Interventions to enhance the quality of South African chevon

By

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Declaration

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Summary

Goat meat is not readily available commercially in South Africa, probable as preferences of the post-Apartheid new upcoming middle-class consumer is not yet taken into consideration. Historically, little is known about goat meat characteristics and perceptions exist that “indigenous” goats produce tougher meat than Boer Goats (BG), synthetically bred to be a meat producing breed making use of the original pure-bred large frame Indigenous Veld Goats (IVG) such as the Cape Lob Ear. With time, uncontrolled cross-breeding between BG with small frame “indigenous” goats increased and these small mostly monotonous white or white and brown goats, labelled “indigenous” and then perceived as too small and not suitable for meat production. Fortunately, some farmers conserved the original large frame IVG eco-types of Southern Africa and saved them from extinction. The aim of the study was to investigate interventions (castration and electrical stimulation) on carcass-, muscle- and meat characteristics of same-aged young wethers and bucks of BG and IVG (Cape Speckled and the Cape Lob Ear), to determine whether IVG could have a similar potential for quality meat production under the same production conditions. Goat muscles are small and forced the project to be performed in two phases to enable all envisaged analyses. The first phase described factors influencing tenderness, and colour attributes of six muscles. The second phase evaluated carcass characteristics, meat tenderness, the calpain system related to ageing, *pre-rigor* muscle energy profile, meat colour, the volatile profile, and resultant sensory characteristics. Outcomes were that wethers, compared to bucks had higher dressing %, subcutaneous fat % in all primal cuts, intramuscular fat (IMF) %, kidney fat % and, overall, slightly less bone %. Variations in meat characteristics such as pH, temperature, water holding capacity, % drip loss, myofibril fragment length, IMF, connective tissue characteristics, and Warner-Bratzler shear force (WBSF) between the muscles were found. The *Longissimus thoracis et lumborum* (LTL) had the highest shear force values (>40.0 N), followed by *Biceps femoris* (BF), *Semitendinosus* (ST), *Semimembranosus* (SM), *Supraspinatus* (SS), and *Infraspinatus* (IS). Bucks were less tender ($P \leq 0.05$) compared to wethers; calpastatin (higher values for bucks) could explain these sex-related differences for WBSF. Calpain-2 played a greater role in tenderisation suggesting that the activation of the system occurred at a later stage than in other species. The pH_u values >5.6 were linked with meat being darker (L* <31), having lower 24 hours *post-mortem* muscle glycogen (18 µmol/g) and lactate levels (25 µmol/mg). High initial lactate concentration, >35 µmol/g (LTL muscle) and low glycolytic potential (GP) (<94 µmol/g), suggested that goats suffered from both chronic and acute stress during *ante-mortem* handling. Overall, the scores for the various sensory attributes were low (<4.00 on a 1 to 8 scale), apart from goat aroma and goat-like flavour (>4.00). A total of fifteen volatile compounds were identified and quantified in the LTL and SM. The present study showed that it is important to use the correct *pre-* and *post-slaughter* conditions to process goats as incorrect procedures could give way to negative perceptions on this commodity.

Opsomming

Bokvleis is nie kommersieël geredelik beskikbaar in Suid-Afrika nie, waarskynlik omdat die post-Apartheid opkomende middelklasverbruiker nog nie in ag geneem word nie. Histories is daar min bekend oor bokvleiskenmerke en persepsies bestaan dat bokke oor die algemeen taaier vleis met onaangename reuke produseer. Nietemin is Boerbokke (BG) gedurende die 1900's sinteties geteel om 'n vleisproduserende ras te wees deur onderandere gebruik te maak van die oorspronklike groot raam Inheemse Veldbokke (IVG) en meer spesifiek die Kaapse Hang Oor. Met verloop van tyd het ongekontroleerde kruisteling tussen BG met kleinraam "inheemse" bokke toegeneem. Hierdie meestal wit- of wit- en bruin kleurige bokke, het verkeerdelik begin bekend staan as "inheemse" bokke en is beskou as minderwaardig vir vleisproduksie. Gelukkig het sommige boere die oorspronklike grootraam IVG eko-soorte van Suid-Afrika bewaar en hulle van uitwissing gered. Die doel van die studie was om intervensies te ondersoek (kastrasie en elektriese stimulering) op karkas- en vleiseienskappe van jong gekastreerde- en intakte ramme van dieselfde ouderdom van BG en IVG (Kaapse Spikkel en die Kaapse Hang Oor) om te bepaal of IVG onder dieselfde produksietoestande 'n soortgelyke potensiaal vir vleisproduksie van gehalte kan hê. Bokspiere is klein en dwing die projek om in twee fases uitgevoer te word om alle beoogde ontledings moontlik te maak. In die eerste fase word faktore beskryf wat die sagtheid en kleurkenmerke van ses spiere beïnvloed. Die tweede fase het die karkaskeienskappe, die sagtheid van die vleis, die kalpainstelsel wat verband hou met veroudering, *voor-rigor* spierenergieprofiel, vleiskleur, die vlugtige vetsuur profiel en die gevolglike sensoriese eienskappe beoordeel. Die resultate toon dat kastrate in vergelyking met die intakte ramme, hoër uitslag %, onderhuidse vet % in alle primêre snitte, binnespierse vet (IMF) %, niervet % en, in die algeheel effens laer been % gehad het. Variasies in vleiskenmerke soos pH, temperatuur, waterhouvermoë, % drupverlies, myofibril-fragmentasie-lengte, IMF, bindweefselkenmerke en Warner-Bratzler-skeurkrag (WBSF) tussen die spiere is gevind. Die *Longissimus thoracis et lumborum* (LTL) het die hoogste skeurkragwaardes (>40.0 N) gehad, gevolg deur *Biceps femoris* (BF), *Semitendinosus* (ST), *Semimembranosus* (SM), *Supraspinatus* (SS) en *Infraspinatus* (IS). Intakte ramme was taaier ($P \leq 0.05$) in vergelyking met kastrate; kalpastatien (hoër waardes vir intakte ramme) kon hierdie geslagsverwante verskille vir WBSF verklaar. Kalpaïen-2 het 'n groter rol gespeel in die versagtings proses, wat daarop dui dat die aktivering van die stelsel op 'n later stadium plaasgevind het as in ander spesies. Die pH_u-waardes >5.6 was gekoppel daaraan dat vleis donkerder was (L* <31), met 'n laer 24 uur spierglikogeen (18 µmol/g) en laktaatvlakke (25 µmol/mg). Hoë aanvanklike laktaatkonsentrasie, >35 µmol/g (LTL-spier) en lae glykolitiese potensiaal (GP) (<94 µmol/g), het voorgestel dat bokke tydens kroniese en akute spanning aan kroniese en akute spanning kon gely het. In die algeheel was die waardes vir die verskillende sensoriese eienskappe laag (<4.00 op 'n skaal van 1 tot 8), afgesien van bok-aroma en bok-smaak (>4.00). Altesaam vyftien vlugtige vetsure is geïdentifiseer en gekwantifiseer in die LTL en SM. Die huidige studie het getoon dat dit belangrik is om die regte

voor- en na-slag prosedures te gebruik om bokke te prosesseer, aangesien verkeerde prosedures negatiewe persepsies oor hierdie kommoditeit kan ondersteun.

This dissertation is dedicated to:

MY FAMILY

A person's own family is, without doubt, the greatest wealth that we will ever possess. Treasure every moment and take the time to ensure that the story you create is one that you will be proud of and look back on with a huge smile - *Untitled*

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Preface

This thesis is presented in the format prescribed by the Department of Animal Science, Stellenbosch University. The language, style and referencing used are as per the *Meat Science* Journal. This thesis is a compilation of individual chapters and some degree of repetition is inevitable, especially in terms of the materials and methods sections and the reference lists.

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Author contributions:

Dr. L. Frylinck, Prof. P.E. Strydom and Prof L.C. Hoffman were responsible for conceptualization. G.L. van Wyk was responsible for methodology, formal analysis, investigation, and writing the original draft preparation.

Dr. L. Frylinck, Prof. P.E. Strydom and Prof. L.C. Hoffman were responsible for reviewing and editing.

Dr. L. Frylinck was responsible for recourses, supervision, project administration, and funding acquisition.

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List of Abbreviations

- ARC = Agriculture Research Council
- ARC-AP = Agricultural Research Council - Animal Production
- ATP = Adenosine-triphosphate
- B = Bucks
- BB = Boer Goat Bucks
- BBES = Electrical Stimulated Boer Goat Carcasses of Bucks
- BBNS = No-Stimulated Boer Goat Carcasses of Bucks
- BBQ = Barbeque
- BCFA = Branched-chain fatty acids
- BF = *Biceps femoris*
- BG = Boer Goats
- BW = Boer Goat Wethers
- BWES = Electrical Stimulated Boer Goat Carcasses of Wethers
- BWNS = No-Stimulated Boer Goat Carcasses of Wethers
- CAF = Central Analytical Facility
- Car = Carboxen
- CCW = Cold carcass weight
- CP = Creatine-phosphate
- DAFF = Department of Agriculture, Forestry and Fisheries
- DFD = Dark, firm and dry
- DL = Drip loss
- DP = Dressing percentage
- DSA = Descriptive sensory attributes
- DVB = Divinylbenzene
- EMA = Eye muscle area
- ES = Electrical stimulation
- FAO = Food and Agriculture Organization
- GC = Gas chromatograph
- GP = Glycolytic potential
- G6P = Glucose-6-phosphate
- HCW = Hot carcass weight
- IB = Large frame Indigenous Veld Goat Bucks
- IBES = Electrical Stimulated Large frame Indigenous Veld Goat Carcasses of Bucks
- IBNS = No-Stimulated Large frame Indigenous Veld Goat Carcasses of Bucks
- IMF = Intramuscular fat
- IF = *Infraspinatus*
- IVG = Indigenous Veld Goats
- IS = *Infraspinatus*
- IW = Large frame Indigenous Veld Goat Wethers
- IWES = Electrical Stimulated Large frame Indigenous Veld Goat Carcasses of Wethers
- IWNS = No-Stimulated Large frame Indigenous Veld Goat Carcasses of Wethers
- LD = *Longissimus dorsi*
- LTL = *Longissimus thoracis et lumborum*
- LW = live weight
- Mb = Myoglobin
- MFL = Myofibril fragment length
- MRA = Metmyoglobin reducing activity
- N = Newton
- NERPO = National Emergent Red Meat Producers' Organisation
- NS = No-stimulation

- PCA = Principal component analysis
- PSE = Pale soft exudative
- PDMS = Polydimethylsiloxane
- pH_u = Ultimate pH
- *pm* = *Post-mortem*
- PM = *Psoas major*
- SACCSS = South African Carcass Classification for Small Stock
- SCF = Subcutaneous fat
- SE = Standard Error
- SEA = Small East African
- SL = Sarcomere length
- SM = *Semimembranosus*
- SS = *Supraspinatus*
- ST = *Semitendinosus*
- r = Correlation coefficient
- RPM = Revolutions per minute
- TB = *Triceps Brachii*
- T_u = Temperature at 24 hours *post-mortem*
- UFA = Unsaturated fatty acids
- USA = United States of America
- VIA = Video image analysis
- W = Wethers
- WBSF = Warner-Bratzler shear force
- WHC = Water holding capacity

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CHAPTER 1

General Introduction

Goats were among the first farm animals to be domesticated. As indicated by the archaeological evidence, they have been associated with man in a symbiotic relationship for up to 10,000 years (Ensminger and Parker, 1986). Goats disseminated all over the world because their great adaptability to varying environmental conditions and the different nutritional regimes under which they were evolved and subsequently maintained. They proved useful to man throughout the ages due to their productivity. In the developing countries, goats make a very valuable contribution, especially to the poor in the rural areas. The importance of this valuable genetic resource is underestimated and its extent of contribution to the livelihood of the poor is inadequately understood (Visser, 2019). Research and development investments to improve the relatively low level of goat's productivity do not match their potential importance, resulting in many goat breeds that are not genetically explored, especially in the developing countries. Nevertheless, goats are going to be a more important source of livelihood for many more people in coming years as a protein source (Mazhangara *et al*., 2019). They are often neglected in comparison with cattle and sheep from a research and productivity point of view. Part of this attitude towards them can probably be due to a recognition of their capability, rather any prejudice against them, as it is believed that goats are intelligent, independent, agile, and tolerant to many diseases and parasites and can look after themselves much better than other livestock species. However, many misperceptions exist also around these animals and their meat products. For instance, although we are used to the term "goat meat" (which in some cultures in Southern Africa have a negative perception), market research in the United States suggests that "chevon" is more palatable to consumers than "goat meat". This is the term for meat from adult goats and cabrito, capretto, or kid then come from young animals which producers and marketers may prefer (Webb *et al*., 2005; Sayer, 2010).

Although goats generally have a positive meaning in the Bible, some scripture in the Bible and in related extra-biblical literature provide a basis for the common association of goats with evil. One of the most important examples of this in the New Testament, in Matthew 25:31 - 46 (Tyndale House, New Living Translation Study Bible, 2008) is where Jesus speaks of the judgment of the nation's using the imagery of sheep and goats: "When the Son of Man comes in his glory, and all the angels with him, he will sit on his glorious throne. All the nations will be gathered before him, and he will separate the people one from another as a shepherd separates the sheep from the goats. He will put the sheep on his right and the goats on his left", (Matthew 25:31 - 33, Tyndale House, New Living Translation Study Bible, 2008). The king then praises the sheep for doing good deeds for him by doing them for "the least of his brothers and sisters" (verse 40) and condemns the goats for failing to do good deeds for him by failing to do them for "the least of these" (verse 45). Then he concludes: Then they (the goats) will go away to eternal punishment, but the righteous (the sheep) to eternal

life. (Matthew 25:46, Tyndale House, New Living Translation Study Bible, 2008). Because Jesus here uses goats as symbols of evil people who fail to do good deeds for God and the neighbour, in Christianity goats have also commonly been associated with evil. This association of goats with evil is not to the advantage of the marketing of goat meat especially among Christians.

Nonetheless, currently consumer concern about the quality of the food that they eat and its impact on their health are increasing. Furthermore, chevon has long been touted as healthy meat because of its low carcass fat content, which generally has a fatty acid profile deemed to be healthy. There is potential to grow the chevon market especially if the meat is marketed as a product of acceptable quality from the outset. Little effort has however been made to promote chevon production in Southern Africa despite there being the potential to develop a market for this product (e.g., USAID/South Africa and ARC, 1998; Simela *et al.*, 2008) or to adopt slaughter procedures to suit the characteristics of goats and their carcasses, such as the low glycolytic potential and low carcass fat. There is therefore a need to optimise the slaughtering procedures in order to optimise the chevon visual and eating quality. Development of the market for chevon in Southern Africa would offer more diversity of species for red meat producers and especially benefit emerging farmers who produce over 90 % of the goats in Southern Africa. This will also promote food security in rural communities and eradicate malnutrition.

Some factors that favour goat production are:

- Under the current South African land reform program, there has been an increase in the number of small livestock farms of 50 to 400 hectares (Cliffe, 2000). These farm units are too small to run economically viable beef enterprises but would probably increase in profitability under small stock production. In fact, of late some smallholder farmers who borrow money from the National Emergent Red Meat Producers' Organisation (NERPO) Livestock Credit Scheme have realised that it is easier for them to build an asset base by starting off with small ruminants (goats and sheep) because of the higher rate of turnover of these species that enables them to pay off their loans faster.
- Bush encroachment has increased over vast sections of grazing land in South Africa, especially in the Eastern Cape, North West and Limpopo provinces. Ward (2005) estimated that up to 20 million hectares could be affected by bush encroachment. Such land becomes impenetrable to beef cattle but goats are able to utilise the bush because they tend to browse more than graze.
- On communally managed land, human settlements have taken over large portions of land, leaving very little for agricultural production. Consequently, the available grazing land tends to be overstocked predominately with cattle, which do not survive the harsh dry periods well. Goats are hardy animals and able to select nutritious feed even in difficult times, such as the dry season (Ndlovu *et al.*, 2000) and are therefore comparatively able to survive harsher

environments compared to cattle. For that reason, goats could be alternative species that farmers could shift to in adaptation to climate changes that result in more inclement production conditions.

- Most of the goat breeds of South Africa belong to the large Southern African breed types that yield heavy carcasses of ~30 kg, and hence are suitable for meat production (Simela and Merkel, 2008).
- Development of a market for chevon in Southern Africa would offer diversity of species for red meat producers and especially benefit emerging farmers who produce over 90 % of the goats.

Conditions that favour the development of a sustainable market for chevon are as follows:

- The consumer is increasingly concerned about the quality of the food that they eat and its impact on their health. Goat meat is generally lean and hence could meet the demands of the discerning consumer.
- The migrant populations in Southern Africa as well as the local Indian / Asian population, some of whom have a culture of consuming chevon on a regular basis. The estimated proportion of foreigners in South Africa for the period 1990 to 2010 was at 3 to 4 % of the national population (Polzer, 2010) while the local Indian/Asian origin population makes up 2.6 % of the population during 2019 (Statistics South Africa, 2019).
- The example of the growth of the ostrich meat industry, which has progressed from being a by-product of the ostrich feather and leather industry to a commodity in its own right. As well as the growth in venison/game meat production (e.g., from 22,100 tonnes in 1990 to 46, 288 tonnes in 2018 in Southern Africa (FAOSTAT, 2019) attests to the potential space in the meat market that could be partly filled in by alternative meat sources such as chevon.
- There are good indications that goats can yield chevon of acceptable quality to consumers, provided that animals of an appropriate age and sex group are slaughtered and handled sufficient during slaughter to minimise *pre-slaughter* stress and prevent cold shortening (Simela *et al*., 2004a; Simela *et al*., 2004b; Webb *et al*., 2005; Simela *et al*., 2008). Research conducted to date suggests that the current slaughter procedures that are employed are not conducive for the production of chevon of acceptable quality because they do not take into consideration that goats generally have a low glycolytic potential at slaughter (Kannan *et al*., 2003; Simela *et al*., 2004a).
- In Southern Africa, recorded data on the consumption of goat meat is minimal, as most of the slaughtering processes are informally done and consumption currently is purely for ceremonial purposes. Commercialization of chevon production, by increasing the percentage slaughtered in the formal sector has the potential to increase income generated from goats. More attention should be given to the promotion of chevon and market development to

increase consumer demand and to encourage stock farmers to farm with goats rather than just to keep them.

Considering that there are emerging markets for goat meat in South Africa, there is need for new studies to evaluate the quality of goat meat between the commercial breeds, according to the recommended slaughtering technologies and consumer demands. Indigenous goats were classified historically under one umbrella although they consist of a variety of breeds (Visser, 2019). Currently their performance is underestimated, and it is even more important to identify the different eco-types and study them in more detail to access their potential in becoming a commercial commodity.

For this reason, there is a need to investigate and compare the carcass characteristics of same-aged young wethers and bucks of Boer Goat (BG) and large frame Indigenous Veld Goats (IVG: Cape Speckled and the Cape Lob Ear) - a collective name for the eco-types conserved by the Indigenous Veld Goat Society of South Africa (https://www.indigenousveldgoats.co.za, accessed, 1 January 2021), as to determine if IVG could have a similar potential for meat production under the same production condition. The information generated will not only support our current knowledge on goat meat characteristics and meat quality on the effect of *pre-slaughter* (castration) and *post-slaughter* procedures (electrical stimulation (ES) vs. no-stimulation (NS)), but further expand our knowledge as the current study is a first to provide more insight on the calpain system related to ageing; volatile profile, resultant sensory characteristics and characterising different muscles in BG and IVG. Through the years, scientists have completed studies that included many muscles in few animals as well as few muscles over many animals. The knowledge of the relative palatability and rank of an individual muscle can serve as a resource at the retail and food service establishment to better meet consumers' demands. Furthermore, it can aid processors and product development specialists in identifying additional muscles suitablebly for value-added processing and possibilities for acceptable muscle substitutions. The results of this ranking can be utilized by all sectors of the meat industry to ultimately provide an improved product for the consumer.

