($P > 0.05$) affected by direction of sampling. The breaking load and tensile strength were higher ($P < 0.05$) in specimens taken parallel to the backbone compared to perpendicular to the backbone (Table 6.1).

Table 6.1: LSMean ± SE of breaking load (N), tensile strength (MPa) and elongation at break (%) for Nguni and non-descript crossbred automotive crust leather samples taken either perpendicular or parallel to the backbone of cows and heifers.

Parameter	**Sampling direction**		**Standard Error**
	Parallel to backbone	**Perpendicular to backbone**	
Breaking load (N)	1257.1[b]	979.5[a]	70.72
Tensile strength (MPa)	28.3[b]	23.6[a]	1.23
Elongation at break (%)	82.2	82.8	2.36

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

Table 6.2 Breaking load, tensile strength and elongation at break of automotive crust leathers from non-descript cattle sampled from the official sampling position in butt region parallel and perpendicular to the backbone.

Parameter	**Sampling Direction**		**Standard Error**
	Parallel to backbone	**Perpendicular to backbone**	
Breaking load (N)	1208.2[b]	885.0[a]	90.10
Tensile strength (mPa)	28.4[b]	21.4[a]	1.46
Elongation at break (%)	85.7	81.4	3.57

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

6.3.2 Fibre architecture in Nguni and non-descript crossbred cattle hides sampled from the different regions

The architecture of the hide matrix of tissues sampled from the butt, belly and neck regions of a Nguni cow and a non-descript crossbred cow are shown in Images 1 to 12 (Appendix 4). The fibre architectures are shown in the longitudinal and cross-sections. The qualitative descriptions of the fibre architecture are given in Appendix 5.

6.3.3 Effects of genotype, hide region and sectioning direction on fibre thickness in the butt, belly and neck regions of Nguni and non-descript crossbred cattle hides

Variations in fibre thickness in different parts of the hide (i.e., butt, belly and neck) of Nguni and NDCC hides are shown in Table 6.3. There were significant ($P < 0.05$) interactions between genotype and direction of sampling. Interaction between hide part and direction of sampling was also significant ($P < 0.05$). Collagen fibre diameters in the Nguni were similar in both longitudinal and cross-sections while they were thicker in the cross-section compared to the longitudinal section of NDCC. In the longitudinal section, thicker fibres were observed in Nguni hides compared to the NDCC hides, while the reverse was true in the cross-section (Table 6.3).

In all the three hide regions, fibre diameters differed ($P < 0.05$) in the two directions of sampling (Table 6.4). Butt and neck regions had thicker ($P < 0.05$) fibres in the longitudinal direction compared to the cross-section unlike the belly region in which the reverse was true (Table 6. 4).

Table 6.3: Variations in fibre thickness (LSMean ± SE) (µm) in the two genotypes due to direction of sectioning of hide specimens.

Genotype	**Direction of sectioning of specimen**	
	Longitudinal	**Cross-section**
Nguni	$3.4^{B} \pm 0.12$	$3.2^{A} \pm 0.11$
Non-descript crossbred	$3.0^{a,A} \pm 0.10$	$3.5^{b,B} \pm 0.11$

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

^{A,B} Means with different superscripts within a column are significantly ($P < 0.05$) different

Table 6.4: Variations in fibre thickness (LSMean ± SE) (µm) in the different hide regions due to direction of sectioning of hide specimens.

Hide Region	Direction of sectioning of specimen	
	Longitudinal	**Cross-section**
Butt	$2.9^{A,a} \pm 0.13$	$3.4^{B,b} \pm 0.12$
Belly	$3.7^{B,b} \pm 0.14$	$2.9^{A,a} \pm 0.11$
Neck	$3.0^{A,a} \pm 0.129$	$3.7^{B,b} \pm 0.16$

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

[A,B] Means with different superscripts within a column are significantly different ($P < 0.05$)

6.3.4 Effect of gender, hide region and sectioning direction effects on fibre thickness in the butt, belly and neck regions of non-descript crossbred cattle hides

Table 6.5 shows the effect of gender (male, female), hide region (butt, belly, neck) and sectioning direction of specimens on fibre diameter. Gender and hide region had significant ($P < 0.05$) effects on fibre diameter. Hide region by sectioning direction of specimen had significant ($P < 0.05$) effects on fibre diameter.

6.3.5 Fibre architecture in Nguni and non-descript automotive crust leathers sampled from the different regions

The architecture of the matrix of tissues sampled from butt, belly and neck regions of automotive crust leather is shown in Images 13 – 24 (Appendix 4) for a Nguni cow hide and a non-descript crossbred cow. The fibre architectures were viewed in the longitudinal and cross-sections.

Table 6.5: Variations in fibre diameter LSMean ± SE (µm) due to gender (male, female), hide region (belly, butt, neck) and sectioning direction of hide specimens on fibre diameter in non-descript crossbred cattle.

Hide Region	Direction of sectioning of specimen	
	Longitudinal	**Cross-section**
Butt	$3.3^{B} \pm 0.17$	$3.6^{B} \pm 0.24$
Belly	$3.3^{B} \pm 0.14$	$3.0^{A} \pm 0.19$
Neck	$2.6^{A,a} \pm 0.13$	$3.51^{B,b} \pm 0.19$

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

^{A,B} Means with different superscripts within a column are significantly ($P < 0.05$) different

6.3.6 Genotype, hide region and sectioning direction effects on fibre diameter in the butt, belly and neck regions of Nguni and non-descript crossbred automotive crust leather

Table 6.6 shows the variation in thickness of the collagen fibre bundles due to genotype, crust leather region and direction of sectioning of hide specimens. There was a significant ($P < 0.05$) three way interaction among genotype, crust leather region and direction of sectioning of the hide specimens fibre diameter.

6.3.7 Effect of gender, crust leather region and sectioning direction effects on fibre diameter in the butt, belly and neck regions of non-descript crust leather

Table 6.7 shows variations in fibre thickness of crust leather due to crust leather region and direction of sectioning of the crust leather samples. There were significant ($P < 0.05$) effects of crust leather region by sectioning direction of crust leather specimens.

Table 6.6: Variations in fibre thickness (LSMean ± SE) (µm) in automotive crust leather due to genotype, crust leather region and direction of sectioning of hide specimens.

Genotype	**Crust leather region**	**Sectioning direction of hide specimen**	
		longitudinal	**Cross-section**
Nguni	Belly	$3.3^{A} \pm 0.24$	$3.1^{B} \pm 0.26$
	Butt	$4.3^{b,B} \pm 0.24$	$3.4^{a,B} \pm 0.25$
	Neck	$2.8^{A} \pm 0.23$	$2.6^{A} \pm 0.23$
Non-descript	Belly	$4.0^{b,B} \pm 0.28$	$3.0^{A,B} \pm 0.29$
crossbred	Butt	$2.8^{A} \pm 0.29$	$3.3^{B} \pm 0.28$
	Neck	$3.5^{b,AB} \pm 0.23$	$2.32^{a,A} \pm 0.27$

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

^{A,B} Means with different superscripts within a column are significantly different ($P < 0.05$)

Table 6.7: Variations in fibre diameter LSMean ± SE (µm) due to gender (male, female), automotive crust region (belly, butt, neck) and sectioning direction of crust leather specimens in non-descript crossbred cattle.

Crust Region	Direction of sectioning of specimen	
	Longitudinal	**Cross-section**
Butt	3.5 ± 0.26	3.2^{A} ± 0.29
Belly	3.7 ± 0.30	4.2^{B} ± 0.43
Neck	3.5^{b} ±0.271	$2.4^{A,a}$ ± 0.30

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

^{A,B} Means with different superscripts within a column are significantly different ($P < 0.05$)

6.4 Discussion

Although Nguni cattle have been classified as smaller-framed compared to non-descript crossbred cattle (Mapiye *et al*., 2009); the area of crust leathers obtained from Nguni and NDCC in this study revealed no significant genotype effects. This observation also held true when slaughter liveweight was used as a covariate. This observation could be attributed to the high proportion of younger animals (heifers and oxen) in the NDCC genotype sampled in this study compared to mature old cows in the Nguni genotype sample.