1.1. Research objectives for this PhD study

Objective of Phase 1: To characterise six muscles (e.g., *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS); and *Semitendinosus* (ST)) of large frame Indigenous Veld Goat (Cape Lob Ear and / or Cape Speckled) and Boer Goat wethers and bucks of Southern Africa with regards to collagen, tenderness, colour, and water holding capacity characteristics (Chapter 4).

Objectives of Phase 2: To evaluate the effect of breed-types and castration on carcass characteristics of Boer- and large frame Indigenous Veld Goats (Cape Lob Ear or Cape Speckled) of Southern Africa (Chapter 3); to evaluate the effect of breed-types; large frame Indigenous Veld Goats (Cape Lob Ear or Cape Speckled) and Boer Goats of Southern Africa, castration and electrical stimulation on meat tenderness and calpain system related ageing of *Longissimus thoracis et*

lumborum and *Semimembranosus muscles* (Chapter 5); to evaluate the effect of breed-types (large frame Indigenous Veld Goat and Boer Goat), sex-types and electrical stimulation on the *pre-rigor* muscle energy profile and meat colour of *Longissimus thoracis et lumborum* and *Semimembranosus* muscles (Chapter 6) and to determine the effect of breed-types; large frame Indigenous Veld Goats (Cape Lob Ear or Cape Speckled) and Boer Goats of Southern Africa, castration and electrical stimulation on volatile profile and resultant sensory characteristics (Chapter 7).

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CHAPTER 2

Literature review

Goat meat production: Undervalued healthy red meat source

2.1. Introduction

Although global warming has become a reality (NOAA, 2019), the current Covid-19 pandemic has forced governments and communities to confront the reality of poverty of families struggling to survive physically and mentally under lock down conditions. One of the major challenges faced by these families, particularly in developing countries, is to readily gain access to meat as a protein source. Dobersek *et al.* (2020) reviewed eighteen scientific studies on the effect of meat abstention on depression, anxiety and related psychological sicknesses and concluded that meat should not be avoided if psychological health is a concern. To alleviate hunger, the emphasis is currently on communities growing their own food and processing their own protein source. Meat is one of the most important food sources in the world and in some countries, it is considered an essential product with very high consumption rates (Guerero *et al.,* 2013). In 2020 the world population is reported to be close to 7.8 billion, with an annual increase of 1.05 % and is expected to reach nine billion by 2050 (www.worldometers.info, accessed August 25, 2020). This huge increase in population is envisaged to further increase the already high demand for meat and other animal-derived products for human consumption (Thornton, 2010; Henchion *et al.,* 2014; Henchion *et al.,* 2017). In order to be able to meet the increased demand, there is the need for sustainable and efficient meat production. This population-mediated increase in the demand of animal-derived protein for human consumption creates a significant potential for goats, which are known to thrive in marginal areas (Aziz, 2010). Compared to cattle, sheep, pigs and poultry, less scientific investment has been made towards improving the productivity of goats (Dhanda *et al.,* 2003).

2.2. Origin of goats

Goats were one of the earliest animals to be domesticated (Normura *et al.,* 2013). The first record of their domestication dates back approximately 10 000 years to where their wild ancestor occurred in South-Western Asia from the Eastern Mediterranean to Turkey and the adjacent Eastern regions. The ancestor of the modern goat was the Bezoar goat, *Capra aegagrus* (Reitz and Wing 1999; Visser, 2019). The earliest records of domestic goats in Africa can be found in Egypt and North Africa. Little is however known about the actual breeds, but differences in horn shapes indicate that two or more breeds could have been present (Roets, 2004). Goats were ideally suited to the requirements of early farmers and the animal dispersed rapidly to Europe, Asia and North Africa. This dispersal was facilitated by their toleration of extreme environmental conditions ranging from the tropical regions with high humidity, to semi-desert aridity (Visser, 2019). To this day they survive

in degraded environments as they are browsers that can utilize all types of vegetation and can also excavate roots and bulbs. Due to this ability to survive in poor environments they are often incorrectly accused of being the main cause of environmental degradation. Natural selection has made the goats very hardy, and they have a tolerance towards the diseases and parasites present in their habitats (Reitz and Wing 1999; Visser, 2019).

2.2.1. World goat population

Galal (2005) assessed biodiversity in the global goat scenario and noted that despite developing countries harbour 96 % of the world goat population, only 60 % of the breeds are found in these countries. In terms of performance traits, Europe has the heaviest goat breeds with largest litter sizes and milk production, while Latin America and the Caribbean rank lowest in all these performance traits. Breed variability indicated lowest in Europe compared to highest in Africa (Galal, 2005). Galal (2005) concluded that according to available information, biodiversity in the goat is similar to that of other farm animal species. Many goat breeds are however not characterized as most goats and breeds are in developing countries and / or under extensive production systems where characterization becomes more demanding, expensive and of less value to producers. The bulk of the world's goat population is found in South-East Asia and Africa, where goats are the major source of meat production (Dhanda *et al*., 2003). World goat numbers and its evolution is presented in Figure 2.1.

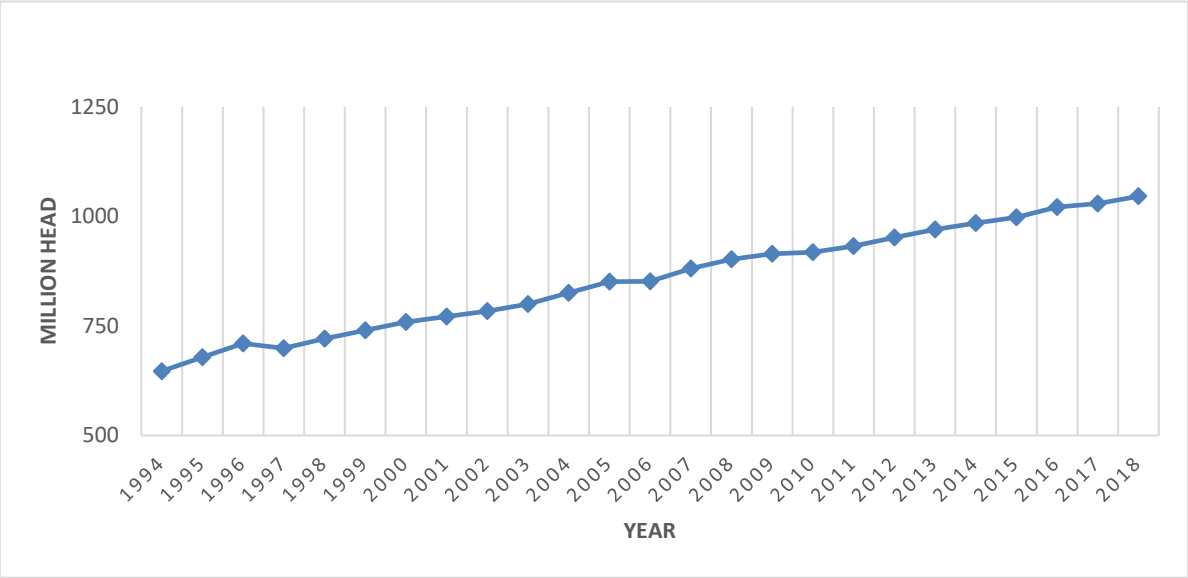

Figure 2.1. World goat population (FAOSTAT, 2020).

The goat population reached the 1 billion head mark during 2016. For the period 2012 - 2018 an increase in goat numbers worldwide (9.87 % or an average 1.7 % per year) was recorded. The world sheep population during the same period only increased by 7.9 % (FAOSTAT, 2020). Considering goat distribution, amongst the continents, Asia has the most goats contributing to the total goat

population by 57 %, Africa has the second highest number (36 %), followed by the Americas, Europe and Oceania respectively (Figure 2.2).

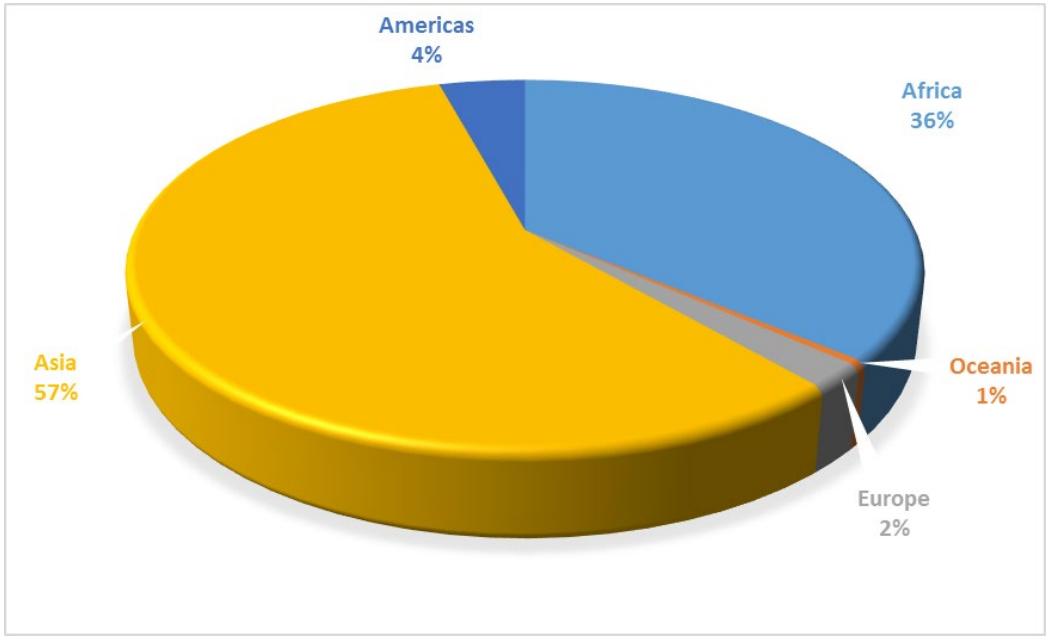

Figure 2.2. Production share of goats per region (FAOSTAT, 2020).

In Africa, the largest goat populations can be found in Nigeria, Chad, Ethiopia, Sudan, and Kenya, with South Africa ranking at position 20 (FAOSTAT, 2020).

2.2.2. Meat goat breeds

Goats reared for chevon constitute a major part of the global goat population (Skapetas and Bampidis, 2016). Several goat breeds are used for chevon production. In New Zealand, the low maintenance Kiko goat is known for its lean meat (Skapetas and Bampidis, 2016) whilst the Black Bengals of Bangladesh are known to be excellent in producing quality meat (Amin *et al*., 2000). The Anglo-Nubian goat however is used as a dual-purpose breed for milk and meat production (Skapetas and Bampidis, 2016). Despite the fact that over the last decade, among livestock, goats have had the largest numerical increase, the goat production industry is still characterized by a lack of organized selection programs in most areas particularly in the developing world (Dubeuf and Boyazoglu, 2009). In developing countries goats are mainly bred randomly with very limited if any dedicated selection programs. However, due to the availability of only a few well characterized breeds for meat production, there is a high potential in these developing countries to select and exploit some of the unimproved goat genetic potential. In addition to limited selection, goat production in these developing countries is mostly typified by an extensive production system and poor record keeping (Visser, 2019). Formally, there were seven goat breeds that were officially recognized by the Animal Improvement Act No. 62 of 1998 (USAID/South Africa, 1998) in South Africa These included the Angora goat for mohair production, three meat types, namely the Boer,

Kalahari Red and Savanna breeds and three dairy breeds consisting of the Saanen, Toggenburg and British Alpine. Besides these recognized goat breeds, South Africa has a large variety of indigenous or unimproved types that contribute towards meat, hides and milk to smallholders and subsistence farmers (Mahanjana and Cronje, 2000). Fortunately, some farmers did conserve some of the original eco-types from which the Cape Speckled and the Cape Lob Ear are two and which were recently formally registered as Indigenous Veld Goats (IVG) – a collective name for the eco-types conserved by the Indigenous Veld Goat Society of South Africa (https://www.indigenousveldgoats.co.za, accessed, 1 January 2021).

2.2.2.1. Boer Goat

The origins of the “Boer Goat” are somewhat vague and are most probably rooted in the animals kept by the Namaqua Hottentots and migrating tribes of the “Southern Bantu” people (Campbell, 1984). Casey and Van Niekerk, (1988) suggested that Boer Goats (BG) originated through a selection process from various existing indigenous goat breeds in Southern Africa and European stock and therefore bears some resemblance to indigenous goats. As stock farmers became more settled and began selecting animals adapted to the distinct characteristic of the Eastern Cape (1800 to 1820), the common Boer or farm goat evolved, which was described as compact, well-proportioned and short-haired (Van Rensburg, 1938). Around 1930, breeders in the Bedford and Somerset-East areas started a more intensive breeding and selection program to improve their goats. Their aims were to breed a more uniform goat with excellent meat characteristics, growth performance and fertility. Empisas was still to remain its hardiness and adaptability. A breeder society was established during 1959 (Snyman, 2014b) and later, more scientific practices were applied to improve the breed. Casey and Webb (2010) reported that since 1970, the National Goat Performance Testing Scheme was applied to the BG breed and assesses:

- The dam’s characteristics, her milk production and pre-weaning growth rate of her progeny.
- The post weaning growth of progeny at various ages.
- The feed conversion efficiency and body weight of male progeny under standardized conditions.
- The post-weaning growth of male progeny under standardised conditions.
- The qualitative and quantitative carcass components of a sire’s progeny.

The system of performance testing has shown its merit to select both male and female breeding stock and is currently applied by commercial producers. This principle should be encouraged among small-scale producers (Casey and Webb, 2010). Presently, the BG is bred and farmed world-wide and is the major goat breed slaughtered in formal registered abattoirs in South Africa.

2.2.2.2. Indigenous goat breeds

Numerous breeds and unspecified eco-types contribute to the more than 33 million goats found in Southern Africa. Indigenous goat is the collective term used for all varieties of native Southern African breeds. Specific breed names are usually given according to the geographical areas in which they occur, or names of breeds and types are taken over from the nations or tribes that own them (Maree and Plug, 1993; Roets, 2004). The general appearance of these goats tends to support theories that they originated in different ecosystems and specific types have been fairly accurately described for Southern Africa (Table 2.1). Although there are highly specialised breeds, most of them are dual- or multi-purpose and in many cases, village flocks are of mixed breeds (Dombo *et al.,* 1999). The history of the BG resulted in that the "indigenous" goat eco-types were either crossed with BG (Campbell, 2003), resulting in limited pure original eco-types remaining. The remaining "indigenous" were mostly of lower quality and thus perceived negatively. The indigenous veld-type goats have been subjected to limited selection and are largely unimproved genotypes (Visser and Van Marle-Köster, 2018; Visser, 2019). Genetic improvement of small stock in South Africa can largely be attributed to the research performed over many decades in official research and prestige flocks. Of the goat breeds, most of the genetic improvement occurred in the Angora goat due to the high economic value of mohair and South Africa being one of the largest producers of mohair in the world (DAFF, 2017). The poor participation in the National Small Stock Improvement Scheme (NSIS) by the meat and dairy goat breeders limits the potential genetic improvement, as limited phenotypic and pedigree recording occurs. Some farmers realised that the original eco-types were being bred out of existence and so the Indigenous Veld Goat Breeders' Society was founded with strict rules to conserve the original genetics to the best of their abilities and with it, conserve their unique appearance and perceived hardiness among other traits. This Society's moto is "do not spoil, transform or improve them out of existence". Some of these natural indigenous eco-types almost disappeared with the purifying of the BG (www.indigenousveldgoats.co.za; Eco-types, accessed, 1 January 2021). From the four recognised eco-types (Table 2.2; Snyman, 2014a), the Indigenous Veld Goat Breeders' Society are conserving two eco-types that have similar frame size to the BG especially at the 0-tooth age stage e.g., Cape Lob Ear and Cape Speckled. These eco-types' hardiness make them ideal for start-up smallholder farming systems and global warming adaption (Ramsay *et al.,* 1987). A renewed interest is being experienced for the disease-resistant and hardy indigenous goats that are not only part of South Africa's unique heritage but can also play an increasing part in maintaining societies in the future. As the demand for goat meat in Southern Africa increases, the quality of animals being bred and the interest to farm with the most prevalent and purebred large frame indigenous goats such as the Cape Lob Eared and Cape Speckled increases in parallel with the better-known synthetic breed, the BG.

Table 2.1. The major indigenous meat goat breeds found in Southern Africa (adapted from Visser, 2019).

Breed	Description	Country
Angola dwarf	Similar to the small East African meat goat.	Angola
Tswana	Relatively large size, flat forehead; multi-coloured medium-sized with long lopping ears, short coarse hair.	Botswana, Zambia, Zimbabwe
Small East African	Heavyset formation, short-coated goat; black-and-white colour pattern, less frequently brown or black coat.	Lesotho
Malawi	Relatively small; coat colour is variable, with black, black-brown, brown-red and white being very common	Malawi
Damara	Long, wide and pendulous ears; coat hair is commonly short, and usually white, red-and-white or brown-and-white	Malawi, Namibia
Pafuri	Large body size; lopped or semi-lopped ears; males and females are bearded; variable coat colour; short coat hair.	Mozambique
Landim	Relatively large; variable coat colour, but commonly dark brown, black, pied, white, yellow and mixed; coat hair usually short and fine.	Mozambique
Nguni type (Mbuzi)	Relatively large; flabby ears; short coat hair (males can have long hair on upper part of the extremities); variable coat colour.	Namibia
Hottentot	Display characteristics of the Damara	Namibia
Small East African	Heavyset, short-coated goat. Black-and-white colour pattern, less frequently by a brown or black coat.	Namibia
Northern Cape speckled	Speckled goats with lob ears	Namibia, South Africa
Eastern Cape lob-eared	Multi-coloured with lob ears	Namibia, South Africa
Kunene-type / Kaokoland	Multi-coloured with lob ears	Namibia, South Africa
Tankwa (feral)	High degree of variation in colour and appearance; longer haired; coat colours include black, red, white and grey, mixed with spotted, dappled and tricolour.	South Africa
Nguni	Fairly large in body size; flabby ears; short coat (males can have long hair on upper part of the extremities); black, white, yellow, grey in plain or mixed pattern coats	South Africa, Swaziland
Swazi	Relatively large in size; medium-long, broad and lopped ears are; variable coat colour but whole colours of grey, black and white predominate.	South Africa, Swaziland
Zulu	Relatively large in size, medium long, broad and lopped ears; coat colour is variable, variable coat colour but whole colours of grey, black and white predominate	South Africa
Small East African	Heavyset formation, short-coated goat. Black-and-white colour pattern, less frequently by a brown or black coat.	Zambia
Berber	Variations in coat colour, form and length of the ears, form and shape of the horns and hair length.	Zambia
Matebele	Large body size; similar to Tswana goats.	Zambia, Zimbabwe
Mashona	Small-framed type goat	Zambia, Zimbabwe

Table 2.2. Various eco-types of Indigenous Veld Goats in South Africa (adapted from Snyman, 2014a; www.indigenousveldgoats.co.za, Eco-types).

Eco-types		Body	Leg	Colour	Head & Profile	Ears	Horns
Nguni type (Mbuzi)		Small frame, compact, well proportioned	Strong, fine, medium to long	Multi uniformed colour, pied, dappled, speckled, tendency for Swiss markings	Concaved (hollow) to flat	Small to medium, semi-pendulous lateral (sidelong and outwards)	Upwards and outwards with many variations
Cape Speckled		Large frame, well-muscled	Strong, medium to long, colours are concentrated too almost solid	White body with red-brown or black sports. Concentrations of spots vary	Convex to flat, rather long with slight dip in front of the eyes	Lobed, large and droopy	Upwards and outwards with tips curving in, more or less the same length as the skull
Kunene Type (Kaokoland)		Medium frame, slender	Finely boned, lanky, excellent walkers	Multi uniformed colours, two toned, pied, speckled and dappled	Flat to slightly convex, narrow face	Lobed, long and droopy. Usually more narrow than other eco-types	Slightly up and a little outwards, usually of head and in line with profile. Base is closely spaced
Cape Lob Ears		Large frame, robust, well-muscled	Strong, medium to long	Multi-coloured, uniformed colours dappled marble and flowery patterns, even speckled	Flat to slightly convex (bulging) rather long and strong	Lobed, large and droopy	Large upwards and outwards, inclined to be larger than the skull

2.3. Goat production systems

Goat meat production is a commercial enterprise in only a few countries in the world including Southern Africa (Botswana, Namibia and South Africa), the Southern states of the USA and Mexico (Casey and Webb, 2010) whilst Australia is the world's largest exporter of goat meat. As in most developed markets, goat meat is a niche protein in Australia, with approximately 10 % of production utilised domestically (www.mla.com.au, accessed 10 April 2021) Among reasons why consumers don't buy goat, cultural familiarity is a key factor, with 47 % of consumers indicates that they did not grow up eating goat or are not familiar with it. Australia has approximately 3.6 million goats and in 2017 the goat industry was worth over $257 million, with approximately 2.07 million head slaughtered (www.mla.com.au, accessed 10 April 2021). During 2018 Australian goat slaughter reduced to 1.65 million head due to persistent poor seasonal conditions. Australian goat meat is almost exclusively (98 %) exported as a frozen whole carcass (www.mla.com.au, accessed 10 April 2021). The USA remains the largest market for boxed goat meat, accounting for 68 % of exports by volume in 2018 (FAOSTAT, 2020). Taiwan, Trinidad and Tobago, South Korea and Canada are also consistent importers of Australian boxed goat meat, while Malaysia is the main destination for live trade (FAOSTAT, 2020). Even though the number of goats found in Southern African countries are small relative to worldwide numbers, they still play an integral part in reducing poverty and increasing food security, especially in subsistence farming systems (Visser, 2019). Goat farming in Southern Africa is aimed at subsistence farmers in rural areas, stud breeders, mohair producers, dairy farms and commercial meat farmers. Meat goat farming mainly consists of mixed cropping-livestock systems in rural areas where goats have to provide milk, dairy products, and meat (Casey and Webb, 2010), of which meat is the main product. Braker *et al.* (2002) concluded that the differences in production systems among different communities become clear when the main features of goat production, namely the reasons for keeping goats, (herd size, kidding percentage, inputs, labour, cash outputs, product utilisation, social obligations, and losses) are evaluated. The importance of these communal goats in terms of food security and the alleviation of poverty is emphasised in almost every research paper on smallholder goat production in Southern African countries (Visser, 2019).

2.4. Goat meat industry

For centuries, humans have used goats for many purposes (milk, meat, fibre, skin and even work) under various conditions. Goat meat is widely consumed around the world but remains a relative niche protein and is in demand only among key ethnic segments. Per capita consumption varies greatly between countries and is largely underpinned by local production as well as tradition (FAOSTAT, 2020). The top ten countries for goat production are presented in Figure 2.3, with China and India the main contributors.

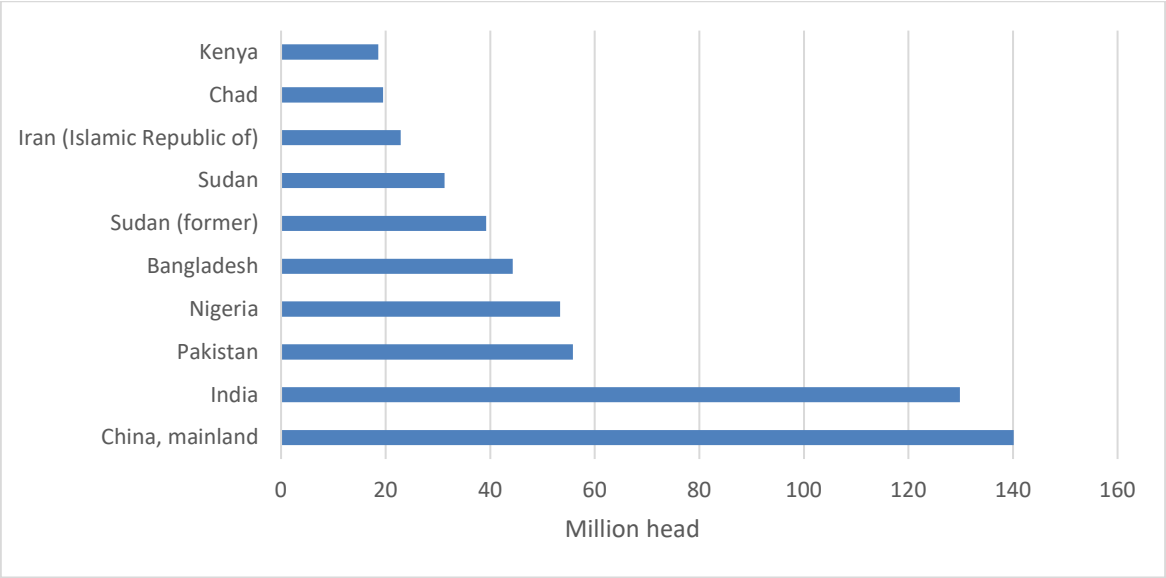

Figure 2.3. Production of goats: the top ten producers (Period 1994 – 2018); (FAOSTAT, 2020).

A global overlook of the goat industry indicates that few well organized sellection programs have been developed, although goats have the largest increase in number among the livestock species over the last 20 years (Dubeuf and Boyazoĝlu, 2009). Increased numbers do not necessarily indicate a positive development of productivity, but simply reflect the fact that many people in rural areas of the developing countries try to survive by keeping small animals such as goats. Selection programs have mainly been established in developed countries, while most goats in developing countries are randomly bred and mainly used to satisfy the immediate needs of the families. A few breeding programs had been established in developing countries, but most of these have failed as most of these projects focused on goat improvement rather than on educating the people who farmed the animals. A limited number of selected and well characterized breeds for producing milk, meat or fibre have been developed, while the majority of breeds are not genetically exploited as a result of the lack of selection schemes and breeding organizations (Gall, 1996). Most organizations engaged in the genetic improvement of goats are located in developed countries and are focused on milk production (FAOSTAT, 2020).

2.4.1. Goat meat industry in South Africa

Goats are traditionally kept by a large part of the population in the rural areas of South Africa (Els, 1996). These goats fulfil important roles within the households of subsistence farming systems in these rural areas. They are used to maintaining social bonds with the community, e.g., as lobola (dowry) (Tapson, 1993) and as exchange with relatives. Goats are also used for ceremonial (Dombo *et al.,* 1999) or religious purposes (Els, 1996). The animals therefor provide an income as well as meat and milk for the household (Tapson, 1993). The formal goat meat industry in South Africa is still in an infancy stage (DAFF, 2017). South Africa is a relatively small goat producing country where only approximately 3 % of Africa's goats and less than 1 % of the world's number of goats is farmed

(FAOSTAT, 2020). In 2017, there was only 250 stud breeders registered in South Africa. The Eastern Cape, Limpopo, KwaZulu-Natal and North West provinces are the largest producers (Figure 2.4) of the total live goats (DAFF, 2017). The Eastern Cape contributes the most goats in South Africa accounting for 39 % of the total flock followed by Limpopo, KwaZulu-Natal, and North West with 18 %, 13 % and 12 %, respectively (DAFF, 2017). The mentioned four provinces account to a total of 82 % with the remainder 18 % shared by the other five provinces (DAFF, 2017).

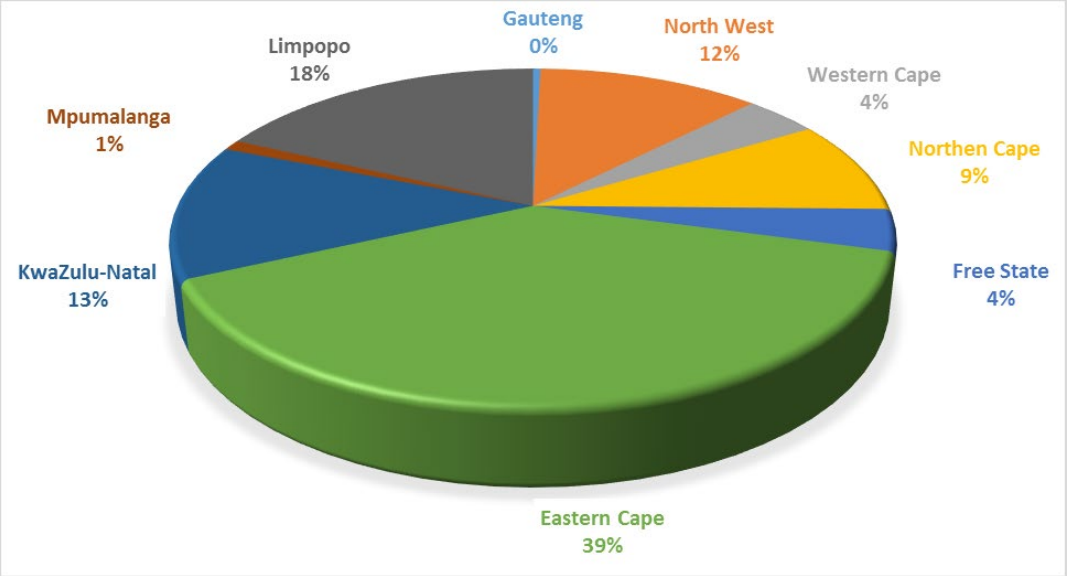

Figure 2.4. Distribution of South African live goats per province. Source: Statistics and Economic Analysis, adapted from DAFF (2017).

Most of the goat slaughtering in South Africa is informal in rural communities where no records are kept, and consumption is purely for ceremonial purposes or household consumption. Goats slaughtered in the commercial sector are predominantly BG and surplus Angora goats (DAFF, 2015). The Angora goat serves a small, niche industry by producing a lustrous and specialized fibre. Mohair is admired for its superior lustre, handle and high quality and is marketed and promoted by a well-organized international mohair industry. South Africa is the major role player, producing almost 50 % of the world product (Visser and Van Marle-Kőster, 2014). To date the indigenous goat industry is still not organised at any provincial or national level (DAFF, 2017). The development and initiation of a formal goat industry in South Africa was started through a programme titled “The commercialisation of indigenous goat production and products” which entailed the primary (animal production) and secondary (meat, milk, leather and cashmere) production of such products (Roets, 2002). This programme unfortunately seems to have had limited success. In other provinces within South Africa, efforts are focused on programs that aim to commercialise indigenous goats. However, most of these types of goats are kept by farmers in rural and peri-urban communities for household consumption as well as for the generation of income through sales (Anteneh *et al*., 2004).

2.5. Goat meat

The common name for goat meat is simply "goat", though meat from adult goats is referred to as chevon and cabrito, while meat from young goats is reffered to capretto, natale or kid (OED, 2003). According to market research, consumers in the United States prefer the French language-derived culinary name chevon (Degner and Jordan, 1991). Cabrito, a word of Spanish and Portuguese origin, refers specifically to young, milk-fed goat. Goat meat is a significant protein source throughout the world and in some circles is known as the ‘poor man’s cow” (Casey, 1992). Informal settlements, goats are mostly free ranging and have been a source of human nutrition since the very beginnings of human civilisation. For little investment, goats provide an easy source of meat and milk to rural people who cannot afford to buy these products or are unable to sustain other food producing animals (Tshabalala *et al.,* 2003).

Goat is both a staple and a delicacy in the world’s cuisines (Alford, 2009). It has historically been less commonplace in American, Canadian, and Northern European cuisines but has become more popular in some niche markets, including those that serve immigrants from Asia and Africa who prefer goat to other meat (Severson, 2008). Since 2011, the number of goats slaughtered in the United States has doubled every 10 years for three decades, rising to nearly one million annually (Scarbrough and Weinstein, 2011). While in the past goat meat in the west was confined to ethnic markets, it can now be found in a few upscale restaurants and purveyors (Alford, 2009); especially in cities such as New York and San Francisco (Fletcher, 2008). Brady in Texas has held its annual world championship barbeque (BBQ) goat cook-off annually since 1973 (McSpadden, 2011). Despite being classified as red meat, chevon is a low calorie, low fat and low cholesterol product. Considering its high nutritional value and its unsaturated to saturated fatty acid ratio, chevon can potentially improve the health of vulnerable human populations when compared to the consumption of chicken, pork, beef or lamb (Mazhangara *et al.,* 2019) and contains less energy than beef or chicken (Scarbrough and Weinstein, 2011; Ivanovic *et al.,* 2016). Therefore, cooking of chevon requires low-heat, slow cooking to preserve its tenderness and moisture. Goat meat has a reputation for having a strong, gamey flavour, but the taste can also be mild, depending on how it is raised and prepared (Alford, 2009). Goat meat can be prepared in a variety of ways, including stewing, baking, grilling, barbecuing, canning, and frying; it can be minced, curried, or made into sausage. Because of its low-fat content, the meat can toughen at high temperatures if cooked without additional moisture. Ribs, loins, and tenderloin are suitable for grilling, while other cuts are best for long braising (Scarbrough and Weinstein, 2011).

Caribbean cultures often prefer meat from mature goats, which tends to be more pungent; while some other cultures prefer meat that comes from younger goats that are six to nine months old (Scarbrough and Weinstein, 2011). Southern African customers have different preferences and mostly purchase directly from the farmer and choose goat for specific purposes, therefore the current status of slaughtering age is a very vague subject. The traditional market and lower income groups would not be concerned about age and would purchase the older animals from 2 teeth age and older.

Many goats are being slaughtered when they become too old to breed (no formal survey exists - informal communication with goat farmers from indigenous veld goat clubs). The consequence of increased physiological maturity and / or advanced age are associated with toughness and less desirable flavour in goat meat (Biswas *et al*., 2007), although these quality attributes might be seen as being desirable by other ethnic groups. For this reason, the market should be trained in cuisine.

2.5.1. Goat meat properties with a focus on quality and muscle biology

The concept of quality is complex and dependent on the aspect considered. Usually, quality is defined as "all those attributes for what consumers are willing to pay more," or an extra in the base price in order to have some specific attributes guaranteed. Quality can be associated with different aspects such as nutritional attributes (low fat content or healthy fat profile), production system (sustainable, organic or welfare friendly, for instance) or particular sensorial attributes (optimal odour, texture or flavour and, at the end, some additional hedonic satisfaction), (Hoffman, 1994, Casey and Webb, 2010). Many of these aspects could be related with certain quality labels that support or guarantee the extra paid for quality (Casey and Webb, 2010). The properties of meat are determined by several factors spanning from conception of the animal to the consumption of the meat (Hoffman, 1994). Meat quality varies with respect to numerous intrinsic and extrinsic factors (Table 2.3). The definition of meat quality is therefore multifaceted and intricate (Casey and Webb, 2010).

Table 2.3. Intrinsic and extrinsic factors affecting meat quality (Casey and Webb, 2010).

Intrinsic factors	**Extrinsic factors related with *ante-mortem* conditions**	**Extrinsic factors related with slaughter and *post-mortem* conditions**
- Species - Breed - Sex - Age and weight at slaughter - Muscle biology	- Management (stress agents)/handling - *Pre-slaughter* conditions	- Slaughter and blood loss (*post-mortem* glycolysis) - Electrical stimulation vs. no stimulation - Ageing - Components and factors of meat quality - Consumer preferences

2.5.1.1. Intrinsic factors affecting meat quality

2.5.1.1.1. Species

Research on species differences for meat quality is inconsistent and can be attributed to various factors such as physical activity levels (Geldenhuys and Muller, 2014), muscle fibre type composition, sarcomere length, concentration of connective tissue and degree of cross-linking, age, sex, *ante-mortem* stress, *post-mortem* ageing, cooking method (Warriss, 2000, Neethling *et al.,* 2016). Meat quality and characteristics differ among species, even within despite similar or homogenous groups such as small ruminants (Guerrero *et al*., 2013). Sañudo *et al*. (2012) compared four goat breeds (meat, double purpose, dairy and one lamb dairy breed). Results by the latter auther

showed that lamb and goat meat differed in carcass characteristics and several instrumental measurements of quality. Differences were mainly breed dependant (Sañudo *et al*., 2012). In contrast, sensorial differences between species are detected by consumers, even when meat is seasoned, as Rhee *et al*. (2003) showed when they compared goat and beef meat. Species-related flavours are predominantly associated with species-dependant adipose tissues. However, the acceptability of meat from different species is also linked to the population's consumption habits (Guerrero *et al*., 2013).

2.5.1.1.2. Breed

There are 102 recognized breeds of goats throughout the world, ranging in mature weight from 9 to 13 kg for small tropical breeds to over 100 kg for the large dairy breeds and improved BG (Table 2.4) (Warmington and Kirton, 1990). In the broadest sense, all goats are meat goats. Irrespective of the breed, every goat put up for sale is eventually slaughtered for human consumption. Yet, certain breeds such as the Boer, Spanish and Anglo-Nubian are better suited for meat production than others. Guerrero *et al.* (2013) summarised that breed is a clear source of variation in carcass morphology related to fat quality and / or meat quality. This however seems to be a complex factor as results depend upon which criteria of comparison are considered e.g., same weight, similar age, or similar degree of maturity (live adult weight %) (Guerrero *et al.*, 2013).

As a general rule, the effect of breed on instrumental and sensory meat quality attributes such as pH, colour, texture, and sensory characteristics, is slight. Most differences are probably justified by difference in maturity or in muscularity levels or other *ante-mortem* factors such as stress (Guerrero *et al.*, 2013). Breed however is a factor that should be considered in studies on the quality of ruminant products in spite of high individual variations and even though it is less important than other factors which may be more relevant (Guerrero *et al.,* 2013). Carcass quality can differ significantly among breeds, but differences mainly depend on the criteria used in the comparisons (same weight, same age, or same proportion of mature weight (Guerrero *et al.,* 2018).

Table 2.4. Mature size (body weight range) of some selected goat breeds around the world (adapted from Dhanda *et al.,* 2003).

Breed	Country	Sex	Body weight (kg)
Saanen	Switzerland	M	80 - 120 kg
	France	F	50 - 90 kg
Toggenberg	Switzerland	M	65 kg
	Switzerland	F	45 kg
Alpine	France	M	80 - 100 kg
	France	F	60 - 90 kg
Criollo	Mexico	M	40 - 50 kg
	Mexico	F	30 - 35 kg
West African Dwarf	Guinea, Angola	M/F	20 - 25 kg
	Namibia	M/F	20 - 25 kg
Feral	Australia	M	50 kg
	Australia	F	30 - 40 kg
	New Zealand	M	27 - 36 kg
	New Zealand	F	19 - 26 kg
Angora	USA	M	46 kg
	USA	F	40 kg
Barbari	India, Pakistan	M	35 - 45 kg
	India, Pakistan	F	27 - 36 kg
Jamnapari	India	M	70 - 90 kg
	India	F	45 - 65 kg
Beetal	India	M	65 - 85 kg
	India	F	45 - 60 kg
Black Bengal	India	M	14 - 15 kg
	India	F	8 - 13 kg
Zhongweni	China	M	39 kg
	China	F	24 kg
Kambing	Indonesia	M/F	30 kg
Boer Goat	South Africa	M	115 kg
	South Africa	F	50 - 70 kg

2.5.1.1.3. Sex

Sex (male, female, castrated) is mainly related to the quantity of fat deposited, deposition site, growth rate and carcass yield. Male animals have higher growth rates than female or castrate animals, and also exhibit higher mature body weights (Mourad and Anous, 1998). Carcass attributes are more affected by sex where male animals will exhibit a greater level of muscularity than castrates and will have more developed necks and shoulders when mature (Goetsch *et al.,* 2011). Females tend to accrete higher levels of fat, while castrates fall midway between intact males and females with regards to growth rate and carcass composition (Hogg *et al.,* 1992). Differences in carcass, fat and conformation might also affect other meat quality parameters such as pH and colour (Guerrero *et al*., 2013). Carcass fat is one factor used to classify the quality or classification of goat meat. There is evidence that some branched-chain fatty acids are responsible for the characteristic aroma of goat meat from uncastrated male animals. In a pioneering study by Wong *et al.* (1975), the authors related the presence of fatty acids with branched chains with the presence of methyl groups in the subcutaneous fat of goats. These components are directly responsible for the characteristic odour of goat meat (Wong *et al.,* 1975; Fonteles *et al.,* 2018). The characteristic of goat meat (e.g., a low-

fat content when compared to other meat such as pork, fish, and poultry) has a strong demand from an increasing health concious consumer market (Wood and Enser, 1997).