In contrast to Li *et al*. (2009), cattle genotype did not affect breaking load, tensile strength and elongation at break in this study. This finding could be attributed to the similarity in collagen fibre diameters in the cross-section of the hides and crust leathers which was observed in the two genotypes, despite the thicker fibres observed in the Nguni cattle in the longitudinal section. Fibrillogenesis and increase in fibre diameter have been reported to be under genetic control (Asano *et al*., 2009; Zhang *et al*., 2009), with approximately 42 genes coding for various proteins useful in the skin. Alterations in collagen genes such as deletions, mutations and insertions can lead to changes in mechanical properties of the skin (Starborg *et al*., 2008; Asano *et al*., 2009). Similarities in the mechanical properties of Nguni and NDCC in this study could indicate similarity in the genes that are important for coding for fibrillogeneis and regulation of fibril and collagen diameter. Non-descript crossbred cattle resulted from non-regulated mating of indigenous breeds such as the Nguni cattle with imported breeds such as Angus, Hereford and Jersey (Mapiye *et al*., 2009). There are inconsistent reports on effect of genotype on mechanical properties of leather. Consistent with the observations in this study, Teklebrhan *et al.* (2012) did not find any significant differences in physico-mechanical properties of leather from indigenous and Dorper-indigenous crosses. Snyman and Jackson-Moss (2000) reported that only the Merino sheep

leather failed to reach minimum expected values for mechanical properties required for clothing leather out of the 10 sheep breeds tested. The other nine sheep breeds did not differ in leather quality and had the desired properties for the intended application (Snyman and Jackson-Moss, 2000). Unlike findings in this study, Oliviera *et al*. (2007) found differences in tensile strength and elongation at break among indigenous breeds, introduced breeds and their crosses in goats and sheep. However, most of the breeds reached the minimum expected tensile strength and elongation at break (Oliviera *et al*., 2007).

It is possible that the combined effect of fibres in the leather matrix could have led to the observed similarity in the physico-mechanical strength. The collagen fibres that are aligned in various planes and are of varying diameters, complement each other to produce the resulting mechanical properties as pointed out by Zhang *et al*. (2009). Furthermore, Parry and Craig (1984) and Kobayashi *et al*. (1999) stated that each part of the animal skin and skin type develops in such a way to satisfy the required mechanical response to loading within the tissue. Other authors (Basil-Jones *et al*., 2010; Basil- Jones *et al*., 2013) also emphasise the importance of fibre architecture in determining mechanical properties of leather. Ottani *et al*. (2001) attributed higher tensile strength in collagen fibrils which have larger diameters, a wider cross-section and higher inter-fibrillar cross-linkages. In this study, collagen fibre diameters (thickness) observed ranged between 2.99 - 4.54 µm. This range of diameters corresponds to the size of elementary fibres, reported as 5 µm by BASF (2009). Elementary fibres result from an aggregation of collagen fibrils (BASF, 2009). These elementary fibres in turn aggregate to form collagen fibre bundles which range between 20-200µm in diameter (BASF, 2009). The three-dimensional collagen matrix is thus composed of varying sizes of fibrils, collagen bundles of supramolecules (Damink *et al*., 1996; Pins *et al*., 1997; Shoulders and Raines, 2009).

The observations that breaking load and tensile strength were affected by sampling direction are consistent with other reports (Luong, 2007; Oliviera *et al*., 2007; Li *et al*., 2009). The findings from this study concur with Luong (2007) and Oliviera *et al*. (2007) who reported higher tensile strength in leather specimens sampled parallel to the backbone than those sampled perpendicular to the backbone. In contrast, Liu *et al.* (2009), found lower tensile strength in longitudinal samples (parallel to the backbone) than the samples taken perpendicular to the backbone. Several authors attributed the variations in mechanical properties of leather to the orientation of collagen fibres, fibril diameter, collagen content of fibre bundles (Liao *et al*., 2005; Li *et al*., 2009; Basil-Jones *et al*., 2010; Wells *et al*., 2013) and amount of strain the tissue is exposed to (Wess, 2008). In this study fibre diameters were studied in specimens cut in the cross-section and in the longitudinal section of the hide not parallel and perpendicular to the backbone. However, the cross-section and longitudinal samples in this study revealed variations in fibre orientation in the 3-dimensional weave of the hides and crust leathers. It is possible that the three-dimensional matrix of the collagen fibres perpendicular to the backbone resulted in less stable leather which broke more easily compared to that of samples parallel to the backbone.

In this study, most of the hides were from mature cows, especially in the Nguni genotype and younger animals from the NDCC genotype. It is possible that the animals experienced more loading in the direction parallel to the backbone throughout their lives, making the perpendicular direction weaker over time. Younger animals are also reported to have less insoluble collagen compared to older animals, resulting in more stretchy leather with less cross-linking and therefore more unstable than leather from mature animals (Covington, 2009). Furthermore, the ages of the animals in this study could have contributed to the findings on the physico-mechanical properties of the leathers. Age-related alterations in the

skin matrix have been reported (Hagisawa and Shimada, 2005). Furthermore, Hagisawa and Shimada (2005) stated that skin from mature or old animals exhibits changes in the quality of the collagen fibres, in orientation of the fibres to a loose appearance and disrupted fibrils in fibre bundles, resulting in associated changes in mechanical properties. With advancing age, there is an increase in the number of intra-molecular cross-links and an increase in the collagen fibre diameter (Hagisawa and Shimada, 2005). While the properties lead to an increase in tensile strength, extensibility is decreased leading to an earlier failure (break) (Li *et al*., 2009). According to Wells *et al*. (2013), cross-linkages among collagen fibrils and fibre diameter have a strong influence on the strength of leather. Depalle *et al.* (2015) also attributed the structural stabilisation of the fibrillary structure to modifications that result in intra and intermolecular cross-linkages.

The other explanation could be a permanent alteration in the structure of the collagen matrix as pointed out by Liao *et al*. (2005). Cows will have given birth several times before slaughter and have generally been regarded as having weaker leather particularly in the flank or belly region (BASF, 2009). In this study, scanning electron micrographs showed variations in the fibre architecture of hides. Variations were evident in the orientation of the fibres in both the longitudinal and cross-sections within the same hide region. For example, while in the cross-section fibres tended to be extended and anisotropic with a low angle of weave, the longitudinal section tended to have highly oriented fibres, which had crimps, were highly interwoven and loosely arranged into a mesh.

The anisotropic nature of fibres observed in this study, has been reported in skin and leather architecture (Hein *et al*., 2007; Li *et al*., 2009). The generally observed variation in the fibre architecture in this study follows the widely known structure exhibited by the skin matrix (Li

et al, 2009; Basil-Jones *et al*., 2010; Kreig and Aumailley, 2011). Furthermore, fibres in the longitudinal section were generally found to be wavy while the fibres viewed in the cross-section were tightly packed and mostly oriented in a parallel fashion. According to Hagisawa and Shimada, (2005), in a resting state, collagen fibres are generally un-oriented, convoluted and held in a matrix of tissue fluid. The orientation, however, changes due to stretching of the skin in either one or both axes resulting in the stretching and straightening of the collagen fibres (Basil- Jones *et al*., 2010). In contrast, active skins generally have well oriented fibrils than the more random orientation exhibited by passive skins (Chapman and Hulmes; 1984; Hagisawa and Shimada, 2005). From this study, it seemed therefore, that the skins were exposed to more strain in the cross-section compared to the longitudinal plane due to the presence of convoluted, crimped fibres in the longitudinal plane.