2.5.1.1.4. Age and weight at slaughter

Age at slaughter can profoundly influence meat quality, particularly with regards to tenderness of goat kids (Webb *et al.,* 2005). A key compositional change in muscle tissue with animal age is the increase of intramuscular fat (IMF) content of muscle tissue, as IMF is the last tissue depot to mature (Warriss, 2000). The negative quality attributes associated with goat meat may also be linked to the past where older goats were consumed and age has a renowned effect on tenderness (Brand *et al.,* 2018). Age and weight at slaughter are analysed together as, taking the same genetic base, a greater weight implies an older age, except when feed is manipulated. When slaughtered at the same age, goat carcasses are leaner than that of lamb, and therefore the meat also has a lower fat content (Hogg *et al.,* 1992). Meat goats are typically slaughtered and marketed as chevon at live weights that range between 20 to 40 kg, before they are able to deposit high levels of fat. Therefore, there is a low likelihood of goats developing adverse flavours or odours when slaughtered at this stage (Brand *et al.,* 2018). Ripoll *et al*. (2011) analysed the effect of slaughter weight (light carcass weight: 7.6 kg vs. heavy carcass weight: 11.4 kg) of milk kids. In this case, weight at slaughter had an important effect on meat quality where light kids had a higher compression on texture rates. However, with regard to sensory analyses, meat from light kids was reported tender and juicier than meat from heavy kids (Guerrero *et al*., 2013). Considdering different production conditions, body weight at different ages greatly differs between meat breeds and their crosses, consequently influencing the outcome on growth performance, carcass and meat properties. This is why the one size fits all approach on kid slaughter decisions of when and what sex to slaughter and at what slaughter weight becomes problematic in goat production considering the diversity of the commercial goat meat market.

2.5.1.1.5. Muscle biology

Muscle fibres, intramuscular connective tissue, and intramuscular fat play key roles in the determination of meat quality (Listrat *et al.,* 2016). The metabolism of muscle energy largely influences meat quality (Scheffler and Gerrard, 2007). This of particular importance during the conversion of muscle to meat (Karlsson *et al.,* 1999). Hence the strong relation between muscle fibre characteristics, energy metabolism and meat quality attributes (Karlsson *et al.,* 1999). In goats, scientific and published information on muscle fibre characteristics, and energy metabolism are however limited (Pophiwa *et al.,* 2016). Consumers, producers, and product development experts often ask about the tenderness ranking of various muscles, with mainly that of beef having been studied (Belew *et al.,* 2003; Von Seggern *et al.,* 2005). Sitthigripong *et al*. (2013) determined the effect of muscle types on biochemical and meat quality traits among four goat muscles: *Infraspinatus* (IF), *Longissimus thoracis et lumborum* (LTL), *Psoas major* (PM) and *Supraspinatus* (SS) from ten

crossbred BG. The results from the study showed that muscle types had variations in meat characteristics as differences in muscle fibre size, sarcomere length, glycogen content, pH and shear force value among different muscle types. In terms of meat quality (longest in sarcomere length, the smallest size of muscle fibre, and the lowest shear force value ($P \leq 0.01$), PM was the best followed by IF, LTL and SS, respectively.

2.5.1.2. Extrinsic factors related with ante-mortem conditions

The environments in which meat goats are produced determine their productivity and the characteristics of the carcass and meat. Also, *ante-mortem* conditions involving several factors will impact directly on meat quality. Animals waiting for slaughter (typically in lairage) can be stressed by factors such as restraint, handling, and novelty of the *pre-slaughter* environment, adverse weather conditions, hunger, thirst and fatigue (Muchenje *et al.,* 2009). Transport time and *pre-slaughter* logistic chains may be considered as the most important for meat quality in ruminants (Guerrero *et al*., 2013). At the abattoir, animals should be rested to recover from stress before slaughtering, however no studies could be sourced that evaluated lairage time in goats on meat quality. An example of handling *pre-slaughter* at a slaughterhouse, is the use of a Judas goat to assist with the general herding. The Judas goat is trained to associate with sheep or other goats, leading them to a specific destination e.g., lead sheep to the killing floor or into specific lairage pens or onto trucks. Exhaustive *ante-mortem* stress yields dark, firm and dry meat with a high ultimate pH (pH >6.0), (Guerrero *et al*., 2013). In addition to handling, adverse seasonal conditions may potentially stress animals and consequently influence meat quality characteristics. Kannan *et al.* (2003) reported that transported goats had less tender muscles compared to non-transported animals. The study of Nikbin *et al.* (2016) indicated that *pre-slaughter* transportation can cause significant ($P \leq 0.05$) effects on carcass shrinkage loss and all meat quality traits of transported goats. In their study, higher stocking density during transportation caused an increase in carcass shrinkage loss and in deterioration of meat quality, such as meat colour traits and drip loss. Since profitability of animals is related to carcass and meat quality, choosing a proper stocking density during transportation should be considered. Casey and Webb (2010) concluded that *pre-slaughter* management practices can have an important economic impact on a goat meat enterprise.

2.5.1.3. Extrinsic factors related with slaughter and post-mortem conditions

2.5.1.3.1. Slaughter and blood loss

As seen in other ruminants (Anil *et al*., 2004; Onenc and Kaya, 2004; Vergara *et al.,* 2005; Sazili *et al.,* 2013), the method of stunning (electrical, penetrative bolt, etc.) could have an influence on the meat quality of the goats. Although both methods are used in commercial abattoirs, as well as the casting of live animals followed by exsanguination in traditional and in some religious slaughtering procedures, no research could be sourced evaluating the effect of slaughtering method on meat quality of goats. The lapse of time between stunning and exsanguination is another aspect worth considering for possible improval of the final product quality. An excessively long period, especially if stunning has been imperfect, may cause blood spots in the meat, with subsequent low acceptability and lower quality (Guerrero *et al*., 2013). At slaughter, the halting of blood circulation initiates a multifaceted sequence of modifications in muscular tissue which may be defined in two stages. The first stage is accosiated with *rigor-mortis* progresses where muscles become inextensible and reach maximum toughness (Lawrie, 1998; Warriss, 2000). Anaerobic glycolysis and the denaturation of some proteins; of which the proteolytic enzymes are of particular interest, are main events associated with *rigor* development. Conditioning, the second stage, is categorised by a gradual improvement in tenderness during *post-mortem* storage. The latter process mainly ascribed to the activity of the calpains and other proteolytic enzymes (Lawrie, 1998; Warriss, 2000).

2.5.1.3.2. Post-mortem glycolysis

The rate and extent of *post-mortem* glycolysis (Lawrie, 1998) and ultimate pH of the muscle are critical factors that determine meat quality (Casey and Webb, 2010). Webb *et al*. (2005) noted that high ultimate pH (pH_u) values for goat muscles are prevalent in literature suggesting that goats may be prone to *ante-mortem* stress. *Peri-mortem* concentrations of glycolytic metabolites in muscles and blood support this hypothesis (Casey and Webb, 2010). The normal glycogen content of skeletal muscle ranges from 30 to 100 µmol/g depending on the nutritional status and activity of the animal and type of muscle. Glycolysis ceases when the muscle glycogen concentration reach about 10 µmol/g and lactic acid has increased from 6 - 16 µmol/g to 80 - 100 µmol/g (Casey and Webb, 2010). The process normally takes 24 to 48 hours in cattle compared to 12 to 24 hours in small ruminants (Simela, 2005). Kannan *et al.* (2003) reported muscle glycogen content of 50 and 55 µmol/g for stressed and unstressed Spanish goat castrates (24 to 30 months old) and 20 and 40 µmol/g for stressed and unstressed young Spanish castrates (6 to 12 months old), respectively. The latter authors also noted that in a goat herd of mixed sex and age, glycogen concentration average 33 µmol/g. In both studies, glycogen levels were ≤50 µmol/g, the minimum concentration required for sufficient lactic acid production in order to attain a satisfactory pH_u of ~5.6 (Kannan *et al*., 2003). The ultimate pH_u is of particular importance to the chilled meat industry as it is a measurement of the factors that directly influences shelf-life, colour and eating quality of the meat.

2.5.1.3.3. Electrical stimulation vs. no stimulation

Electrical stimulation (ES) is a common practice used in the meat industry to increase meat tenderness and colour of beef, lamb, and goat carcasses (Biswas *et al.,* 2007). Electrical stimulation is used as a means of accelerating the *post-slaughter* decrease of pH and the onset of *rigor* by passing an electrical current through the carcass after slaughter (Taylor, 1981; Taylor *et al*., 1995; Strydom *et al*., 2005). The mode of action of ES is based on its ability to accelerate *post-mortem* glycolysis resulting in pH decline via rapid depletion of muscle glycogen (Taylor, 1981; Taylor *et al*., 1995; O'Neill *et al*., 2004; Strydom *et al*., 2005). The application of ES results in extensive contraction of skeletal muscles whereby, the fibres become extended preventing additional contraction thus preventing shortening (Adeyemi and Sazili, 2014). Myofibrillar matrix is physically disrupted thus accelerating proteolysis (Hwang *et al.,* 2003). Two crucial *post-mortem* changes accelerated by ES are the onset of *rigor-mortis* by acceleration of the rate of glycolysis and pH decline to values less than 6.4 (Adeyemi and Sazili, 2014). On applying ES, the rate of the aforementioned processes increases significantly but decreases on its cessation (Bendall, 1980). Furthermore, ES precludes thaw *rigor* in hot carcass frozen prior the onset of *rigor-mortis* and *rigor* resolution. Based on this, the major merit of ES is the prevention of cold shortening that could arise during *post-mortem* refrigeration due to a swift decline in temperature. Cross (1979) identified several factors that could be responsible for the tenderising effect of ES. These include the accelerated depletion of Adenosine-triphosphate (ATP), which results in the prevention of cold shortening and rapid decline in *post-mortem* muscle pH amidst high muscle temperature (30°C to 32°C), which enhances the activity of proteolytic enzymes or degradation of muscle fibres. In the last four decades, ES has been extensively researched and proved to be one of the most effective and popular methods for improving the quality of meat. Food safety is a major concern in the meat industry, especially when intervention is applied. Electrical stimulation (ES) also partially decreases the microbial total count of the carcasses by preventing cold shortening thereby allowing the carcasses to enter the chilling regime earlier (Adeyemi and Sazili, 2014).

Electrical stimulation (ES) is a suitable strategy for improving the tenderness and colour of meat of several species including goat (Biswas *et al*., 2007). Research showed that ES improved tenderness by not only preventing cold shortening, but also stimulating an early onset of proteolysis, which initiate the stretching and tearing of myofibrils (Savell *et al.,* 1977; Savell *et al.,* 1978a; b). In addition, it is proposed that ES also causes a reduction of calpastatin activity, and hence an acceleration of proteolysis (Ferguson *et al.,* 2001). Further, beneficial properties of ES include enhancement of meat colour and flavour, and extension of shelf life (Savell *et al.,* 1977; Savell *et al.,* 1978a; b). The impact of ES on goat meat is shown in Table 2.5.

Table 2.5. The effect of electrical stimulation on goat eating quality.

Eating quality measurements	Stimulated	Non stimulated	P level
Flavour rating	5.40	5.40	Not significant
Overall tenderness	4.50[a]	3.50[b]	P < 0.01
Shear force (Newton)	47.40[a]	62.50[b]	P < 0.01
Sarcomere length (µm)	1.85[b]	1.76[a]	P < 0.05
Overall palatability	4.60[b]	3.80[a]	P < 0.05

Source : Savell et al. (1978a)

From Table 2.5, it is notable that with ES there is an improvement in both tenderness (higher values for overall tenderness with lower shear force) and sarcomere length (SL) of goat meat; resulting in a higher overall palatability which is thus more preferred by the consumer.

2.5.1.3.4. Ageing

Ageing is the most important factor that modifies meat texture and consequently eating quality, consumer acceptability, and satisfaction (Guerero *et al.,* 2013). The metabolic-biochemical reactions that happen after *rigor-mortis* result in a progressive tenderisation of the meat (Dransfield, 1994b). Tenderness can be evaluated instrumentally by texturometers or by sensory methodologies. Ripoll *et al.* (2012) recorded the effect of slaughter weight and breed on instrumental and sensory meat quality of suckling kids. Ageing of samples was for 3 days and the higher myofibrillar toughness of light kids was explained by a lower activity of muscle proteolytic systems, causing a lower rate of *post-mortem* tenderisation (Ripoll *et al.*, 2012). As a general rule, by increasing the ageing period, tenderness will increase. Tenderising tends to be more intense in older animals due to the higher action of the proteases within their muscles (Devine and Graafhuis, 1995).

2.5.1.4. Components and factors of meat quality

Managing goat production for meat quality is a deliberate, active process that extends from conception to consumption (Casey and Webb, 2010). Figure 2.5 depicts this process.

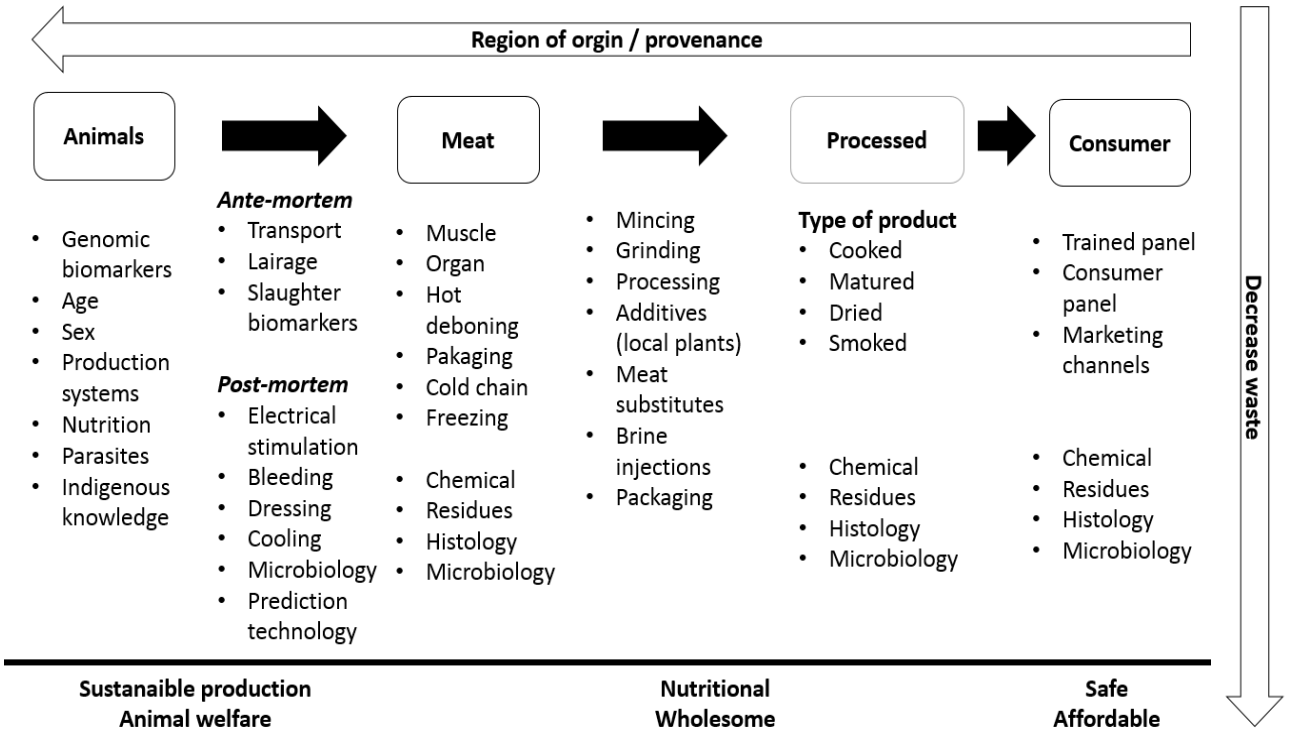

Figure 2.5. Factors influencing goat meat quality attributes.

2.5.1.4.1. Structure and composition of meat

Most studies on the structure and composition of meat have focussed on the loin and the hindquarter of the carcass as the muscles found in these regions are large and have a high economic value when sold as fresh meat (e.g., mainly species such as beef and sheep). Other muscles with lower commercial value have not been studied extensively; these muscles are typically processed further as mince or incorporated into processed / value added products such as sausages and fermented meat products (Torrescano *et al*., 2003). Ironically, little research on any of these muscles (loin, fore- or hindquarter) in goats have been documented. Studies on the structure, composition of meat and the commercial value for different goat muscles should therefore be considered for future studies. With a better understanding of the tenderness of individual muscles, the meat industry may make better use of under-utilized muscles for new-product development and other product opportunities. Muscles are classified into metabolic types on the source of their myofibre types, which are determined by the metabolic and contractile properties of their basic myofibres. Four metabolic types can be catagorized of which the three major types are the red (type I or β-red); intermediate (type IIA or α-red) and white (type IIB or α-white) (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971). The type IIC (fourth class), exists normally in neonates and is a temporary association in the development of types IIA and IIB (Young, 1984; Brandstetter *et al.,* 1998). For myofibre classification, muscles are categorised into red (type I), intermediate (type IIA), and white (IIB). Red muscles have a high percentage of type I myofibres. These are predominately postural muscles (e.g., *Semimembranosus* (SM) in the hind leg), with high oxidative capacity to meet the requirements for

stamina. Muscles involved in movement (e.g., *Semitendinosus* (ST) in the hind leg) have a higher glycolytic than oxidative capacity for rapid contraction and so are dominated by the type IIB myofibres. Within individual muscles there is a structural distinction in myofibre type (Brooke and Kaiser, 1970; Ashmore and Doerr, 1971, Young, 1984; Brandstetter *et al.,* 1998). Muscle metabolic type is also influenced by differences between animals, such as species, breed, sex, age, weight, nutrition and exercise (Essén-Gustavsson, 1996).

2.5.1.4.2. The pH temperature relationship

There are a number of factors which can influence the tenderness and the early *post-mortem* carcass. The pH and temperature relationship is one such factor. The temperature at the point when a carcass reaches pH = 6.0 and enters *rigor* can be used to predict meat quality. If the carcass temperature decreases too fast before the onset of *rigor*, cold shortening may result, which can have adverse effects on meat tenderness (Tornberg, 1996, Hwang and Thompson, 2001). Locker and Hagyard (1963) showed that muscle shortening occurs when *pre-rigor* muscle is held at either low or high temperatures. At low temperatures cold shortening occurs which leads to increased toughness of the meat. In order for cold shortening to occur the muscle pH has to be >6.0 at a temperature <10°C and still have ATP available for muscle contraction (Pearson and Young, 1989). *Rigor* or heat shortening is caused by a combination of a high temperature with a low pH. The low pH is usually due to a rapid pH decrease causing early exhaustion of proteolytic activity (Dransfield, 1994a; Simmons *et al.,* 1997). A favourable relationship between pH and temperature seems to be a pH >6.0 at temperatures >35°C and a pH <6.0 for temperatures <12°C as reported for beef (Thompson, 2002). In most studies, chevon pH_u is often around or above 5.8 (Table 2.6). The high pH_u is probably due to *ante-mortem* stress since goats are excitable (Simela, 2005). If this hypothesis is correct, it may be deducible from the glycolytic potential (GP) values. Glycolytic potential (GP) is the sum of products from glycogen metabolism that are likely to produce lactic acid (Maribo *et al.,* 1999).

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

A low GP at slaughter is indicative of prolonged stress prior to slaughter while a high lactate concentration and a low glycogen: lactate ratio is indicative of acute *ante-mortem* stress (Simela, 2005).

Table 2.6. Ultimate pH values for chevon (adapted from Simela, 2005).

Type of goat	Muscle	Mean/ Range of pH_u	References
Criollo males	LTL	5.77 - 6.19	Nuñez Gonzalez *et al.*
Criollo males	BF	5.80 - 6.10	(1983)
Saanen females		5.88	Hogg *et al.* (1989)
Saanen males	Not specified	5.90	
Feral males		5.55	
Unspecified breed castrates		6.01	Hogg *et al.* (1992)
Unspecified breed females	*Iliopsoas*		
		6.00	
Boer Goat		6.04	Swan *et al*. (1998)
Cashmere	LTL	5.70	
Boer x Cashmere		5.78	
Bucks of various breeds	LTL	5.6 - 5.8	Dhanda *et al*. (1999)
Various breeds intact males	Composite	6.36	Madruga *et al.* (1999)
Various breeds castrated		6.83	
Boer cross breeds	LTL	5.8 - 6.2	Husain *et al.* (2000)
Spanish does	LTL	5.96	Kannan *et al.* (2001)
	SM	6.07	
	TB	6.33	
2 yr. old Spanish castrates	LTL	5.7	Kannan *et al*. (2003)
≤ 1 yr. Spanish castrated		6.1	
Boer Goats	SM	5.73 - 5. 80	Pophiwa *et al.* (2016)
Indigenous goats		5.72 - 5.74	
Boer Goats	LTL	5.75 - 5.80	Brand *et al*. (2018)
South African indigenous goats	SM	5.88 - 6.01	Simela *et al*. (2004a)
	LTL	5.88 - 6.03	Simela *et al.* (2004b)

Longissimus thoracis et lumborum (LTL), *Biceps femoris* (BF), *Semimembranosus* (SM), *Triceps brachii* (TB)

Simela *et al*. (2004a) reported that high pH_u values of goat muscles (pH_u >5.8) are evidently not an inherent characteristic of chevon. Since a high incidence of high pH_u meat often occurs amongst temperamental animals such as young bulls, heifers on heat and boars, chevon pH_u values suggest that goats are generally prone to stress caused by handling and possibly other *ante-mortem* stress factors.

2.5.1.4.3. Sarcomere length

Sarcomeres are the smallest contractile units and serve as the basic force producing machinery of striated muscles (Ertbjerg and Puolanne, 2017). Sarcomere length (SL) is related to tenderness, especially in cases of severe shortening (Whipple *et al*., 1990). The resting lengths of sarcomeres vary also with muscles and animal species. The typical reported SL is 2.5 µm, which is longer than the values found in *rigor* muscles (around 2 µm) (Ertbjerg and Puolanne, 2017). Sarcomere length tenderness relationship with different pork muscles, where all muscle with SL ≥2.0 µm (*Semitendinosus* (ST) and *Triceps brachii* (TB)) were regarded the most tender while those with SL <2.0 µm (LTL, BF and SM) were catogorized less tender by taste panels (Wheeler *et al.,* 2000). The latter authors concluded that if SL were 2.0 µm or longer, meat would be tender regardless of collagen content or extent of proteolysis. Nagaraj *et al.* (2006) reported on the variation of SL amongst different muscles of goat as different percentage decrease during 20 days of storage as

follows: ST (18.68 %), LTL (17.97 %), SM (17.48 %) and BF (16.85 %). In agreement, Olsson *et al.* (1994) reported a lower level of shortening in SM compared to the LTL of beef. The reason might be that the latter has significantly more oxidative fibres therefore it has a higher level of shortening (Olsson *et al.,* 1994).

2.5.1.4.4. Meat colour

Meat colour is an important characteristic that influences consumers' perceptions of the quality of the product (Hoffman *et al*., 2005). Bright red meat is the usual preference, and consumers often discriminate against meat that does not meet their expectations. Colour can indicate flavour, tenderness, safety, and freshness to consumers (Hoffman *et al*., 2005). Preferences for a specific colour (paler or darker) depends on the type of consumer considered; usually conditioned by the nationality, cultural background and experience or consumption habits (Font-i-Furnols and Guerrero, 2014). The characteristic colour of goat meat has not been established, but there are perceptions that goat meat is darker than other types of red meat. The colour of fresh meat is influenced by the amount and chemical state of myoglobin (Mb), (Faustman and Cassens, 1990; Mancini and Hunt, 2005; Suman and Joseph, 2013; 2014) and by the structure of the muscle tissue, which is directly related to its ultimate pH (Insausti *et al.,* 1999). Myoglobin (Mb) is a protein and, as with all proteins, it is susceptible to changes in response to the external environmental conditions (e.g., season, feeding management, storage temperature and *ante-mortem* stress). Changes in pH or temperature could cause protein denaturation, which can alter the structure and functionality of the protein (Solomon *et al.,* 1998). These changes could have a significant effect on the colour of the meat (Kim *et al.,* 2014). Furthermore, Egbert and Cornforth (1986) explained that dark coloured muscle is caused by inadequate acid formation during the process of *post-mortem* glycolysis as the myoglobin remains in the deoxygenated form (Kadim *et al.,* 2006). However, Janz *et al.* (2000) reported that meat tends to be brighter and more intense red when rapidly chilled and / or when the carcasses has been held at high temperatures until it has reached the onset of *rigor-mortis*. Kim *et al.* (2014) also found the increased redness in muscles is ascribed to accelerated glycolysis rates in muscles at high temperatures.

Another factor which has an impact on colour of meat is the rate and extent that muscle pH declines *post-mortem* and the temperature at which this occurs. Dark, firm and dry (DFD) meat is a phenomenon that occurs when there is exercise or stress *ante-mortem* resulting in the muscle being deficient in glycogen at point of death and therefore having a higher ultimate pH (5.8 and higher) *post-mortem* (Simela, 2005). Dark, firm and dry (DFD) meat allows the growth of spoilage organisms which are slower at the usual ultimate pH of meat (Newton and Gill, 1981; Shange *et al.,* 2019). The susceptibility of muscles to DFD differs and is determined mainly by differences in muscle fibre type. Muscles with a higher proportion of oxidative fibres (type I) are a darker, deep red colour in comparison to those with a higher proportion of glycolytic fibres (type IIX) due to a higher Mb content (Hunt and Hedrick, 1977; Kirchofer *et al.,* 2002). Stress-prone animals typically have a greater ratio

of white, more anaerobic fibre types (Briskey, 1964; Hunt and Hedrick, 1977, Neethling *et al.,* 2017). Colour in meat is typically measured as *L** (lightness), *a** (redness), *b** (yellowness) and Chroma (saturation index), and Hue angle (Simela, 2005, Neethling *et al.,* 2017).

Kadim *et al.* (2004) investigated the meat quality differences between four muscles (LTL, BF, ST, and SM) of three different Omani goat breeds, Batina, Dhofari, and Jabal Khaddar. No differences were observed between the *a** and *b** colour values among breeds for any of the muscles, whereas differences in *L** were observed, with the LTL of the Jabal Khaddar goats being lighter than those of the Batina and Dhofari, and the SM of the Jabal Khaddar and Dhofari being lighter than their counterparts from Batina. The authors concluded that both breed and muscle source influenced the colour of goat meat. Previous work of Dhanda *et al.* (1999) also supported the differences in muscle colour among goat breeds. Dhanda *et al.* (1999) also reported chevon becoming darker as an animal increase in age. In contrast Nuñez Gonzalez *et al.* (1983) did not observe any differences in the colour of chevon from goats ranging from 8 to 24 kg. Some *L**, *a** and *b** values that have been reported for LTL and SM of goats are depicted in Table 2.7.

Table 2.7. Hunter colorimetric colour co-ordinates of different muscles from different goat breeds (adapted from Simela, 2005).

Goat	Muscle	Carcass weight (kg)	*L**	*a**	*b**	References
Male Sudanese desert	SM	28 - 30 kg	31.9	16.5	8.7	Babiker and Bello (1986)
Sudanese desert	SM	35 kg	34.8	13.1	8.7	Babiker *et al*. (1990)
Boer x Saanen	LTL	32.4 kg	37.7	12.0	3.0	Dhanda *et al.* (1999)
Boer x Saanen	LTL	36.2 kg	37.7	14.8	2.1	Dhanda *et al.* (1999)
Feral	LTL	30.6 kg	37.1	14.4	2.0	Dhanda *et al.* (1999)
Saanen x Angora	LTL	34.1 kg	37.0	14.0	2.5	Dhanda *et al.* (1999)
Saanen x Feral	LTL	36.0 kg	34.6	12.7	1.7	Dhanda *et al.* (1999)
Boer crosses	LTL	Capretto	42.0	13.0	3.0	Husain *et al.* (2000)
Boer Goats	SM	30 - 40 kg	36.3	19.1	12.8	Pophiwa *et al.* (2016)
Indigenous goats	SM	30 - 40 kg	35.9	18.9	12.5	Pophiwa *et al.* (2016)
Boer Goats (Wethers)	LTL	38.8 kg	28.1	17.4	16.8	Solaiman *et al.* (2011)
Boer Goats (buck)	LTL	45.7 kg	29.9	16.2	15.4	Solaiman *et al.* (2011)
Indigenous goats Bravia	SM	-	38.6	13.8	9.6	Simela *et al.* (2004a)
Serrana × Bravia Serrana	LTL and GB	8 - 11 kg	49.1	16.4	5.9	Santos *et al*. (2007)

Longissimus thoracis et lumborum (LTL), *Semimembranosus* (SM), *Gluteobiceps* (GB)

The effect of different *post-mortem* rates of chilling on meat colour were compared by Babiker and Bello (1986). These authors reported that even though exposing carcasses to high ambient temperatures *post-mortem* caused, lower *L** and *b** values, and that the differences were not observed / detected by consumers. This was confirmed in another study, where a taste panel did not observe colour differences between meat from Sudanese desert lambs and kids, even though the chevon had lower *L** and *b** and higher *a** values (Babiker *et al.,* 1990). The authors hypothesised that in these studies, the differences in the meat colour may have been in a range that was too narrow to be detected by consumers. No clear pattern (Table 2.7) could be observed in the different goat breeds or muscles ranging in carcass from 28 to 45.7 kg for reported *L**, *a** and *b** values.

2.5.1.4.5. Water in meat

A large portion of the water in muscle tissue exists as free molecules within the muscle fibres while a smaller portion is located in the connective tissue (Huff-Lonergan and Lonergan, 2005). It is possible for some of the water to remain (during storage, curing and heat treatment) within muscle fibres because of the three-dimensional structure of the fibres. Water retained under forces of pressure and temperature increase is termed “bound water” while the water which is lost is referred to as “free water”. The water holding capacity (WHC) of the muscle can be decreased by disruptions of muscle structure. Grinding, chopping, freezing, thawing, salting, degradation of connective tissue by enzymatic or chemical means, application of other chemicals or organic additives that change acidity (pH), and heating are treatments that can affect the final water content of meat products (Offer and Trinick, 1983; Hamm, 1986; Huff-Lonergan and Lonergan, 2005).

At a high muscle pH, water holding capacity (WHC) is high and water is not readily lost from meat that is cut soon after slaughter (Offer and Trinick, 1983). Further, the net negative charges of myofilaments result in strong negative repulsive electrostatic forces between the filaments, which push the filaments apart, swells up the lattice and hence increase the space where the water can be lodged (Hamm, 1986). The negative charge and hence the repulsive force of the filaments is gradually lost as the pH declines, to a point when the filaments have no net charge, at the iso-electrical point of actin and myosin (about pH 5.4) (Hamm, 1986). The myofilaments relax, the interfilamentous space shrinks and in so doing expel the water. The expelled water accumulates in the space between the muscle fibres and the endomysium and is driven to the cut surfaces by the pressure of the endomysium (Offer and Trinick, 1983). Any alteration of pH in the range 5.0 to 6.5 has a great influence on WHC (Hamm, 1986). On the macroscopic level, factors affecting water-holding of meat are well-known, and all relevant practical aspects can be controlled by reasonable means. Water-holding continues to be determined in a great number of studies, and therefore, there is a significant amount of data available on the subject. These studies, however, have not markedly increased our knowledge on the foundations of water-holding (Puolanne and Halonen, 2010; Bakhsh *et al.,* 2018) nor our knowledge as applicable to goat meat.

High drip loss (DL) is undesirable as it detracts from the appeal of the meat, and valuable proteins and flavour compounds are lost in the exudate (Varnam and Sutherland, 1995; Lawrie, 1998). Drip loss is normally approximately 3 % in beef but may be exacerbated by very low ultimate pH (pH_u; determined by the extent of the pH decline at 24 hours after slaughter) and by freezing and thawing to as much as 15 % (Offer and Trinick, 1983). Leygonie *et al*. (2012) describes in a comprehensive review the effects of freezing and thawing on the physical quality parameters of meat. The formation of ice crystals during freezing damages the ultrastructure and concentrates the solutes in the meat which, in turn, leads to alterations in the biochemical reactions that occur at the cellular level and influence the physical quality parameters of the meat. The quality parameters that were evaluated in their review were moisture loss, protein denaturation, lipid and protein oxidation,

colour, pH, shear force and microbial spoilage. Leygonie *et al.* (2012) suggested that water loss from meat muscle tissue may lead to an increase in the concentration of solutes, which consequently caused a decline in pH. Chilling and drip losses not only affect the appeal of the meat, but also reduce its weight, and hence economic value. Simela *et al.* (2000) studied water losses in chevon and concluded that evaporative losses during chilling are probably the first water losses to have an impact on the appeal of chevon because carcasses are relatively lean with minimal subcutaneous fat (SCF) and have a high surface area to volume ratio. These losses further tend to be higher for smaller than the larger carcasses. Chilling losses from goats that were lighter than 35 kg were ~3 %, while the losses from heavier goats were only 2.3 % due to a better subcutaneous cover in the latter (Simela *et al.,* 2000). Arain *et al.* (2010) examined physical properties (WHC and DL) of goat meat to evaluate the relationship between goat meats in different age groups. A total of 21 goat meat samples were collected equally from three age groups each containing 7 samples. The mean WHC value of goat meat of group A, B, and C (61.77 %, 63.36 % and 63.36 %, respectively) did not differ significantly from each other. Water holding capacity of goat meat group B (63.36 ± 0.28 %) and group C (63.36 ± 0.21 %) were very similar and higher ($P \leq 0.05$) than meat from group A (61.77 ± 0.32 %) (Arain *et al.,* 2010). The DL in goat meat of group A (4.93 ± 0.16 %) were higher compared to advanced slaughter age (8 to10 months of age: 4.02 ± 0.10 % and >11 months of age: 4.06 ± 0.14 %, respectively) (Arain *et al.,* 2010). The study concludes that the meat of older goats may have an advantage to reduce qualitative and quantitative losses of end products and by products. This was also confirmed by a study of Sheridan *et al.* (2013) that concluded that although diet did not influence DL, DL increased with an increase in slaughter age.

2.5.1.4.6. Fat to lean muscle, marbling

Fats are present in meat as structural components of muscle membranes and as storage droplets between muscle fibres. The latter constitute what is perceived as marbling (Varnam and Sutherland 1995). Fats are implicated in the oxidative stability of meat and hence, shelf life (Gray *et al.,* 1996). The oxidative stability of meat is dependent on the balance between oxidative substrates (e.g., the polyunsaturated fatty acids of predominately the phospholipids); pro-oxidants (e.g., heme proteins such as myoglobin, haemoglobin, and cytochromes) and antioxidants (e.g., vitamin E) (Morrisey *et al*., 1998). Once the balance is upset, oxidative deterioration occurs which results in adverse changes in colour, flavour, texture, nutritive value and possibly the production of toxic compounds (Kanner, 1994; Gray *et al*., 1996).

The evaluation for fat content of meat can be done in the following ways: Firstly, in the laboratory, intramuscular and subcutaneous fat are determined by dissections of a side or a three-rib sample (Miller *et al.,* 1988). Intermuscular fat is determined by extraction with an organic solvent such as petroleum ether (Boccard *et al*., 1981). Secondly, in the industry, online methods used are by visual scoring of carcasses' subcutaneous fat cover or measuring fat depth at specific points on the carcass, usually along the LTL (Fisher and De Boer, 1994). In addition, several other methods

have been developed and used for live animal and carcass evaluations, such as ultrasound imaging, optical lean / fat probes, x-ray computerised tomography and magnetic resonance imaging (Cross and Belk, 1994; Monin, 1998). Chromatographic analysis is typically used to determine a more detailed composition of fats, such as fatty acid and cholesterol content (Maxwell and Marmer, 1983).

In goats, the development of fat occurs very late physiological age and only reaches appreciable levels when the animals are near or at their mature body weight (Owen *et al*., 1978; 1983). Factors such as nutrition, age, sex, body weight, and growth rate influence fat content, that is highly variable (Owen *et al.,* 1978). Goat carcasses are considered lean, mainly due to that the fat is deposited in the visceral rather than carcass depots (Kirton, 1988; Casey, 1992). Goat carcasses typically have about 60 % dissectible lean and 5 % to 14 % dissectible fat (Devendra and Owen, 1983; Norman, 1991). Goat subcutaneous fat cover is negligible (Pike *et al.,* 1973b; Dhanda *et al.,* 1999; Simela *et al.,* 1999) and in too a narrow a range to allow for the creation of meaningful classes (Pike *et al.,* 1973b; Smith *et al.,* 1978; Devendra and Owen, 1983; Simela *et al.,* 1999). For that reason, a measure of subcutaneous fat depth is not perceived as a useful quality indicator for goat carcasses (Pike *et al.,* 1973b; Simela *et al.,* 1999) and hence is not employed in most goat carcass classification systems (SAMIC, 2019). In cases, where subcutaneous fat is included in goat carcass classification, its assessment is often based on classifications developed for sheep carcasses (e.g., Government of Zimbabwe, 1995) and currently implemented in South Africa. This has resulted in the downgrading of the carcasses because of insufficient fat (Devendra and Owen, 1983; Simela *et al.,* 1998). However, the low-fat content of chevon “goat meat” also has an advantage, due to that the actual amount of the undesirable fat that is consumed by consumers is much lower when considering meats that have inherently higher fat content, such as beef and mutton (Teh, 1992; Simela, 2005).

2.5.1.4.7. Meat juiciness

In research, meat juiciness is usually determined by sensory evaluation or inferred from measures of water in meat, such as water holding capacity and cooking losses. Chevon and / or chevon related products have been reported to be less juicy than lamb and / or mutton products (Pike *et al*., 1973a; Schönfeldt *et al*., 1993a; Tshabalala *et al*., 2003) The latter has been attributed to the low-fat content of chevon (Tshabalala *et al*., 2003). Juiciness in cooked meat has two organoleptic components (Lawrie 1998); the impression of wetness during initial chewing, and sustained juiciness. The impression of wetness during initial chewing is due to the rapid release of meat fluids. Whereas the sustained juiciness result from the stimulatory effect of fat on salivation and could be explained by the fact that, meat from young animals gives an initial impression of juiciness but ultimately a dry sensation due to the relative absence of fat (Lawrie, 1998). Similarly, good quality meat is juicier than poor quality meat due to a higher intramuscular fat (IMF) content (Lawrie, 1998). Schönfeldt *et al.* (1993b) found that young goats with carcasses ranging from ~10 to 25 kg were juicier than the older goats with carcasses ranging from 15 to 30 kg. In contrast, Pike *et al.* (1973b) and Smith *et al.* (1978) compared kids with carcasses of 5 to 7 kg to yearling goats with carcasses of 12 to 13 kg and

found the older goats juicier and more palatable. Brand *et al.* (2018) suggested that goats slaughtered at a live weight lower than 50 kg can be fed diets that vary in energy content between 9.7 and 10.6 MJ ME/kg feed to produce chevon with acceptable, uniform eating quality, when similar feed ingredients are used in the diets.

2.5.1.4.8. Meat flavour and aroma

Meat flavour is a combination of aroma and tastes (James and Calkins, 2008). Volatile compounds primarily determine the aroma and thus flavour attributes of cooked meat (Mottram, 1998; Pegg and Shahidi, 2004), however, no single compound or class of compounds is solely responsible for meat flavour (Pegg and Shahidi, 2004). The contribution of volatile compounds to meat flavour is linked to their concentrations, as well as their odour threshold values (Moon *et al.,* 2006; Lu *et al.,* 2008). Taste is defined by non-volatile compounds (salts, free amino acids, peptides, nucleotides, etc.) perceived on the tongue. Without aroma, one or more of the five primary taste sensations (sweet, sour, salty, bitter and umami) will dominate (Lawrie and Ledward, 2006). Most compounds will elicit a greater response in one of these two systems (olfactory or taste), while some compounds might stimulate both (Delwiche, 2004). Factors influencing meat flavour are summarised in Table 2.8.

Table 2.8. Factors influencing meat flavour (adapted from Neethling *et al.,* 2016).