It is generally difficult to obtain information on the quality of the state-of-the art automotive leather standard requirement in literature as observed also by the EU Commission (2001) and BASF (2009). Individual automotive manufacturers specify characteristics that they require and specific test methods (EU Commission, 2001; BASF, 2009). However, EU Commission (2001) reported that chrome-free automotive upholstery leather must have a tensile strength ≥ 8 N/mm^2 and an elongation at break ranging between 35-60 %. Chrome-free leathers generally have lower performance compare to chrome-tanned leathers (Covington, 2009). According to BASF (2009), desirable tensile strength for general upholstery leather is above 27.5 N/mm2 (1MPa = 1N/mm^2) with an elongation at break > 75 %. Tensile strength values obtained in this study ranged between 21.4±1.46 to 28.4±1.46 in the NDCC genotype and 23.58±1.225 MPa to 28.28±1.225 MPa across the two genotypes. Samples parallel to the backbone had higher tensile force (28.3-28.4 MPa) compared to perpendicular to the backbone (21-23.58MPa). The elongation at break was over 80 %.

6.5 Conclusions and recommendations

Leather area, breaking load, tensile strength and elongation at break were similar in automotive crust leathers from Nguni and non-descript crossbred female cattle hides. However, tensile strength and elongation at break differed with direction of cutting (parallel to backbone vs perpendicular to backbone). Similarities in mechanical properties of automotive upholstery crust leathers in this study were attributed to similarities in the thickness of the collagen fibres in the cross-section of the butt region. Fibre architecture varied among hide regions of the butt (belly, butt and neck) and sectioning directions (longitudinal section and cross-section). Collagen orientation and fibre diameter varied in the hide and crust leather matrices. In all the three hide regions, fibre diameters differed in the two directions of sampling. Raw hides and automotive upholstery crust leathers had similar collagen fibre diameters in the longitudinal and cross-section. Although it is difficult to conclude on the usability of the crust leathers in this study based on the values given by BASF (2009) for general chrome tanned upholstery and by the EU Commission (2001) for chrome-free leathers, it can generally be seen that there is a high potential for producing good quality automotive leather from Nguni and NDCC genotypes in South Africa. Automotive upholstery leather is an important export commodity and part of a strategic economic sector in South Africa. Incorporation of these Nguni and NDCC hides in the leather industry in South Africa would go a long way in addressing some of the challenges encountered in hide supply.

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Chapter 7: General Discussion, Conclusions and Recommendations

7.1 General discussion

The main objective of this study was to determine the adaptive responses of Nguni and non-descript crossbred cattle to heat stress, nutritionally-related blood metabolite profiles, fatty acid profiles, carcass and meat characteristics, physico-mechanical properties of automotive upholstery crust leather and the associated collagen fibre architecture of hides and crust leather. In South Africa, over 75 % of small-scale farmers practice extensive farming. On the other hand, there are reports of increasing global warming which is projected to have a devastating effect on livestock production in the tropics. Unless, adapted breeds are used for faming under low-input systems, the challenge of climate change will severely affect extensive livestock production and livelihoods of the small-scale farmers. It is also of interest to determine the nutritional status of animals reared in such environments and the associated animal performance and product quality. Determination of product quality informs decision making on the usability of products and how to improve them to meet the requirements of the formal markets.

In chapter 3, adaptability of extensively grazing cattle to environmental heat load (i.e., prevailing thermal environment) were determined through monitoring rectal and skin temperature, cortisol and creatine kinase activity (CK) over a 16 week period. There were variations in environmental variables (ambient temperature, relative humidity, solar radiation wind parameters) due to week of sampling. The observed variation in environmental variables during the study period shows that cattle grazing in extensive systems are subjected to widely varying environmental conditions which may compromise their welfare as pointed out by several authors (Nardone *et al*., 2010; Scholtz *et al*., 2013). Animals subjected to high temperature coupled with high ambient temperature can succumb to heat stress as a result of

an increase in core body temperature (Kumar *et al*., 2015). Livestock managers, therefore, need to be on alert and constantly monitor the welfare of animals especially during periods of high THI. The evidence of increasing climate change reported by Fourie *et al*. (2013) in South Africa, is a cause for concern. Various strategies for coping with exposure to hot weather include use of adapted breeds (Mirkena *et al*., 2010), provision of either natural shade or artificial (Brown-Brandl *et al*., 2005; Tucker *et al*., 2008) for animals to escape the direct effects of solar radiation and cooling mechanisms such as the use of sprinklers or provision immersion water (de Mira Geraldo *et al*., 2012).

In this study, cattle from both genotypes managed to maintain normal core body temperature for the duration of the study. There was no correlation between rectal temperature and environmental variables. Skin temperature was negatively correlated to all weekly variations, maximum THI, solar radiation, all wind parameters, body condition and coat score. Hair length was observed to vary across months, being longer at the end of the study period than at the beginning of the trial. Coat score also increased throughout the study period. Non-descript crossbred cattle had higher coat scores than Nguni. The study ended as winter (cool-dry season) was approaching. Various authors (Bertipaglia *et al*., 2007; McManus *et al*. 2011; Fadare *et al*., 2013) pointed out the importance of hair and coat characteristics in the response of animals to environmental heat load. Thicker coats trap air which acts as in insulator, preventing the heat produced by the animal in metabolic activities from escaping to the surrounding environment. Such situations lead to heat build-up in the animal leading to heat stress which can severely affect productivity or lead to death. Hair colour has also been reported to play a major role in heat absorption or reflection, with dark-coloured hair absorbing more heat from solar radiation compared to light coloured ones (Bertipaglia *et al*., 2007; Fadare *et al*., 2013). Intermediate colours such as red also have intermediate

absorbance to that of the extremes. Rectal and skin temperatures were negatively correlated to body condition, skin pigment, coat score and skin and thickness. Both genotypes possessed sufficient morphological and physiological mechanisms to be able to regulate core body temperature under the prevailing environmental heat load. However, both genotypes need to be monitored so as to respond to acute cases of heat stress during the period of high THI.

In Chapter 4, the objective was to determine changes in nutritionally-related blood metabolites and how associated growth performance, weights of hides and carcass characteristics in Nguni and non-descript crossbred steers reared on a sweetveld. Weekly liveweights and blood metabolites related to protein intake increased through the study period. Body condition increased only up to the 8th week, dropped slightly in the 10th week, increased slightly in the 12th week and become constant to the end of the study. Beyond the 8th week, the nutritive value of the veld forages could have been insufficient to support a much higher level of production beyond maintenance and growth requirements. Body condition is an indicator of subcutaneous fat deposition (Roche *et al*., 2009). The storage of energy fat depots occurs during favourable periods when forage quality and quantity surpass the requirements of the animals (Ermias *et al*., 2002). These reserves are later drawn upon in periods of energy deficits (Ermias *et al*., 2002).

The declining blood glucose level in this study shows the limitation faced by these animals in terms of meeting energy requirements. Glucose levels declined throughout the study period, although they were still within the normal range of values expected in cattle (Merck Veterinary Manual, 2010). The stagnation in body condition score could also be linked to the prevailing thermal heat load in Chapter 3. From the 2nd week, maximum THI was high but animals started off at a low body condition as the rainy season had just commenced and the

improvement in nutrition could have resulted in the increase in body condition and coat scores. However as the study proceeded, THI remained high while animals had improved in condition and had higher coat scores. To mitigate the potential challenge of heat stress due to high THI, the steers could have maintained the observed level of body condition. Van Laer *et al*. (2014) pointed out that when certain breeds of cattle such as the Hereford and Aberdeen Angus are exposed to extreme cold, they accumulated energy reserves such as body fat and muscle tissue, increasing subcutaneous fat and coat thickness for increased insulation. The converse can be assumed to be true in animals that are exposed to heat stress as subcutaneous fat can alter heat transfer depending on thickness as reported by McLellan *et al*. (2009). The other reason could be a reduction in feed intake due to metabolic heat production regulation. Bernabucci *et al*. (2010) reported that animals exposed to high ambient temperatures reduce feed intake. The reduction in feed intake may lead to a negative energy balance which the animals attempt to alleviate by drawing on body reserves such as skeletal muscle and fat depots (Bernabucci *et al*., 2010). Body condition score was negatively correlated to both rectal and skin temperature. At the same time, coat score and hair length were increasing throughout the study period. Creatinine, a protein metabolite related to muscle metabolism and increased muscle mass (Whittet *et al*., 2004), clearly show that energy was limiting at the point when animals had higher energy requirements due to higher liveweights.