Factors	Impact on flavour	References
Animal breed	Animal breed has impact on intramuscular fat (IMF) content, and affects the rate of sensory changes	Brennand and Lindsay (1992); Campo *et al.* (1999); Chen *et al.* (2002)
Sex of animal	Subcutaneous and IMF vary for different sexes. Female animals have juicier meat and sex of animal also influences flavour related compounds (e.g., branched chain fatty acids in goats)	Seideman *et al.* (1982); Ellis *et al.* (1997); Jayasena *et al.* (2014)
Animal age	Age affects intramuscular collagen solubility, increases flavour intensity. Older animals have higher straight chain fatty acids. Age of animal also influences colour, flavour, juiciness, tenderness, and overall palatability	Young *et al.* (1997); Awan *et al.* (2014)
Chiller aging	*Post-mortem* ageing improves tenderness by endogenous enzymes and amount of flavour compounds. Number of volatile compounds derived from fatty acid degradation also increased during aging	Geesink *et al.* (2001); Gorraiz *et al*. (2002)
Meat cooking	Cooking modifies chemical and nutritional composition, enhances flavour, and improves tenderness of meat. Cooking leads to controlled oxidation of lipids. Cooking also influences amount of free amino acids, carnosine, pyrazines, and hexanol	Byrnea *et al.* (2002); Lorenzen *et al.* (2005); Brugiapaglia and Destefanis (2012)
Animal feed	Feed affects carcass composition, degree of fattening, fatty acid profile of meat and formation of short branched-chain fatty acids (BCFAs)	Lewis *et al.* (2002); Young *et al.* (2003); Wood *et al.* (2008);

Flavour is described by Schönfeldt *et al.* (1993a) as a complex sensation that exists from the combination of olfactory and gustatory attributes of meat that are perceived during tasting. The characteristic flavour of chevon closely resembles that of mutton or lamb (Madruga *et al.,* 2009). The differences in flavour between chevon and mutton may be ascribed to the differences in fat content (Tshabalala *et al.,* 2003). It has also been noted that the flavour intensity increases with age and is more pronounced in older animals which have higher fat levels (Schönfeldt *et al.,* 1993a). Ryan *et al.* (2007) also found that goats that were fed higher concentrate levels, which increases the degree of fat deposition, had higher goat-like flavour intensity. The level of intramuscular fatness, as well as the composition of fatty acids, can affect the flavour and aroma profile of meat.

Flavour is influenced by fats. Firstly, by oxidation of unsaturated fatty acids (UFA), which yields carbonyl compounds that at one level of concentration produce desirable flavours and at another, undesirable flavours (Moody, 1983). Secondly, fats strongly affect flavour by serving as a depot for fat-soluble compounds that volatilise upon heating. During cooking, many of the flavour compounds are produced due to reactions such as the Maillard reaction, Strecker degradation, lipid peroxidation and their interactions (Moody, 1983). In sheep and goat species, branched chain fatty acids (BCFA) have been associated to flavour (Wong *et al.,* 1975; Ha and Lindsay, 1990). For example, 4-ethyloctanoic acid has been detected in goat and associated with a goat odour (Ha and Lindsay, 1990). Whereas 4-methyloctanoic, 4-methylnanoic (Wong *et al*., 1975) and 4-ethylheptanoic (Ha and Lindsay, 1990), are associated with a goat-like flavour due to their low threshold levels as well as their distinct odour characteristics, which include malty, pungent and sweet (Madruga *et al.,* 2009).

2.5.1.4.9. Meat tenderness

Meat tenderness has been defined as “the composite of those properties which arise from structural elements, and the manner in which it registers with the physiological senses” (Lawrie, 1998). This definition recognises three essential elements: tenderness which is the result of the structure; it is a composite of several properties and sensory quality (Lawrie, 1998). The most important attribute of eating quality is, meat tenderness, a factor that determines consumers’ continued awareness and interest in meat (Issanchou, 1996; Boleman *et al*., 1997). Tenderness is also defined as the ease of mastication, which involves the initial ease of penetration by teeth, the ease with which the meat breaks into fragments and the amount of residue remaining after mastication (Lawrie, 1998). The concept of meat tenderness is very complex since it is dependent on many physiological factors such as connective tissue characteristics (total collagen and collagen solubility) (Monin, 1998), the energy status of muscle, which influences the extent of muscle contraction (studied by measuring myofibril fragmentation, proteolytic calpain system levels, pH_u, etc.) *post-mortem*.

According to Johnson *et al.* (1995), breed (e.g., Florida native, Nubian × Florida native, Spanish × Florida native goats) had no effects on Warner-Bratzler shear force (WBSF) values. In agreement, Santos *et al.* (2007) concluded that shear force was not affected by genotype (Serrana,

Bravia, and Serranan × Bravia crossbred genotypes) despite significant interactions between sex and genotype. Naudé (1985) in contrast found that tenderness is directly affected by breed type (cattle, sheep, and goats) as it influences the solubility of the connective tissue in the muscles. Wheeler *et al*. (2000) reported that the differences in muscle type has some influences on the meat tenderness. According to Peňa *et al.* (2009) and Warmington and Kirton (1990) meat tenderness decreases with maturity but shear force increases with increasing age. Shear forces values are indicative of toughness in meat (Webb and Erasmus, 2013). Furthermore, Kirton (1970) also concluded younger animals have more tender meat as compared to yearlings and older animals, due to the reduced collagen solubility as the animals' age.

2.5.1.4.9.1. Connective tissue and collagen contribution to meat tenderness

When tissue hardly changes during the *post-mortem* period of meat storage it is referred to as background toughness and / or connective tissue toughness (McCormick, 1994). Its contribution to toughness is believed to be a product of the state of connective tissues in the perimysium, which constitutes almost 90 % of the intramuscular connective tissue (Light *et al*., 1985) and explains less than 10 % of the total variance in meat tenderness (Harper, 1999). In the perimysium and endomysia connective tissues, collagen is the predominant protein, constituting some 1.6 to 14.1 % of the dry matter weight of muscle (Purslow, 1999). The content and solubility of collagen are the main characteristics that are used for the determination of connective tissue and its contribution to meat toughness. In addition to these characteristics, biochemical methods and rheological methods are also used for determining the contributor of connective tissues to meat tenderness. For example, connective tissue toughness is perceived as the difference between initial and peak force of the Warner-Bratzler deformation curves (Bouton *et al*., 1975). It has been shown that between 52 and 70°C, collagen shrinks during cooking, which increases the toughness of the meat (Bendall and Restall, 1983). Therefore, the degree to which the meat is cooked is important in this determination (Warriss, 2000), as collagen gelatinises at temperatures above 70°C, and the extent to which this happens also depends on the length of cooking time (Baily and Light, 1989).

2.5.1.4.9.2. Myofibril fragmentation and its contribution to meat tenderness

The conditions during *rigor* development and *post-mortem* tenderisation determine the myofibrillar contribution, and the extent of shortening during *rigor* development and proteolysis during conditioning on meat tenderness (Warriss, 2000). The decrease in ATP is due to muscle contracting, which is caused by the 'leaking out' of Ca^{++} from the semi-permeable membrane of the sarcoplasmic reticulum (SR). ATP is used for (i) pumping the Ca^{++} back (ii) for breaking the actin-myosin bond and keeping the actin and myosin apart (Koohmaraie and Geesink, 2006; Kemp *et al*., 2010). The weakening and proteolytic breakdown of the Z-line is directly responsible for most of the decrease in toughness between 24- and 72-hours *post-mortem* (Watanabe and Devine, 1996).

2.5.1.4.9.3. Proteolytic calpain system levels and its contributions to meat tenderness

It is acknowledged that the calpain system is not the only proteolytic system involved in *post-mortem* tenderisation and knowledge continuously expand (Koohmaraie and Geesink, 2006; Lonergan *et al.,* 2010; Kemp *et al*., 2010; Ertbjerg and Puolani, 2017). The calpain system amongst others contains four known proteins that could be involved in meat tenderness (Koohmaraie and Geesink, 2006):

- μ-calpain (mu-calpain)(Calpain-I), a proteinase that requires 5 to 50 μM Ca^{2+} for half maximal activity;
- m-calpain (Calpain-2), a proteinase that requires 300 to 1000 μM Ca^{2+} for half maximal activity;
- a third proteinase (p94 or Calpain-3) identified in 1989 and still poorly characterised; it evidently requires 3000 to 4000 μM Ca^{2+} for half maximal activity;
- and calpastatin a group of polypeptides that specifically inhibit the proteolytic activity of Calpain-1 and Calpain-2.

The concentration of free calcium after the onset of *rigor* will determine which calpain enzyme will be activated to act on myofibril proteins and cause fractionation of the myofibrils and resultant increased meat tenderisation (ageing). Depending on the species and temperature *post-mortem* could cause the Ca^{2+} to increase to anything from 5 to 200 μM (Jeacocke, 1993; Hopkins and Thompson, 2001; Geesink *et al.,* 2001). The differences in calpastatin activity are caused by differences in muscle metabolic and contractile types between species (Ouali and Talmant, 1990). Many reports suggested that Calpain-1 is the most important contribution towards tenderisation (Pomponio and Ertbjerg, 2012; Pomponio *et al*., 2008, as reviewed in Ertbjerg and Puolani, 2017), but more and more evidence indicate that the calpain system presentation across species differ e.g., camel and cattle exhibited more calpain activity than sheep and goat (Gheisari *et al.,* 2007). Other enzyme systems have been studied and been implicated in catalysing some proteolytic degradation in *post-mortem* muscle (Sentandreu *et al.,* 2002). Although the calpain system should be considered to be mainly responsible for texture development in meat, an increasing number of proteases have been implicated in contributing to *post-mortem* proteolysis, thereby supporting the view that *post-mortem* protein degradation is multi-enzymatic in nature.

2.5.1.5. Consumer preferences

Overall palatability can be attributed to three primary traits, tenderness, juiciness, and flavour, as well as the interaction amongst these traits (Smith and Carpenter, 1974). Specific consumption patterns and preferences for goat meat are dictated by cultural and traditional backgrounds and the socio-economic status of the community (Casey and Webb, 2010). Consumers are the last link in the food chain and their opinions on a product are highly relevant, not only when assessing the potential of a new product, but also in warranting the quality control of existing products and identifying the specific factors that influence meat quality. Several studies comparing consumers

from different regions, countries and eating habits have investigated choice tendencies and to understand the factors that would relate to consumers' perceptions and meat quality (Guerrero *et al*., 2013). Compared to sheep and cattle, knowledge of yield and quality of goat meat is limited due to the traditionally low economic significance of goats in developed countries. Generally, consumption of goat meat is limited to certain groups in speciality dishes centred on festival or holiday events. In South Africa, meat from young BG kids is sold as an alternative to lamb whereas, meat from mature goats is specifically sought after by the local Indian community which prefers it to beef and lamb (Tshabalala, 2000). The live goat market is characterised by peak demand periods. The Indian community prefer to slaughter white goats with long ears during their religious festivals and consequently the prices of goat meat rise dramatically each year around Christmas, Easter, and Ramadan periods (Pinkerton *et al.,* 1994). Therefor the demand for sheep and goat meat is affected by seasonal factors. The consumption of small ruminants increases at the end of the dry season when cattle are in limited supply and producers are reluctant to sell their available cattle. As a result, prices fluctuate significantly during the year. In most countries, including South Africa, holiday prices for live animals are higher compared to the normal price. In developing countries where goats are reared, they are mostly farmed under natural veld with very little, if any, use of supplementary feed and pharmacological agents to improve health and productivity. Despite some negative perceptions around chevon as being stringy, tough, and too strongly flavoured, its health benefiting fatty acid profiles and leanness clearly stand out and make it a potential significant contributor to the increased demand of animal products for human consumption (Mazhangara *et al.,* 2019). A marketing cocktail that highlights the health beneficial fatty acid composition of chevon not only helps educate the consumers to the benefits of the product, but it also creates a special niche for the product which will translate to greater benefit for producers. A deliberate effort needs to be made to showcase chevon as a unique product and avoid the traditional approach of benchmarking it against lamb. It is fundamental that beside the traditional manner of packaging and consumption of chevon, that it be processed into various types of snack foods, or other convenience products tailored for specific ethnic or cultural groups in developed countries (McMillin and Brock, 2005, Mazhangare *et al.,* 2019).

2.6. Conclusion

Goats currently offer the largest scope for improvement and development in the animal agriculture industry; this includes the commercialization of indigenous goat resources. Chevon is often compared to mutton or lamb, as the meat from goats is associated with a flavour and aroma that is similar to mutton, although older more mature goats do present an additional goat-like flavour which is considered undesirable by people who are not familiar with it. Due to its low-fat content, chevon is a good protein source for health conscious groups although it is less popular than lamb. Goat meat is generally consumed by ethnic communal populations, as well as Hindu and Muslim populations, who find goat meat to be an acceptable substitute for beef or mutton. Seasonal peaks in the demand for goat meat are experienced around religious or cultural holidays and festivals. Commercialization

of chevon production, by increasing the percentage slaughtered in the formal sector has the potential to increase income generated from goats. More attention should be given to the promotion of chevon and market development to increase consumer demand and to encourage stock farmers to farm with goats rather than just to keep them for traditional household purposes. To expand on the current knowledge of meat of goats, the following chapters will describe and compare various interventions (applying different *pre-* and *post-slaughter* procedures such as castration, or not and applying electrical stimulation) to enhance the quality of same-aged young wethers and buck of BG and a mixture of large frame IVG eco-types (Cape Lob Ear and Cape Speckled). In conclusion, the adaptability and resilience of goats make them an indispensable resource to safeguard sustainable production and contribute to the increasing protein requirements of the growing human population.

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CHAPTER 3

Effect of breed types and castration on carcass characteristics of Boer and large frame Indigenous Veld Goats of Southern Africa*

Abstract

Weaner male Boer Goats (BG; n = 36; 21 bucks and 15 wethers) and large frame Indigenous Veld Goats (IVG; n = 41; 21 bucks and 20 wethers) were raised on hay and natural grass ad libitum and the recommended amount of commercial pelleted diet to a live weight between 30 and 35 kg. Carcass quality characteristics (live weight, carcass weights, dressing %, chilling loss and eye muscle area) were measured. The right sides of the carcasses were divided into wholesale cuts and dissected into subcutaneous fat, meat and bone. Large frame Indigenous Veld Goat (IVG) wethers were slightly lighter than the IVG bucks with no significant difference observed between BG. Wethers compared to bucks had higher dressing %, subcutaneous fat % in all primal cuts, intramuscular fat %, kidney fat % and, overall, slightly less bone %. Some breed - wether interactions were noticed. Indigenous Veld Goats wethers were slightly lighter than the IVG bucks, but the IVG bucks tended to produce higher % meat compared to other test groups. Judged on the intramuscular fat % characteristics, it seems as if wethers should produce juicier and more flavoursome meat compared to bucks.

Keywords: yield; slaughter characteristics; lean meat; grazing and supplementary feeding

3.1. Introduction

Goats farmed for meat production constitute the major part of the world goat population. In developed parts of the world, goats are frequently considered as specialty or exotic livestock, whereas in the developing countries, especially those in Southeast Asia and Africa, goats constitute the major source of meat production (Dhanda *et al.,* 2003). South Africa is a relatively small goat producing country contributing approximately 3 % of Africa's goat population and less than 1 % of the world's number of goats.

Little effort has been made to promote goat meat production in South Africa. Despite this, the demand for goats for traditional slaughter (e.g.,slaughter of goats to mark significant occasions such as birth, coming of age, weddings, sickness, healing and death) purposes and export is rising, and in fact a shortage of goat production is experienced. Early researchers recognized the potential of the Boer Goat (BG) as a meat-producing animal (Owen and Norman, 1977; Casey, 1992) and today it is considered to be one of the most desirable goat breeds for meat production. It has gained worldwide recognition for excellent body conformation, fast growth rate and good carcass quality. Its

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popularity as a meat goat breed soared during the last decade due to its availability in Australia, New Zealand and later in North America and other parts of the world (Lu, 2011).

Southern Africa farming areas being a harsh environment, with challenges such as tick-borne diseases, drought and other extreme climates, require animals that are adaptable and disease resistant. The original indigenous eco-types migrated during the fifth century AD by various means from mid Africa, endured numerous tick-borne diseases and adapted well to tropical conditions (Van Rensburg, 1938; Epstein, 1983). During the twentieth century, producers started “improving” the indigenous goats, and from there the BG was developed (Van Rensburg, 1938). Unfortunately, through this development, the original indigenous eco-types nearly disappeared, and most so-called indigenous goats are actually Boer x indigenous goat crosses. Fortunately, some farmers did conserve some of the original eco-types, the Cape Speckled and the Cape Lob Ear are two of them, which were recently formally registered as Indigenous Veld Goats (IVG) - a collective name for the eco-types conserved by the Indigenous Veld Goat Society of South Africa.

Compared to sheep and cattle, knowledge of the meat yield and quality of BG and large frame Indigenous Veld Goats (IVG, Cape Speckled and the Cape Lob Ear) of South Africa is limited due to the traditionally low commercial interest. In Africa, small ruminants (goats and, to a lesser extent, sheep) are an integral part of smallholder (subsistence) farming systems. In these operations, goats and sheep make a significant contribution to the total farm income, the stability of farming systems and human nutrition (Devendra, 1994). These smallholder farming systems mainly operate under communal situations, which refer to where large areas of state rangeland (veld) are used communally by farmers for grazing domestic livestock and harvesting natural products (Masika and Mafu, 2004). Nonetheless, there are commercial opportunities within the goat industry in South Africa that could be developed to increase the income of rural populations (Smuts, 1997). In fact, interest has also grown for the potential of rounding off of goats in feedlots (Brand *et al.,* 2017; Sheridan *et al.,* 2000; Brand *et al.,* 2020).

The acceptability of a carcass lies in its perceived economic value, which includes the potential meat yield of the carcass (Chrystall, 1998). Although live animal and carcass attributes are principally concerned with the quantity of saleable meat that can be obtained from the carcass, they also have significant implications on the technological value of the carcass (e.g., the morphology of some specific muscles and cuts). These attributes influence the biochemical and physiological processes in meat during slaughter and chilling, and hence the resultant quality of the meat (Brand *et al.,* 2018). Therefore, early identification of animal characteristics that affect meat quality is beneficial for the production of meat of acceptable quality. Traits such as the sex, age, weight and conformation of the live animal and carcass as well as the fat distribution in the carcass are therefore of importance in producing goat meat of acceptable quality. The proportion of high-value cuts is also an important indication of the overall value of the carcass (Sheridan *et al.,* 2003; Simela and Merkel, 2008), yet little data exist on these carcass attributes for both the BG and IVG. The purpose of this

paper is to describe and compare the carcass characteristics of same-aged young wethers and bucks of BG and IVG (Cape Speckled and the Cape Lob Ear).

3.2. Materials and Methods

3.2.1. Animals and experimental design

This research was approved by the Agricultural Research Council - Animal Production (ARC-AP) Ethics Committee (ref no. APIEC16/021). Weaner Boer Goats (BG; n = 41; 21 bucks and 20 wethers) and large frame Indigenous Veld Goats (IVG; n = 41; 21 bucks and 20 wethers) were purchased from commercial breeders at three months of age (17 kg on average for IVG and 20 kg on average for BG). The commercial breeder when bought in had already castrated the male animals on farm. The animals were reared at the at the Small Stock Section of the Agricultural Research Council - Animal Production (ARC-AP) facility situated in Irene, in the Gauteng province of South Africa. During the rearing phase, the goats were randomly placed (breed and sex mixed) in two similar large grazing camps (~1500 m^2) with similar natural grass available during the summer rainfall areas in South Africa, with enough space to move and graze without affecting each other. From time to time they were moved to other camps, when the grass seem to be withered and to lessen the chance of worm infestation. The aim was to simulate a small farm situation that is typical in the grassland areas. The natural grass diet was supplemented with hay ad libitum and an average of 250 g commercial “Ram, lamb and ewe - 13” pellets (protein 130 g/kg, fat 25 - 70 g/kg, fiber 150 g/kg, moisture 120 g/kg, calcium 15 g/kg, phosphorus 3 g/kg, urea 10 g/kg; Meadow Feeds, Lanseria Corporate Estate, Malibongwe Drive, Lanseria, Gauteng, South Africa) per day per animal. Pellets were spread evenly along 20 m long narrow feeding troughs, giving all goats in the camps an equal opportunity to feed. Water was provided ad libitum. The duration spent under these farming conditions was on average 6 to 8 months to a live weight (LW) of between 30 and 35 kg. After weighing (LW), the goats were transported for 3 km to the abattoir of the ARC-AP on the day of slaughter. The experimental design is presented in Figure 3.1.