Non-descript crossbred cattle finished off heavier than Nguni cattle and had higher hide weights, warm carcass mass and cold carcass mass. This shows that the nutritive quality of the rangeland was able to support positive growth as shown by high total protein in both genotypes. Non-descript crossbred cattle are generally regarded as larger framed than Nguni cattle (Mapiye *et al*., 2009). The fact that Nguni cattle finished off with lower weights than the NDCC despite the higher total protein concentration could be linked to the slow growth

rate of the indigenous cattle compared to imported breeds (Strydom *et al*., 2000; Frylinck *et al*., 2013).

In terms of carcass grading, both genotypes had medium body conformation. The subcutaneous fat level obtained in this study show that the energy level in the diet was not sufficient to promote a higher level of fat deposition. Pasture-finished cattle have frequently been reported to finish off with a low subcutaneous fat level (Strydom *et al*., 2008). An energy supplement, preferable a non-conventional forage seed, from the natural environment may be required, especially if the beef has to be marketed as natural beef.

The albumin, globulin and albumin:globulin ratio show the immune response to infection. In this study, albumin was lower than the standard expected values while globulin was above the normal value. These values could be indicative of infection and the attempt to fight off the infection through elevated globulin levels. Nguni cattle are reported to be resistant to ticks, diseases and infection prevalent during the wet season (Muchenje *et al*., 2008; Marufu *et al*., 2011).

In chapter 5 the objective of the study was to determine the fatty acid profiles and physico-chemical quality of beef from Nguni and NDCC reared on a sweetveld and to compare the physico-chemical quality of two beef muscle types from the two genotypes. The IMF content was found to be higher in Nguni than NDCC. Interestingly, the reverse was true in subcutaneous fat deposition. A higher proportion (75 %) of non-descript finished off as very lean compared to 50 % of the Nguni cattle. Intramuscular fat is more desirable to consumers as it improves the sensory properties of meat such as juiciness, aroma and taste. However, consumers desire a certain level of fatness, i.e., lean beef as fat affects sensory properties of

meat such as tenderness, juiciness and flavour. However, subcutaneous fat levels in this study are below the premium level of fatness class 2 (Soji *et al*., 2015). The higher level of intramuscular fat in Nguni cattle would make it more desirable compared to beef from non-descript cattle. However, the darker colour in Nguni beef makes it less preferable at the point of purchase (Grunert *et al*. 2004). All the other physico-chemical properties, fatty acid composition, and health related lipid indices were similar. Furthermore, LTL and TB muscles were similar in ultimate pH and meat colour. This could be attributed to the age of the animals. Meat fibres might not have differentiated enough for significant differences to be detected between these muscles.

The objective of the study in Chapter 6 was to determine some physico-mechanical characteristics of Nguni and NDCC automotive upholstery leather and the associated collagen fibre architecture of various body regions. Skins and leather are made up of collagen, a fibrillary protein as the major protein. Collagen properties such as fibril and fibre diameter, alignment and collagen content determine the strength of the skin and leather (Li *et al*., 2009; Basil-Jones *et al*., 2010; Wells *et al.*, 2013). Various body parts are exposed to various levels of strain (Parry and Craig, 1984; Li *et al*., 2009) and are therefore structurally modified to suit the mechanical requirements of the tissues. Therefore, different body regions differ in leather quality (BASF, 2009).

In this study, Nguni and NDCC had similar crust leather area, breaking, load, tensile strength and elongation at break. Genotype did not have a significant effect on breaking load, tensile strength and elongation at break. This study also revealed variations in collagen fibre thickness and orientation in different body parts (butt, belly and neck) and within the matrix of the collagen architecture (cross-section vs longitudinal sections) and variations in different

genders. However, despite these differences, similarity was observed in the physico-mechanical tests performed. The NDCC used are a result of non-discriminate crossing between Nguni and other imported breeds such as the Jersey, Angus and Hereford (Mapiye *et al*., 2009). It has been reported that collagen fibrillogenesis is under genetic control and this regulates the diameter of collagen fibrils and fibres (Asano *et al*., 2009). It is possible that the genes for fibrillogenis and skin regulation could be the same in the two genotypes. Alternatively, the nutrition of these animals could have supported collagen fibre development to the same extent. Poor nutrition has been reported to result in papery leather of poor substance (Mwinyihija, 2006). These leathers in this study had sufficient tensile strength and therefore had fully developed collagen matrices. In the NDCC genotype, there were no differences in the two genders in breaking load and tensile strength and elongation at break. The samples cut parallel or perpendicular to the backbone, however differed in tensile strength and breaking load. This observation is consistent with other reports (Oliviera *et al*., 2007; Liu *et al*., 2009; Teklebrhum *et al*., 2012; Salehi *et al*., 2013). Collagen fibre orientation in hides and crust samples varied between longitudinal and cross-sections. This is consistent with reports by other authors (Hagisawa and Shimada, 2005; Basil-Jones *et al*., 2013). Collagen forms a complex three dimensional weave with different fibril and fibre diameters through fibrillogenesis and self-aggregation into high order supra-fibrillar architectures.

7.2 Conclusions

It was concluded that Temperature- humidity- index values, hair coat, skin traits and body condition affect skin temperature, but not rectal temperature, cortisol and CK activity in Nguni and non-descript crossbred cattle reared extensively. It was further concluded that when under extensive sweet rangelands, Nguni and NDCC vary in nutritionally-related

blood metabolites, growth performance, hide weights and carcass traits. Blood metabolite concentrations in both genotypes vary with week of sampling. Under similar grazing conditions, beef from Nguni and NDCC differs in IMF and meat lightness but is similar in fatty acid composition and some physico-chemical quality parameters. Automotive crust leathers from Nguni and NDCC were similar in area, tensile strength, breaking load, and elongation at break, but varied in some collagen architecture aspects such as collagen alignment and fibre diameter in different regions of the hides and crust leathers. Furthermore, breaking load and tensile strength varied with direction of sampling.

7.3 Recommendations

The study has generated the following recommendations:

1. There is need to monitor conditions that may predispose beef cattle in extensive systems to heat stress especially during the night or in the early-morning hours during hot weather. Non-invasive remote sensing equipment such as infrared cameras and infrared thermometers may be useful in detecting cattle at risk of succumbing to heat stress without physically handling them.
2. Further studies are needed determine the genetic regulation of heat stress in both adapted and unadapted breeds using advanced quantitative molecular genetic techniques such as micro-satellite arrays and single nucleotide polymorphism (SNP) to better understand the quantitative trait of heat tolerance.
3. Nutritional adequacy of grazing animals needs to be monitored. This is especially important for animals ready for slaughter in order to attain desirable carcass characteristics with good fatness levels. In this regards, it is recommended to carry out research on potential naturally occurring forages that can be used to fatten animals ready for slaughter.
4. Beef from Nguni and non-descript crossbred cattle raised on the sweetveld can be considered

as good quality healthy meat when slaughtered at a young age. Further research needs to be done on breed differences to further understand genetic control of subcutaneous fat and intramuscular fat deposition. Genetic regulation of fatty acid profiles also deserves attention to be better able to produce health-beneficial beef.

5. Nguni and non-descript crossbred cattle hides can be processed into leather for automotive upholstery. However, what still needs to be established are the physico-mechanical properties required by the export market so that cattle can be raised to yield good quality hides that have the desired leather properties.
6. Currently, there is no direct link between farmers and leather industry stakeholders, particularly the smallholder sector. It is difficult to conduct research that benefits the fragmented industry. There is need to identify research needs of leather industry stakeholders to address the problems they are facing in hide supply and hide quality.
7. Research needs to be done on extrinsic quality of hides from the smallholder sector to identify factors which may lead to pre-slaughter defects.

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Appendices

Appendix 1: Process Sheet for Wet blue

PROCESS SHEET

LEATHER TYPE: Bovine Wet Blue

CUSTOMER Fort Hare University

NO. OF SKINS 6

PROCESS	%	PRODUCT	WEIGHT	TIME	pH	COMMENTS
Static soak				O/n		
Soak	150	Water @ 20°C				
	1,0	Simsoak SA				
				5 hrs		
		Drain				
Lime / Unhair	30	Water @ 25°C				
+	0,8	Simlime GS		30’		
+	1,5	Sodium sulphide		15'		
+	1,5	Lime				
	1,0	Sodium sulphide		15'		
+	1,5	Lime				
	50	Water @ 25°C				
	0,1	Simsperse 6065		20’		
+	50	Water @ 25°C		15’		
				Timer o/n		
		Drain				
Wash	150	Water @ 20°C		15'		
		Drain				
Flesh						
Weight						
Wash	200	Water @ 38°C				
	0.5	Ammonium sulphate		15’		
		Drain				

Bovine Wet Blue

PROCESS	%	PRODUCT	WEIGHT	TIME	pH	COMMENTS
Wash	200	Water @ 38°C				
	0,5	Ammonium sulphate		15'		
		Drain				
Delime / Bate	30	Water @ 35°C				
	3	Ammonium sulphate				
	0,5	Sodium metabisulphite		60'		Check pH and cut
+	50	Water @ 38°C				
	1,0	Bate		45'		
		Drain				
Wash	100	Water @ 20°C		15'		
		Drain				
Pickle / Tan	50	Water @ 20°C				
	7	Salt		10'		Check Baume
+	0,8	Formic Acid				
	1,8	Sulphuric acid				
	0,05	Fungicide				
				60'		pH = 2.0 - 2,5
+	5,5	Chromosal B				
+	0,55	Basifying Agent		O/n		pH = 3,6 - 4,0
		Drain				
Wash	100	Water @ 40°C				
	0,05	Fungicide		20'		
		Drain				

Appendix 2: Process Sheet for Automotive upholstery leather

PROCESS SHEET

LEATHER TYPE **Upholstery**

CUSTOMER **Fort Hare University**

NO. OF SKINS 6

PROCESS	%	PRODUCT	WEIGHT	TIME	pH	COMMENTS
Wet Back	300	Water				
	0,5	Borron SAF		30’		
				Drain		
Neutralise	150	Water				
	0,5	Sodium Formate		15’		
	0,5	Sodium Bicarbonate		60’		
				Drain		
Wash	150	Water		15’		
				Drain		
Retan/Dye	50	Water				
	4	Black Dye				
	6	Basyntan MLB				
	6	Sellatan RLS		45’		
Fatliquor	100	Water				
	6	Coripol SLG				
	2	Magnopol SOF				
	2	Derminol SPE				
	2	Cutapol TIS		60’		
Fix +	1	Formic Acid		15’		
	1	Formic Acid		15’		
	1	Formic Acid		15’		
				Drain		
Wash	150	Water		10’		
				Drain		
Wash	150	Water		10’		
				Drain		

Appendix 3: Automotive crust leather area determination

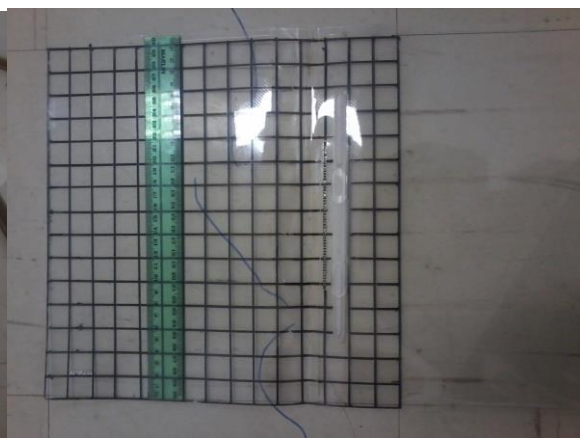
Step 1 Nguni automotive crust leather spread out on tiled floor

Step 2 Numbering on the crust leather recorded for traceability. Below left: The 3 Ns represent the third Nguni hide in Batch 3.

Step 3 Nguni crust leather shape traced out onto the tiled floor

Step 4 Rows and columns covered full tiles falling with the traced diagram of the leather identified by a letter and number for the column and row identities, respectively and recorded. Partly covered tiles were also identified and recorded

Step 5: Transparent plastic tile used for determining area of floor tiles not fully covered



Appendix 4: Fibre architecture of specimens of a Nguni cow hide, a non-descript cow hide and crust leather specimens

A: Hide specimens from the belly, butt and neck regions of a Nguni cow and a non-descript cow