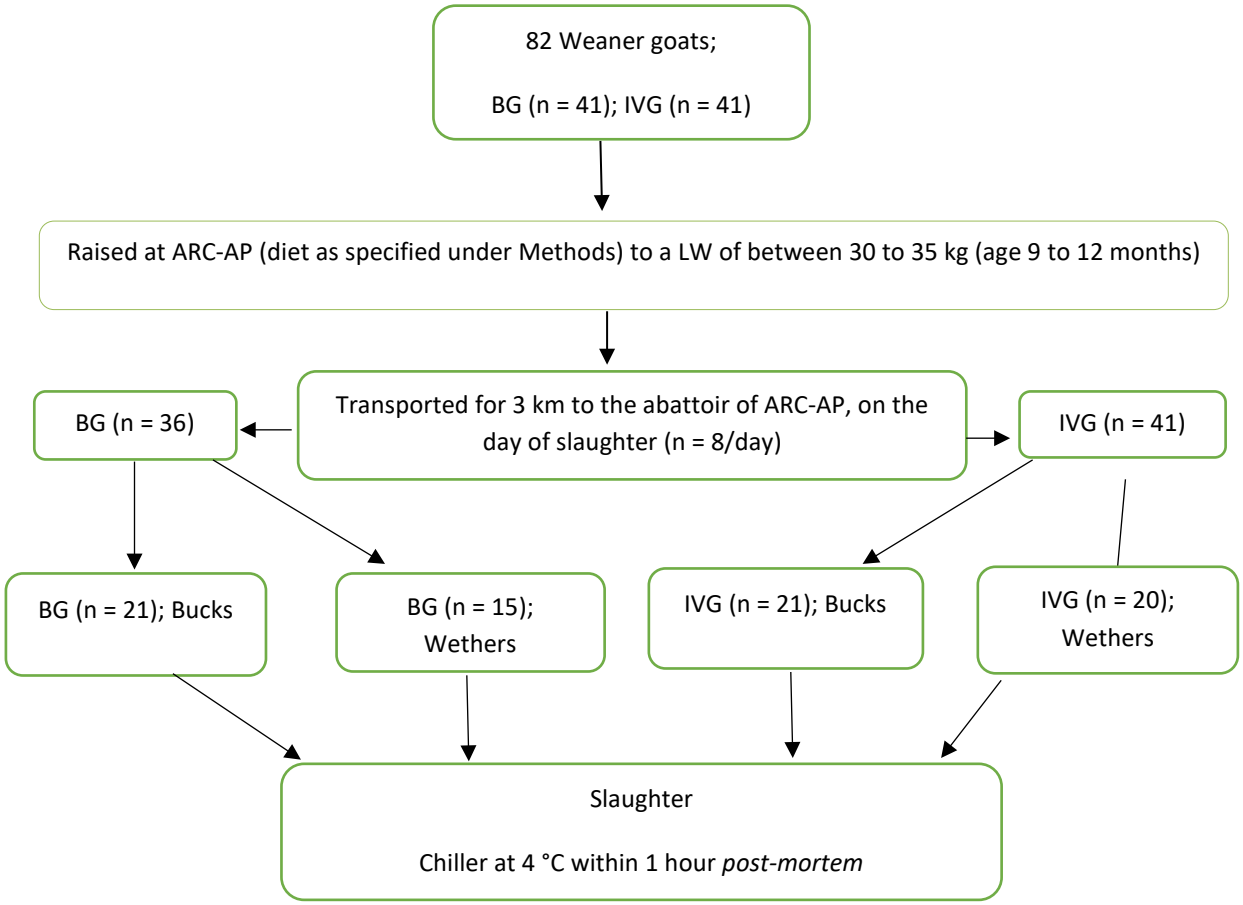

Figure 3.1. Experimental design to determine yield of Boer Goats (BG) and large frame Indigenous Veld Goats (IVG), bucks and wethers slaughtered at a pre-determined weight (30 to 35 kg); ARC-AP – Agricultural Research Council – Animal Production, Irene, South Africa.

3.2.2. Slaughter and sampling procedures

A maximum of eight goats per day representing all experimental groups were slaughtered. After a lairage period of 2 hours, the goats were rendered unconscious by electrical stunning (5 seconds at 200 volts, 0.5 A), exsanguinated and carcasses suspended by both Achilles heels and allowed to bleed out for 5 minutes (Cloete *et al.,* 2004). The head was removed after evisceration by further cutting the neck and was severed from the spinal column at the occipito-atlantal joint. The trotters were removed by severing the joint between the metacarpus and the radius/ulna in the forelimbs and severing the joint between the metatarsus and the tibia/fibula in the hind limbs. The red offal was plucked from the abdominal cavity during evisceration. The red offal consisting of the heart, liver, lungs and spleen were not part of this study and was discarded. The warm carcass weight (1 hour *post-mortem*) was recorded before the carcasses were suspended from both hind legs in the chiller. All carcasses were placed in the chiller at 4°C within 60 minutes *post-mortem*. The carcasses were classified according to the South African Carcass Classification for Small Stock (SACCSS) according to age, fat-cover and conformation (Government Notice No. R863). Cold carcass weight (24 hours *post-mortem*) were measured. The kidney fat and kidneys were plucked from the abdominal cavity where after the chilled carcasses were sectioned down the vertebral column by band saw after removing the tail. Both the kidneys and kidney fat were weighed for each carcass.

The left side was subdivided into ten South African retail cuts e.g., neck, shoulder and shank, breast, rib, loin, chump, leg, shin and tail (Figure 3.2) as follows:

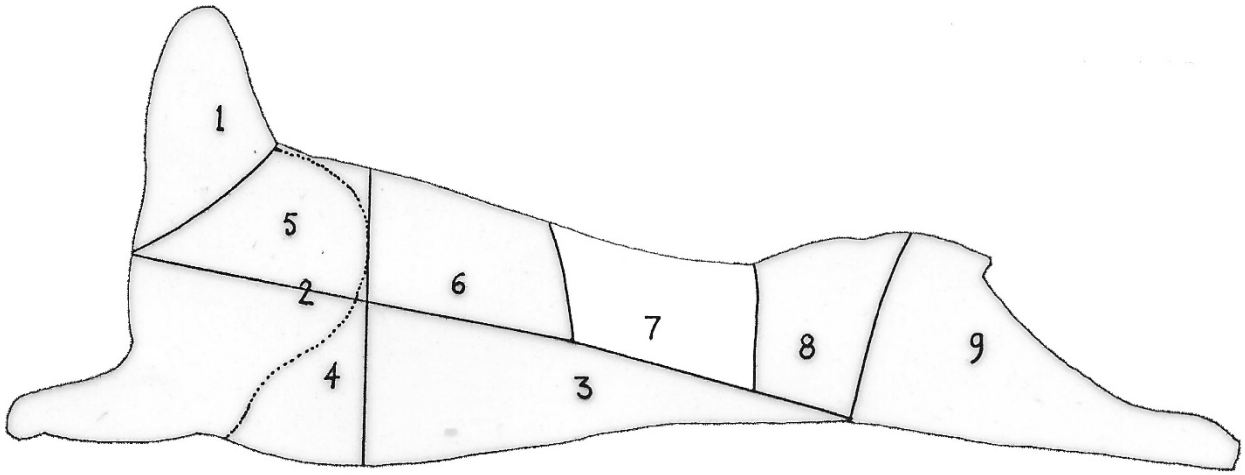

Figure 3.2. Dissection diagram representing goat carcass composition. 1 – Neck (Cranial end); 2 – Thick Rib; 3 – Flank (abdominal muscles); 4 – Shoulder; 5 – Breast; 6 – Lower rib; 7 – Loin; 8 – Chump; 9 – Leg and shin (Caudal end) (Strydom *et al*., 2009).

In the halved carcass the flank fold (*Tunica flava*) was freed from its caudal (tail) end over the thigh (*quadriceps femoris*) up to the level of L6, just in front of the last lumbar vertebra. From this reference point (in front of L6), a straight guideline was drawn up to halfway down the 1st rib (Figure 3.2) (breast). Along this line the flank (abdominal muscles) was cut through until the last rib, following the ribcage ventrally (along the *Arcus costalis*) up to the xiphoid process (the cut was extended ventrally) to free the flank. At the original reference point (in front of L6) the spinal cord was divided by cutting to remove the hind limb (red line). To remove the chump a second guideline was made approximately 2 cm cranial of the ilium along the dorsal plane. The leg and the shin were separated by making a guideline from the second distal of the stifle joint (often simply stifle), a complex joint in the hind limbs. Around the dorsal edge of the scapular (shoulder) cartilage a line was drawn extending caudally to follow the shape towards the elbow point and cutting the *latissimus dorsi* and *trapezius* muscles. This guideline was extended cranially just over the *supraspinatus* muscle, keeping the neck muscles and pectoral muscles attached to the carcass. The limb was pulled away from the carcass by starting ventrally and working up to the medial aspect of the limb. The nerves, lymph nodes and fat were left behind. To separate the shoulder and shin from the trunk a cut through the *rhomboideus* was made as close to the scapula as possible. At the elbow, the shoulder was reflected, and a guideline was drawn for the saw to separate the shin. To separate the neck from the trunk; seven vertebrae (cervical vertebrae) were counted, and a cut was made caudal to the 7th vertebra (C7, cranial of T1 of the 1st rib). Another six vertebrae (thoracic vertebrae) were counted, and a guideline mark were cut, dorsally behind T6 / the 6th rib. This guideline was used for the dorsal part of the ribs to separate the thick rib from the "loin" (rib and loin). The breast was provided by the bottom half of

the 1st guideline, including all 13 ribs (this was cut before the thick rib and loin were separated). The bottom half of the 1st guideline including all 13 ribs gave the breast.

The cut weights were recorded to the nearest gram where upon each cut was deboned and subcutaneous fat (SCF) removed. Weights of meat (including muscle, intermuscular and intramuscular fat), bone (including large sinews and cartilage) and SCF were recorded to calculate the physical composition of each cut and of the carcass side (Strydom *et al.,* 2009). Eye muscle areas were measured in mm^2 from traced images of the *longissimus thoracis* (LT) muscle on the surface of the cut made at the 1st lumbar vertebrae (L1) using a Video Image Analyser equipped with a XC30 Colour Camera (Olympus Soft Imaging Systems Gmbh, Münster, Germany), and cellSens Life Science Imaging Software (Olympus Corporation, Tokyo, Japan) after calibrating the X and Y axes. Moisture, protein, fat (representing chemical determined intramuscular fat - IMF) and ash percentages of lean loin meat were analysed using the procedures of the Association of Official's Analytical Chemist (AOAC, 1990) at the ARC-AP Analytical Laboratories.

3.2.3. Dressing and chilling loss percentage calculations

Dressing percentages (DP) and chilling losses of goat carcasses were calculated according to the formulas used by Simela *et al*. (2011) as follows;

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

Where, CCW = Cold carcass weight; LW = Live weight at slaughter; HCW = Hot carcass weight.

3.2.4. Statistical analysis

The data were subjected to analysis of variance (SAS, 1999) using a two-way ANOVA to evaluate the effect of the two goat breeds (BG and IVG), two sex-types (bucks (B) and wethers (W)) and interactions as factors on live weight, carcass weight and other carcass characteristics (Snedecor and Cochran, 1980). Slaughter date and age (presence of number of teeth) as random effects had no significant effect on results. Five BG wethers died during the study due to wilted grass, anemia and coccidiosis, causing an unbalanced dataset (see Figure 3.1 – experimental design).

Prior to analyses, a Shapiro–Wilk test for normality was performed on the data (Shapiro and Wilk, 1965) and where applicable, outliers were classified when the standardized residual for an observation deviated with more than three SDs from the model value. Few outliers for specific parameters were removed as specified in tables in brackets under means. Whole animal data were however not removed. Statistical significance (Fisher's t-test, least significant difference) was calculated at a 5 % level to compare means ($P \leq 0.05$) was considered statistically significant, although in some instances data with a $P \leq 0.1$ (10 % level) was considered as a trend.

3.3. Results and Discussion

When evaluating the commercial cuts in this study % of cuts per carcass weight of the neck, thick rib, loin, and leg cuts showed significant differences (P ≤ 0.05). A tendency (P ≤ 0.01) between breed x sex interactions for shoulder % was record (Table 3.1). The neck and chump differed (P ≤ 0.05) between sexes and the neck, flank, breast, and tail differed (P ≤ 0.05) between breeds.

Table 3.1. Least square means and standard error (SE) of means for carcass characteristics of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats (number of outliers removed indicated in brackets).

	Breed						
Carcass characteristics	**BG**		**IVG**		**Significance (P – Values)**		
	Bucks n = 21	**Wethers n = 15**	**Bucks n = 21**	**Wethers n = 20**	**Breed**	**Sex**	**Breed × Sex**
Live weight (kg)	35.5^{xy} ± 3.26 (1)	35.7^{xy} ± 2.91 (1)	36.4^{x} ± 2.09	34.3^{y} ± 2.38 (1)	0.748	0.114	0.070
Warm carcass weight (kg)	15.4^{y} ± 1.48	16.4^{x} ± 2.08	15.8^{xy} ± 0.73	15.9^{xy} ± 1.20	0.918	0.063	0.130
Cold carcass weight (kg)	14.8^{y}± 0.48 (2)	15.8^{x} ± 1.40	15.2^{xy} ± 0.72 (1)	15.4^{xy} ± 1.19	0.774	0.055	0.164
Chilling loss (%)	3.5^{a} ± 0.52 (2)	3.5^{a} ± 0.57	3.3^{ab} ± 0.50 (1)	3.0^{b} ± 0.56	**0.011**	0.221	0.125
Dressing (%)	41.9^{b} ± 2.69 (1)	44.2^{a} ± 1.12 (1)	41.9^{b} ± 2.49	44.9^{a} ± 2.06 (1)	0.347	**<0.001**	0.580
Eye muscle area (mm^2)	1043^{xy} ± 265	1184^{x} ± 269	1049^{xy} ± 242	964^{y} ± 194	0.101	0.732	0.053
Commercial cuts (% of carcass weight):							
Neck (%)	13.5^{b} ± 1.4	13.3^{b} ± 1.7	15.6^{a} ± 1.8	13.4^{b} ± 0.9	**0.001**	**0.014**	**0.002**
Thick rib (%)	6.5^{bc} ± 0.9	7.2^{a} ± 1.0	7.1^{ab} ± 1.2	6.4^{c} ± 0.7	0.824	0.859	**0.005**
Flank (%)	6.9^{a} ± 0.8	6.8^{a} ± 1.2	6.1^{b} ± 6.1	6.5^{b} ± 0.2	**0.015**	0.475	0.363
Shoulder (%)	12.9^{x} ± 0.6 (1)	13.1^{x} ± 0.7	12.9^{x} ± 0.9 (1)	12.6^{y} ± 0.8	0.123	0.816	0.096
Breast (%)	12.1^{a} ± 0.8	12.3^{a} ± 0.7 (1)	11.8^{b} ± 0.7	11.7^{b} ± 0.6 (1)	**0.005**	0.715	0.403
Loin (%)	12.7^{ab} ± 12 (1)	12.0^{b} ± 1.3	12.2^{b} ± 1.0	13.1^{a} ± 1.2 (1)	0.359	0.629	**0.003**
Chump (%)	7.0^{bc} ± 0.6	7.2^{ab} ± 0.4	6.8^{c} ± 0.4	7.4^{a} ± 0.6	0.183	**<0.001**	0.230
Leg (%)	18.4^{b} ± 1.3	18.3^{b} ± 1.4	18.1^{b} ± 1.2	19.3^{a} ± 0.7	0.231	**0.022**	**0.007**
Shin (%)	9.7 ± 0.7 (1)	9.4 ± 1.2 (1)	9.2 ± 0.8	9.2 ± 0.8	0.115	0.585	0.376
Tail (%)	0.6^{a} ± 0.1	0.6^{a} ± 0.1	0.5^{b} ± 0.1	0.6^{a} ± 0.1	**0.048**	0.088	**0.049**
Additional (% of kidney and kidney fat together)							
Kidney (%)	23.4^{xy} ± 4.4	19.4^{x} ± 4.4 (2)	22.7^{xy} ± 6.9	16.7^{y} ± 5.7 (1)	0.576	0.415	0.076
Kidney Fat (%)	76.6^{b} ± 4.4 (1)	80.6^{a} ± 4.4 (2)	77.3^{b} ± 6.9	83.3^{a} ± 5.7 (1)	0.062	**<0.001**	0.745

^{a,b} Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

3.3.1. Carcass characteristics

Only a few of the parameters measured showed a breed sex interaction (Table 3.1) and where applicable these will be discussed. Where there were no interactions, the main effects are discussed further. Generally, the evaluation of carcass characteristics and yield of the carcasses of the two breed types (BG vs. IVG) from wether and buck goats showed more differences between the sexes (bucks vs. wethers) than between the breeds (Table 3.1).

There was a tendency to differ (P = 0.070) between breed and sex for the live weight at slaughter of the goats. The average LW of IVG wethers was lighter (P = 0.05) compared to that of the IVG bucks although neither of the two IVG sexes differed from the BG bucks and wethers. No interaction between the breed x sex for the warm carcass weight could found. The average warm carcass weight of the BG wethers tended to be higher (P = 0.063) compared to that of the BG bucks whilst that of the IVG did not differ between the two sexes. Simalr results were recorded with respect to the cold carcass weights. The mean values of cold carcass weight for BG (bucks = 14.8 kg; wethers = 15.8 kg) found, is comparable to the mean values previously recorded for BG fed on different energy diets (low energy diets = 15.28 kg; high energy diets = 17.05 kg) (Sheridan *et al.,* 2003).

Boer Goats (BG, both sexes) presented significant (P = 0.011) higher chilling losses (≥3.5 %) compared to that of the IVG wethers (3.0 %) (Table 3.1), but similar to IVG bucks (3.3 %). Chilling losses in goat carcasses are normally in the range of 2.3 % to 3.0 %, and the loss tend to be higher compared to sheep carcasses at comparable ages and sexes (Webb *et al.,* 2005). This phenomenon can be attributed to the absence of thinner subcutaneous fat cover (SCF) found in goats (Webb *et al.,* 2005). The goat carcasses were all classified as being fat codes between -1 and 1 according to the South African Carcass Classification for Small Stock (Government Notice No. R863), and the specific depth of the SCF was not measurable in the present investigation. Goats are late maturing compared to sheep and grow at a slower rate; thus, fat is only deposited as they progress in chronological age and / or weight (Dhanda *et al.,* 1999; Webb *et al.,* 2005; Brand *et al,* 2009; 2020). Goat meat is generally considered a lean meat that is an ideal protein source for health conscious groups that try to limit their fat intake. None the less, IVG wethers had the lowest (P ≤ 0.05) chilling loss (Table 3.1) and the highest (P ≤ 0.05) proportions of SCF in all of the commercial cuts (Table 3.2); a finding that support the argument that higher levels of SCF reduce chilling losses (Ragni *et al.,* 2015; Rotondi *et al.,* 2018; Colonna *et al.,* 2020). High chilling losses are undesirable as they reduce the weight and the economic value of the carcasses as seen between the BG bucks and IVG wethers.

Table 3.2. Least square means and standard error (SE) of means for proportions of tissue composition dissected (bone, subcutaneous fat and muscle as % of each primal cut) and comparison of yield means of primal cuts (kg) of Boer (BG) and large frame Indigenous Veld (IVG) buck and wether goats (number of outliers removed indicated in brackets).