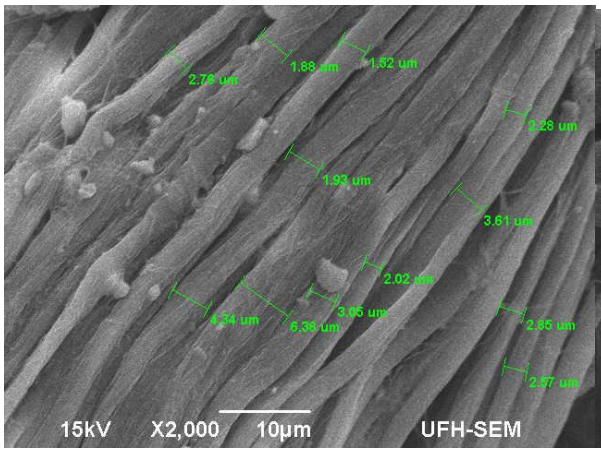


Image 1: cross-section of the belly region of a Nguni cow hide

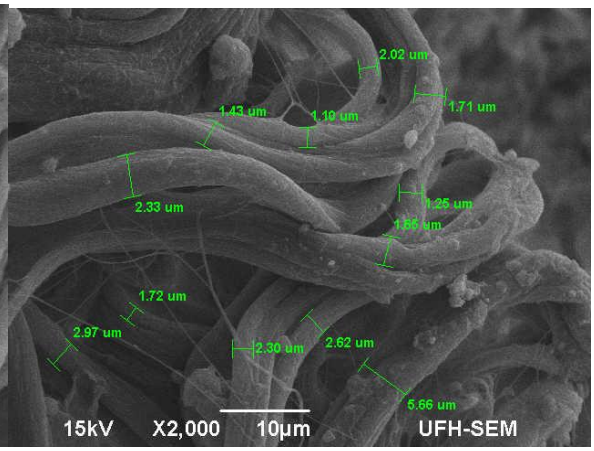


Image 2 Right: longitudinal section of the belly region of a Nguni cow hide

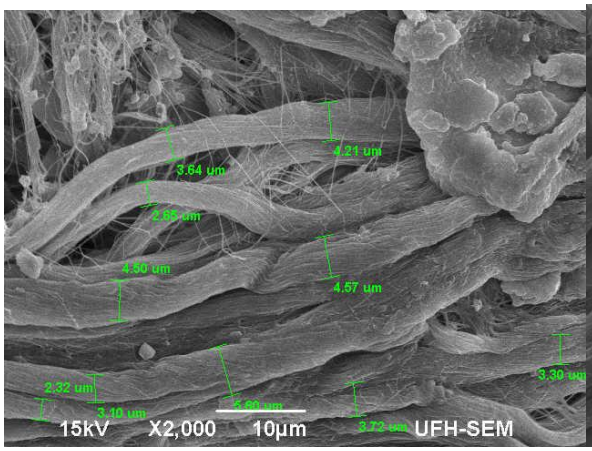


Image3 Right: cross-section of the butt region of a Nguni cow hide

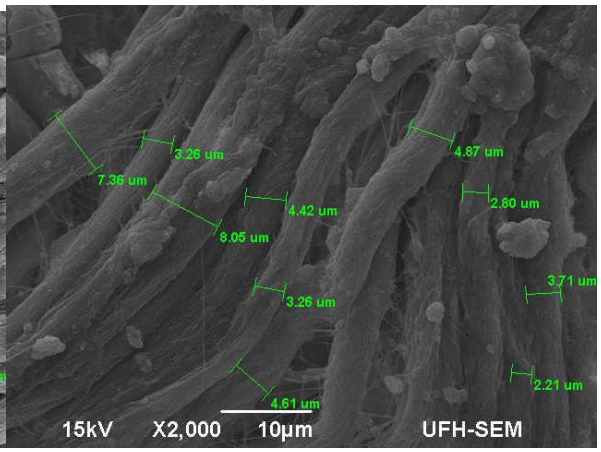


Image 4 Left: longitudinal of the butt region of a Nguni cow hide

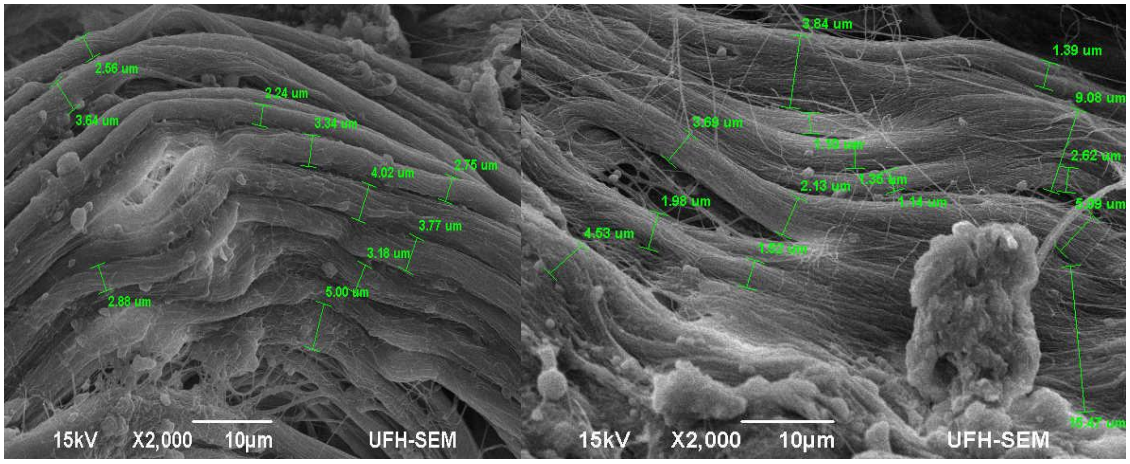


Image 5 Left: cross-section of the neck region of a Nguni cow hide

Image 6 Right: longitudinal section of the neck region of a Nguni cow hide

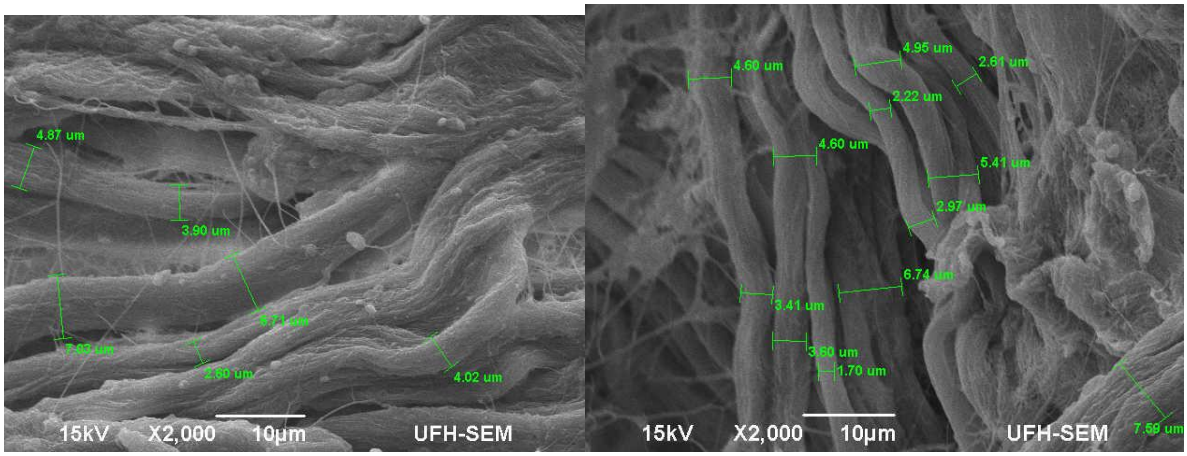


Image 7 Left : cross- section of the belly region of a nondescript cow

Image 8 Right : longitudinal section of the belly region of a nondescript cow

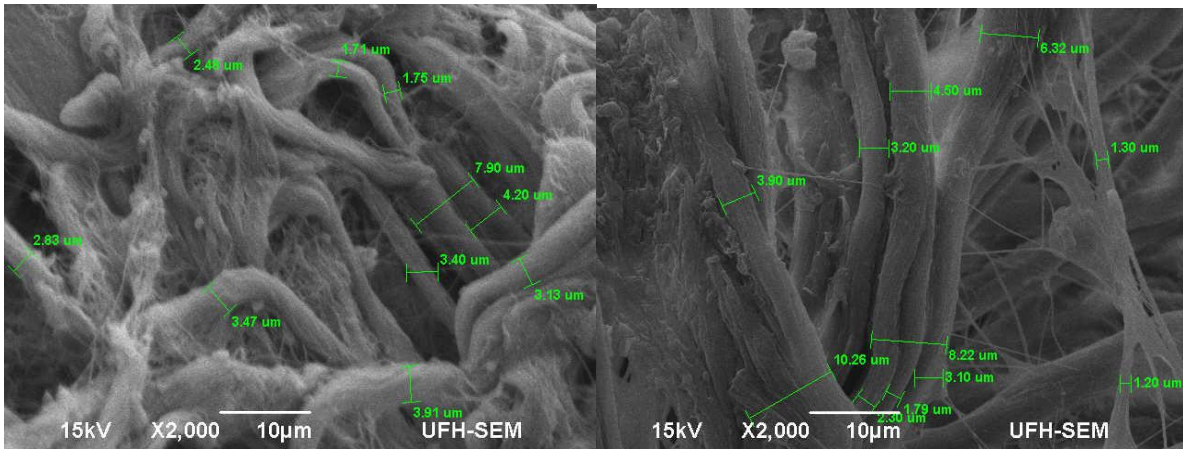


Image 9 Right : cross section of the butt region of a nondescript cow

Image 10: longitudinal section of the butt region of a non-descript cow

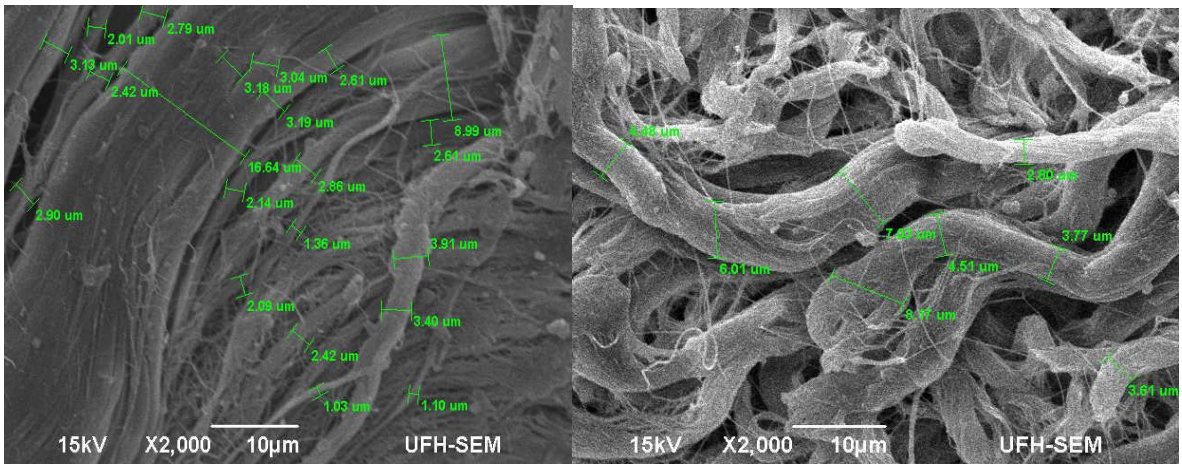


Image 11: Left: cross section of the neck region of a non-descript cow

Image 12: Right: longitudinal section of the neck region of a non-descript cow

B: Crust leather specimens from the belly, butt and neck regions of a Nguni cow and a non-descript cow

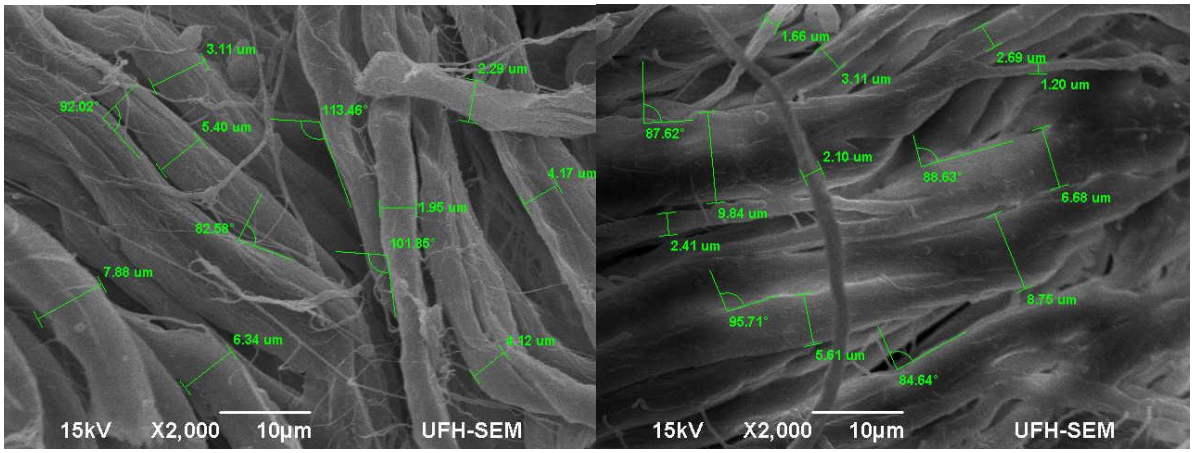


Image 15 Left :cross section of the belly region of a Nguni cow crust leather

Image 16 Right: longitudinal section of the belly region of a Nguni cow crust leather

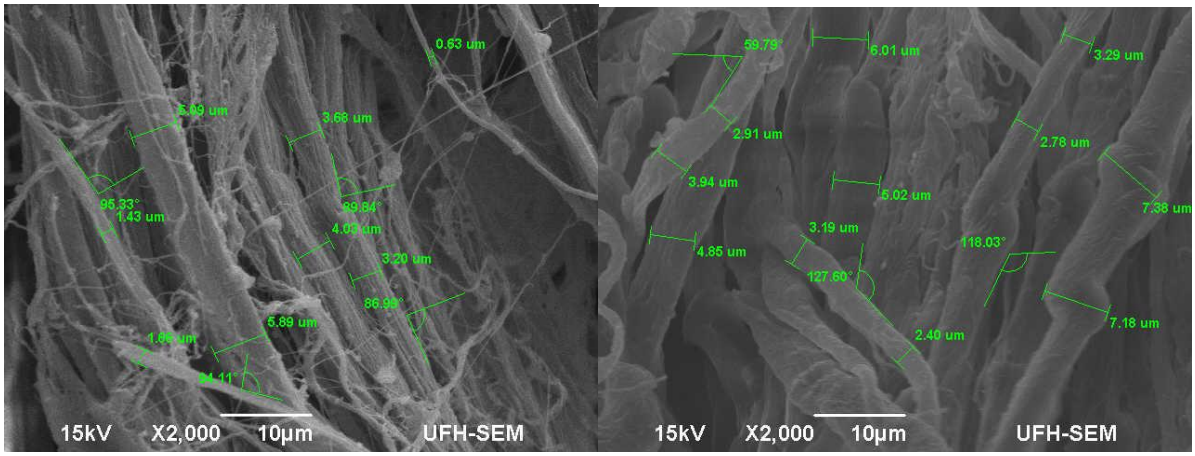


Image 17 Right : cross section of the butt region of a Nguni cow crust leather

Image 18 Left: longitudinal section of the butt region of a Nguni cow crust leather

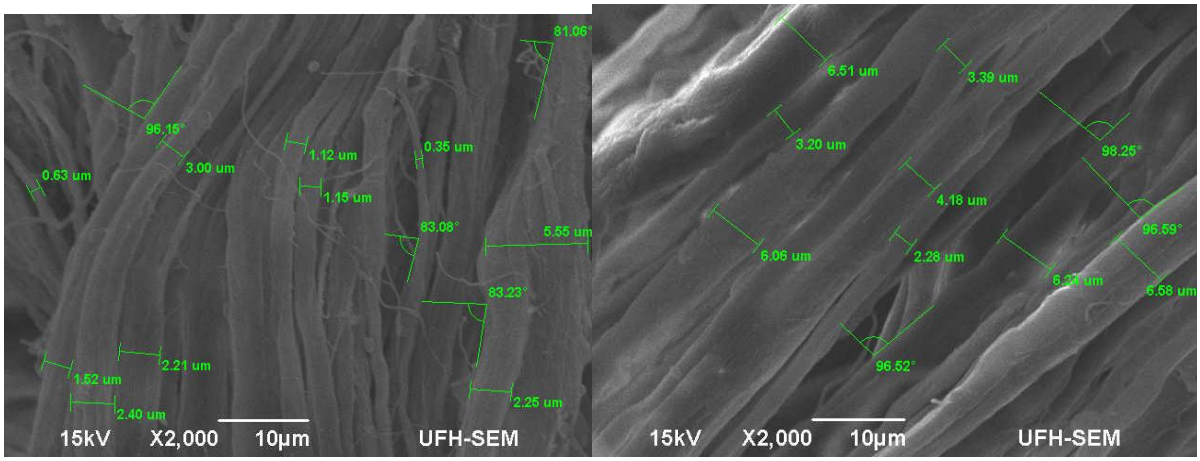


Image 13 Left: cross section of the neck region of a Nguni cow crust leather

Image 14 Right: longitudinal section of the neck region of a Nguni cow crust leather

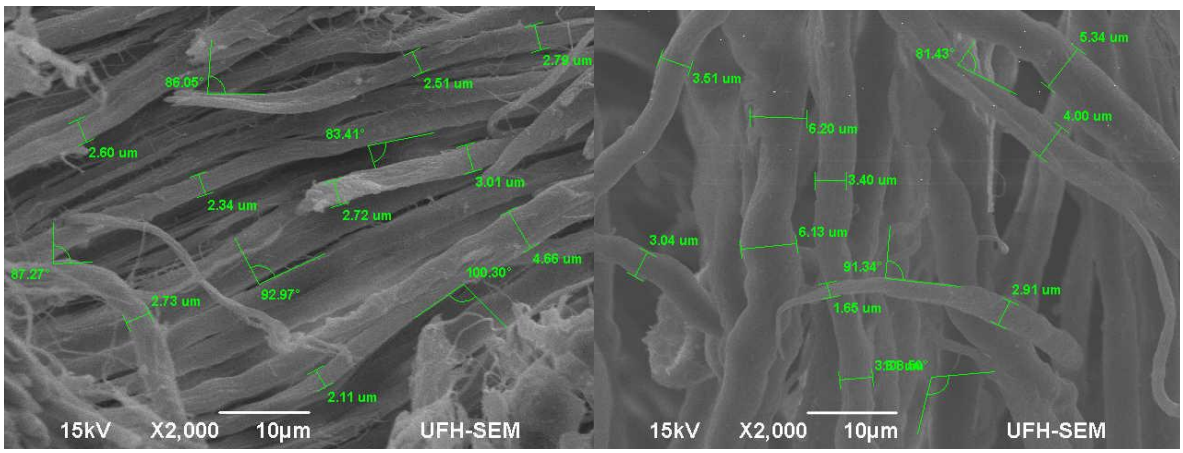


Image 19 Left: cross section of the belly region of a non-descript cow crust leather

Image 20: longitudinal section of the belly region of a non-descript cow crust leather

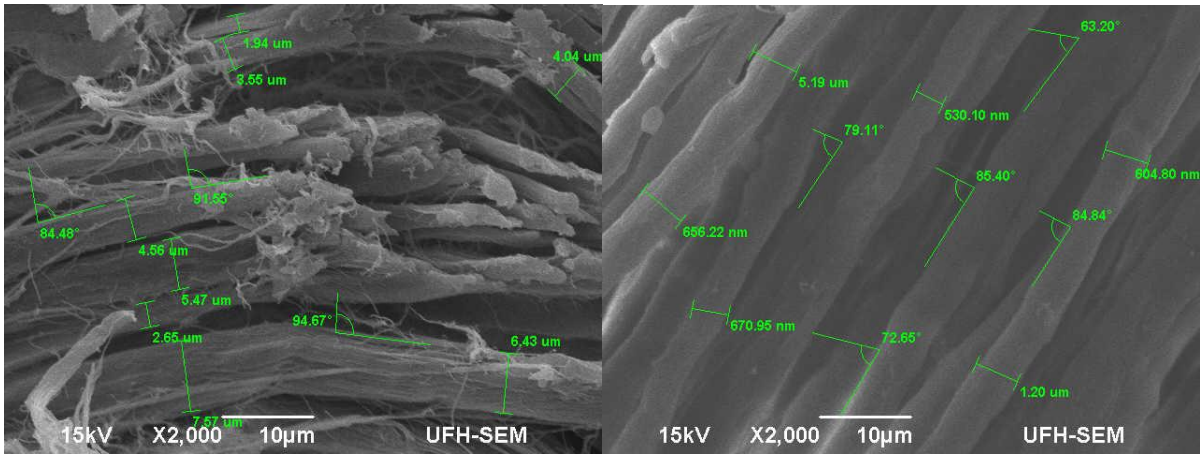


Image 21 Left: cross section of the butt region of a non-descript cow crust leather

Image 22: longitudinal section of the butt region of a non-descript cow crust leather

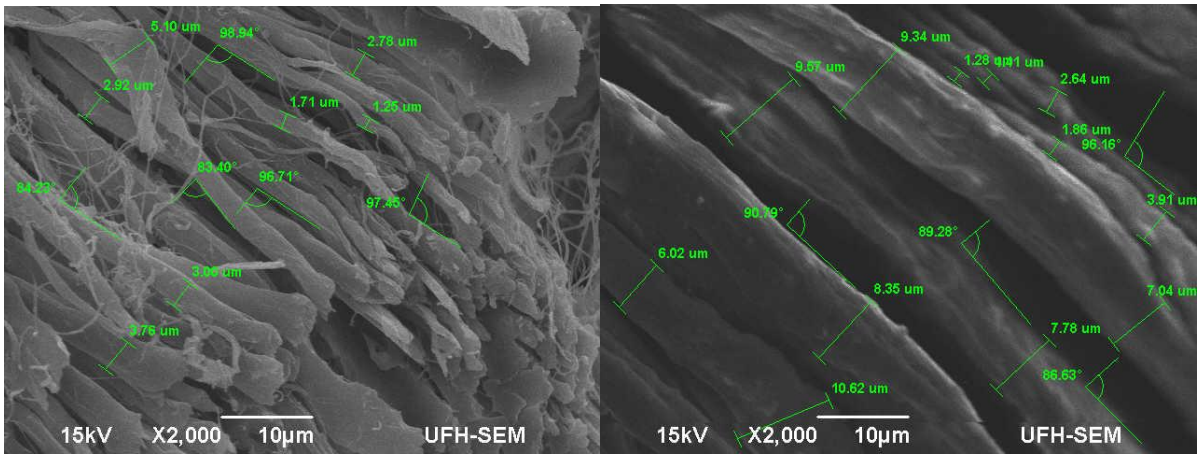


Image 23 Left: cross section of the neck region of a non-descript cow crust leather

Image 24: longitudinal section of the neck region of a non-descript cow crust leather

Appendix 5: Characteristics of hides from SEM images

Hide region	Sectioning direction (View)	Skin Characteristics			
		Nguni cow	**Non-descript cow**	**Non-descript heifer**	**Non-descript steer (ox)**
Belly	Cross section	• Anisotropic • Tightly packed • Low angle of weave • Stretched, almost straight • Left deflexion	• Anisotropic • Both tightly packed and loose fibres present • Tightly packed fibres are parallel to each other open up into loosely packed fibres	• Horizontal and vertically oriented fibres • Horizontal fibres tightly packed • Low angle of weave • Some loose fibres, high angle of weave • Interweaving with crimps	• Anisotropic • High interweaving • High angle of weave • Fibres extremely coiled up on themselves
	Longitudinal	• highly oriented • very wavy • high interweaving • mixture of both low angle and high angle of weave	• high angle of weave • Not very straight but have crimps • Criss-crossing	• Loosely arranged in layers that form a dense mesh-work • Single fibres loose but crimped and not very straight	• Loosely aligned, wavy collagen bundles • Aligned diagonally • interweaving
Butt	Cross section	• densely packed wavy fibres	• fibres aligned horizontal are wavy • densely packed • crimps observed in the vertically aligned fibres	• anisotropic • some vertically aligned and slanted, loose and interweaving • horizontally aligned fibres are in bundles of collagen fibres	• fibres are elongated and aligned horizontal • very low angle of weave
	Longitudinal	• Wavy pattern of horizontally aligned fibres running parallel to each other • Fibres highly oriented • Tightly packed • Low angle of weave • Not very elongated,	• Higher order hierarchy of macro-bundles vertically aligned • Fibres in macro-bundle tightly packed and parallel • Macro-bundles quite spaced from each	• Fibres highly oriented, criss-crossing and interweaving • Tightly packed • Low angle of weave • Highly crimped • anisotropic	• anisotropic • single loose fibres aligned in all directions • wavy • coiling • interweaving • forming a dense mesh of fibres

		somewhat undulating	other • Loose highly convoluted interweaving fibres embedded in supporting matrix • Loose fibres highly anisotropic		
Neck	Cross section	• Fibres densely packed but high anisotropic in some places	• Elongated but not very straight fibres • Originating from some point and radiating in all directions in a fan-like repeating pattern, angle of weave increasing at the fan spreads out	• Fibres densely packed parallel to each other • Most fibres are fused together and deeply embedded in the supporting matrix	• Wavy collagen fibres • Tightly packed, almost fused • Interweaving
	Longitudinal	• Anisotropic but parallel fibrils in each fibre bundle	• Bundles running parallel to each other in the horizontal plane • Tightly packed and deep waves and forming thick almost fused bundles	• High mesh • Loose fibres running at a diagonal angle • Wavy and highly crimped • High interweaving	• Anisotropic • Convoluting, not stretched • Criss-crossing