		Breed						
		BG		IVG		Significance (P – Values)		
		Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed × Sex
Total meat (%)		69.4^{b} ± 2.6	69.5^{b} ± 1.8	71.0^{a} ± 3.3	67.4^{c} ± 1.5	0.790	0.555	**0.015**
Total bone (%)		22.7^{a} ± 2.0	21.5^{b} ± 1.7	23.1^{a} ± 1.4	22.2^{ab} ± 1.4	0.240	**0.008**	0.690
Total subcutaneous fat (%)		7.9^{b} ± 1.6	9.1^{b} ± 1.8	5.9^{c} ± 2.3	10.5^{a} ± 1.7	0.639	**<.0001**	**0.003**
Primal cuts and primal cut tissue composition:								
Neck	Total (kg)	1.0^{b} ± 0.16	1.0^{b} ± 0.18	1.2^{a} ± 0.13	1.0^{b} ± 0.09	**0.006**	**0.014**	**0.001**
	Bone (%)	18.5 ± 3.0	17.6 ± 3.2	18.2 ± 2.8	18.7 ± 2.6	0.646	0.841	0.310
	Subcutaneous fat (%)	13.0^{a} ± 3.9 (2)	15.3^{a} ± 2.8	7.9^{b} ± 3.6	15.3^{a} ± 3.7 (1)	**0.004**	**<.0001**	**0.003**
	Muscle (%)	68.4^{b} ± 5.9 (2)	67.1^{b} ± 5.4 (1)	73.9^{a} ± 4.1	66.0^{b} ± 4.40	0.065	**<.0001**	**0.007**
Thick rib	Total (kg)	0.5^{b} ± 0.11	0.6^{a} ± 0.12	0.5^{ab} ± 0.10	0.5^{b} ± 0.06	0.868	0.841	**0.006**
	Bone (%)	30.1^{ab} ± 4.6	28.4^{b} ± 3.3	31.4^{a} ± 3.7	29.3^{ab} ± 3.1	0.258	**0.027**	0.837
	Subcutaneous fat (%)	6.8^{b} ± 1.5	7.0^{b} ± 2.1	5.1^{c} ± 0.5	8.5^{a} ± 2.1	0.767	**<.0001**	**0.001**
	Muscle (%)	63.1 ± 5.2 (1)	64.6 ± 4.0 (1)	63.5 ± 4.0	62.2 ± 3.6	0.383	0.980	0.144
Flank	Total (kg)	0.5^{xy} ± 0.09	0.5^{x} ± 0.12	0.5^{y} ± 0.08	0.5^{xy} ±0.09	0.075	0.317	0.932
	Subcutaneous fat (%)	16.5^{bc} ± 5.9	20.7^{ab} ± 7.7 (2)	15.6^{c} ± 5.9	23.6^{a} ± 6.9 (1)	0.414	**<.0001**	0.216
	Muscle (%)	83.3^{ab} ± 6.0	79.1^{bc} ± 7.6	84.3^{a} ± 5.9	76.4^{c} ± 6.9	0.473	**<.0001**	0.238
Shoulder	Total (kg)	1.0^{b} ± 0.10 (1)	1.0^{a} ± 0.10	1.0^{ab} ± 0.10 (1)	1.0^{b} ± 0.10	0.652	0.535	**0.028**
	Bone (%)	18.6^{b} ± 1.4 (1)	18.5^{b} ± 1.8	19.5^{a} ± 1.7 (1)	19.5^{a} ± 1.9 (1)	**0.020**	0.807	0.951
	Subcutaneous fat (%)	5.3^{ab} ± 3.0 (1)	5.5^{ab} ± 2.7	3.8^{b} ± 1.5 (1)	7.3^{a} ± 3.5	0.886	**0.004**	**0.001**
	Muscle (%)	76.1^{a} ± 3.1 (1)	76.0^{a} ± 3.9	76.7^{a} ± 1.8 (1)	73.3^{b} ± 3.1	0.147	**0.010**	**0.020**
Breast	Total (kg)	0.9^{y} ± 0.10	1.0^{x} ±0.11 (1)	0.9^{xy} ± 0.07 (1)	0.9^{y} ± 0.08	0.183	0.319	0.080
	Bone (%)	28.8^{x} ± 2.9	27.8^{y} ± 3.5 (1)	28.6^{x} ± 1.6 (1)	27.3^{y} ± 2.9	0.501	**0.070**	0.808
	Subcutaneous fat (%)	11.0^{a} ± 3.5	12.25^{a} ± 3.7 (1)	8.1^{b} ± 3.6 (1)	12.9^{a} ± 3.6	0.224	**<.0001**	**0.032**
	Muscle (%)	60.3^{b} ± 4.0	60.1^{b} ± 3.6 (1)	63.4^{a} ± 3.2 (1)	59.8^{b} ± 3.7	0.093	**0.019**	0.053
Loin	Total (kg)	0.9 ± 0.16 (1)	0.9 ± 0.12	0.9 ± 0.09	1.0 ± 0.14 (1)	0.380	0.418	0.185
	Bone (%)	25.3^{ab} ± 5.2	24.5^{b} ± 4.4	27.4^{a} ± 3.7	23.7^{b} ± 0.79	0.532	**0.014**	0.146
	Subcutaneous fat (%)	6.7^{bc} ± 3.3 (1)	8.7^{b} ± 2.9	4.7^{c}± 3.9 (3)	11.4^{a} ± 4.0	0.624	**<.0001**	**0.005**
	Muscle (%)	67.9^{x} ± 4.9 (1)	66.9^{y} ± 6.1	68.0^{x} ± 4.5	64.9^{y} ± 4.7	0.390	0.066	0.386
Chump	Total (kg)	0.5^{b} ± 0.07	0.6^{a} ± 0.08	0.5^{b} ± 0.04	0.6^{a} ± 0.05	0.720	**0.004**	0.733
	Bone (%)	24.2^{a} ± 4.6	20.3^{b} ± 3.5	22.6^{ab} ± 3.6	22.6^{ab} ± 3.6	0.840	**0.027**	0.058
	Subcutaneous fat (%)	7.4^{ab} ± 2.2	7.7^{ab} ± 2.7	6.6^{b} ± 2.2	9.2^{a} ± 2.6	0.512	**0.007**	**0.040**
	Muscle (%)	68.5^{y} ± 4.5	72.0^{x} ± 4.8	70.8^{xy} ± 3.3	68.7^{y} ± 4.6	0.849	0.655	0.055
Leg	Total (kg)	1.4^{b} ± 0.12	1.4^{ab} ± 0.12	1.4^{b} ± 0.11	1.5^{a} ± 0.11	0.132	**0.012**	0.554
	Bone (%)	17.6^{a} ± 1.9	15.9^{b} ± 2.3	17.6^{a} ± 1.8	17.4^{a} ± 1.5	0.158	**0.046**	0.085
	Subcutaneous fat (%)	5.3^{b} ± 1.6	5.1^{b} ± 2.2	4.2^{b} ± 1.5	7.4^{a} ± 1.9	0.190	**<.0001**	**<.0001**
	Muscle (%)	77.1^{b} ± 2.8	79.0^{a} ± 3.5	78.2^{ab} ± 2.2	75.2^{c} ± 1.8	0.061	0.231	**<.0001**

Table 3.2. (continued)

Shin	Total (kg)	0.7 ± 0.07 (1)	0.7 ± 0.08 (1)	0.7 ±0.07	0.7 ± 0.08	0.162	0.220	0.774
	Bone (%)	40.5^{ab} ± 2.4	39.5^{b} ± 2.7	41.5^{a} ± 1.8	40.8^{ab} ± 2.5	**0.047**	0.111	0.720
	Muscle (%)	58.4 ± 2.6	59.1 ± 2.8	58.1 ± 1.8	58.2 ± 2.7	0.315	0.507	0.602
Tail	Total (g)	46.2^{x} ± 1.26	47.4^{x}± 1.19	39.0^{y} ± 1.70	46.5^{x} ± 2.16	0.100	0.066	0.207

^{a,b} Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

The mean dressing percentage (DP) varied between 41.9 % and 44.9 %, which generally agrees with the values reported for various goat breeds worldwide (Devendra and Owen, 1983; Kadim *et al.,* 2003). Both the BG and IVG bucks had 3 % to 5 % lower (P < 0.001) DP compared to wethers, while there was no breed effect (Table 3.1). Dressing percentage is both a yield and financial value-determining factor (Warmington and Kirton, 1990) and is affected by factors such as age, weight, level of nutrition, the degree of gut fill at slaughter, head and skin weight, fatness and dressing procedures (Kadim *et al.,* 2003; Simela *et al.,* 2011; Gökdal, 2013). Castration slows down an animal's growth, by increasing the rate of deposition of adipose tissue (fat) to the detriment of the muscular tissue (meat) on the carcass at slaughter (Mahgoub *et al.,* 2011). This phenomenon also explains the higher (P ≤ 0.05) percentage of kidney fat in wethers compared to that of the bucks in the current study (Table 3.1) and is likely one of the main reasons for differences in DP between the two sexes. Factors such as gut fill, head and skin weight were not measured in the current study and should be considered in future studies to define the impact on DP between BG and IVG. Dressing percentages of goats are usually between 35 % to 53 % (Warmington and Kirton, 1990), although DP toward the higher end of the range of between 42 % to 45 % have been reported for Boer and undefined South African indigenous goats (Tshabalala *et al.,* 2003), which is in agreement with the current study (Table 3.1).

A trend (P = 0.053) for interactions between the breeds and sexes for the eye muscle area (EMA) were observed. Boer Goat (BG) wethers had the largest EMA whilst the IVG wethers had the smallest. The bucks of both breeds (BG and IVG) had intermediate EMAs that did not differ from each other (Table 3.1). An interesting observation is that the IVG wethers had the smallest EMA but presented the group with heavier loins. This could be caused by longer loins and / or more subcutaneous fat accumulation in the loin region (Table 3.2). Further research would need to be conducted to compare breeds and sexes from different eco-types and determine whether longer loins could be more than a casual observation to indicate that the IVG wether goats had longer carcasses. A phenomenon known to be associated with time of castration, pubertal development and the change caused thereby in cycling androgens and oestrogens (Nur-Vaizura *et al.,* 2016). The animals in this study had all been castrated by the age of three months when they entered the trial, although the specific age of castration is not known. This phenomenon should be studied further as the length of the carcass will have an influence on the weight of high value cuts available for sale.

3.3.2. Commercial cuts and proportions of tissue composition

The changes related to goats' body conformation are associated with the onset of puberty. With the onset of puberty, animals start to develop secondary sexual characteristics which adapt the musculature for survival and reproduction (Berg and Walters, 1983). Therefore, it can be expected that sexually mature bucks will have a more developed neck and thorax while does will exhibit a greater rump region to aid with birth (Berg and Walters, 1983). Castrated goats were found to still exhibit body shape changes that are associated with puberty in intact males (Brand *et al.,* 2009), although to a lesser extent, while generally exhibiting a higher degree of fatness (Mahgoub *et al.,* 2004).

The IVG bucks recorded the highest % yields for the neck compared to all other groups, but similar % yields were recorded for the other cuts such as the thick rib and shoulder than that of BG bucks and wethers. In contrast, the IVG wethers differed in % yields where the thick rib and shoulder had the lowest % yield and the loin and leg had the highest % yield compared to the IVG buck and BG bucks and wethers (Table 3.1). The similarities between BG bucks and wethers can be explained by the fact that the wethers and bucks used in this study were not yet at mature adult weights when slaughtered. It would be interesting to see at what physiological age and / or weight these goat breeds reach their mature status and whether the rules of Berg and Walters (1983) apply. For both the breast and the flank cuts, the BG recorded higher yields than the IVG. Boer Goats (BG) had a significant ($P \leq 0.05$) higher flank % (>6.8 %), breast % (>12.1 %) and tail % (0.62 %) compared to IVG (<6.5 %, <11.7 % and 0.56 %, respectively) of carcass weight. For the averages between the values shown in Table 3.1, a significant ($P \leq 0.05$) breed difference was observed for the neck, with IVG (14.5 %) presenting higher yields compared to BG (13.4 %). When evaluating differences between the sexes, both chump % and leg % of carcass weight differed significantly ($P \leq 0.05$) with higher yields observed for wethers (7.3 % and 18.9 %, respectively) to that of bucks, whereas bucks presented higher yield in terms of % neck of the carcass (14.5 %). No significant differences were observed for the % shin in terms of an interaction between the breeds and the sexes, nor for the main effects evaluated.

Wethers recorded higher proportional yields for kidney fat irrespective of breed, however, IVG had a tendency to yield higher percentages of kidney fat compared to BG. Generally, wethers tend to be fatter than bucks (Kebede *et al.,* 2008), although, unlike lamb, goats have relatively lower levels of subcutaneous and intramuscular fat (Hogg *et al.,* 1992; Sheridan *et al.,* 2003; Goetsch *et al.,* 2011).

The proportions of tissue composition dissected (bone, subcutaneous fat and meat as % of each primal cut) and comparison of yield means of primal cuts (kg) from BG and IVG, wethers and bucks are presented in Table 3.2.

Typically, goat carcasses have more than 60 % dissectible lean meat and 5 % to 14 % dissectible fat (Tshabalala *et al.,* 2003). Subcutaneous fat is poorly developed in goats, and fat

accretion occurs at a later stage in the growth process compared to other livestock species (Webb *et al.,* 2005). This was also reflected in this study when compared an average of 63 % lean, 22 % bone, 10 % intermuscular fat and 5 % subcutaneous fat reported for whole carcasses (Simela, 2005). However, the current study presented higher SCF % (5.9 % to 10.5 %) compared to reported values of 2.7 % to 5 % (Simela, 2005). An explanation could be that the animals used in the study of Simela (2005) were slaughtered at a weight of at least 25 kg (6 to 10 months) vs. 30 to 35 kg (9 to 12 months) supporting that *pre-slaughter* conditioning (to slaughter at a later stage in the growth process) improved fat/bone indices.

Boer Goat (BG) wethers and bucks showed no differences in fat and meat, while, for IVG, wethers recorded higher fat and lower meat proportions than bucks (Table 3.3). Low carcass fat is one of the main attractions to chevon production. However, the low and rather variable subcutaneous fat cover is a particular cause for concern in commercial chevon production since it is often well below the levels considered necessary for effective carcass chilling, without the risk of cold shortening (Smith *et al.,* 1876; Dikeman, 1996). The lean carcasses, coupled with the faster growth of the bucks, are the basis for the drive to produce young bucks in preference to wethers. However, at sexual maturity and beyond, meat from bucks is believed to have an unacceptably strong odour caused by androgens and branched chain fatty acids (Norman, 1991), which leads to the downgrading of their carcasses.

Table 3.3. Least square means and standard error (SE) of means for the chemical composition of the loins of Boer (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

Proximate analyses (%)	BG		IVG		Significance (P – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed × Sex
Moisture	$76.3^{x} \pm 1.8$	$75.1^{y} \pm 3.0.$	$76.8^{a} \pm 1.7$	$75.6^{b} \pm 3.4$	0.099	**<.0001**	0.350
Protein	20.0 ± 1.79	20.3 ± 2.3	$19.6^{b} \pm 1.8$	$20.1^{a} \pm 2.5$	0.200	**0.039**	0.855
Fat*	$2.2^{b} \pm 1.8$	$2.8^{a} \pm 1.7$	$1.6^{b} \pm 1.2$	$2.7^{a} \pm 1.1$	**0.032**	**0.001**	0.473
Ash	$0.9^{b} \pm 0.3$	$1.0^{a} \pm 0.2$	$1.0^{b} \pm 1.0.2$	$1.1^{a} \pm 0.2$	**0.001**	**0.001**	0.140

**Fat % = chemically determined intramuscular fat (IMF)*

^{a,b} Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

The general trend in commercial goat production is to use cuts similar to that in lamb (Wilson, 1992). The effectiveness of this in marketing chevon is debatable since the two species differ in distribution of joints within the carcass as well as the dissectible tissues within the joints (Casey, 1992). Previous research shows that the preference for the cuts varies with cultural backgrounds. Whereas, in most of the western world, cuts from the hind limb and the dorsal region are of prime value and the breast region is of lower value whilst a high preference for the breasts has been shown in some studies conducted in Africa and Asia (Wilson, 1992; Prasad and Kirton, 1992). An understanding of the market needs within each country, taking into consideration the different eco-types (genotypes) available, is therefore essential for the development of a market for goat meat.

When evaluating the primal cuts and the weight that each cut contributed to the total carcass (Table 3.2), the neck, thick rib and shoulder as primal cuts, showed a significant ($P \leq 0.05$) weight interaction between the breeds and sexes. Large frame Indigenous Veld Goat (IVG) bucks had heavier necks (1.19 kg) compared to IVG wethers as well as BG bucks and wethers. For both thick rib and shoulder, BG wethers were heavier (0.56 kg and 1.02 kg, respectively) than BG bucks as well as IVG bucks and wethers. All primal cuts having SCF except the flank showed significant ($P \leq 0.05$) interactions (breed x sex). Large frame Indigenous Veld Goat (IVG) bucks always seemed to be trending lower, with the highest percentages measured in IVG wethers. In contrast, the opposite observation was made for muscle % where IVG bucks had significant ($P \leq 0.05$) higher percentages for the neck (73.9 %) and shoulder (76.7 %), with a tendency ($P \leq 0.10$) observed in the breast (63.4 %), compared to IVG wethers and BG (wethers and bucks). In addition, BG wethers presented higher % muscle for the leg (79.0 %) and a tendency to be higher for the chump (72.0 %). No significant interactions for % bone was observed, apart from a tendency ($P \leq 0.10$) for the leg and chump, with higher percentages observed for BG bucks followed by IVG bucks, IVG wethers and BG wethers. The proportion of bones in most joints could be explained by the early maturing nature of bone tissue (Kerth *et al.,* 2007). Bone matures early in lifetime such that its turnover rate is slower than that of fat and muscles later in life (Atti *et al.,* 2006).

When considering the main effects, wethers in general had higher percentages SCF (neck, flank, shoulder, breast, loin and chump) compared to bucks; however, bucks had higher percentages bone (thick rib, loin, chump and leg) and muscle (flank, shoulder and breast). Large frame Indigenous Veld Goats (IVG) significantly ($P \leq 0.05$) had higher % bone for the shoulder (>19.5 %) and shin (>40.8 %) with a tendency towards higher % muscle in the neck and breast compared to BG. No significant breed differences were observed for SCF % in all the primal cuts. Within the carcasses, overall, the leg and shoulder seem the most ideal high-value cuts in terms of saleable meat yield due to their exceptional lean and low-fat levels, although the possibility exists that the quality (particularly tenderness) of these cuts might not be ideal.

3.3.3. Proximate composition of loins

There were no interactions for any of the proximate chemical composition between breed and sex (Table 3.3) after the removal of the SCF. There were sex effects for moisture, protein, fat and ash percentages. In addition, significant ($P \leq 0.05$) breed effects were observed for fat and ash percentages, whereas no significance were observed in terms of moisture and protein. Values recorded in this investigation correspond favourably to that reported previously (Ripoll *et al.,* 2012).

Both BG and IVG bucks had higher % moisture, whilst BG and IVG wethers had higher % fat. The IVG wethers demonstrated higher values for kidney fat (Table 3.1) in combination with more subcutaneous fat in the various commercial cuts (Table 3.2), and they can be associated with higher order of development of the various fat depots (Berg and Walters, 1983). Goats deposit more visceral fat and less subcutaneous, inter-, and intramuscular fat compared to sheep and cattle (Webb *et al.,*

2005). Several studies have compared the chemical composition of sheep and goats at the same slaughter weight, age or under similar feeding management and has found that goat meat is characterised by lower intramuscular fat and higher moisture content (Babiker *et al.,* 1990; Mahgoub and Lodge, 1998; Sen *et al.,* 2004; Santos *et al.,* 2008). Even though significant differences (P = 0.001) for ash % were detected between the breeds and between sexes, the numerical % were still low (0.9 % to 1.1 %). Although there is documentation on chemical composition and meat quality of sheep and goat meat (Sheridan *et al.,* 2003; Santos *et al.,* 2008; Lee *et al.,* 2008), the results from the current study highlight that differences between indigenous goat eco-types and breeds in South Africa. This could be an area for further exploration as has been done with different sheep breeds.

3.4. Conclusion

Although the Boer Goat (BG) is the most popular goat breed across the world for meat production, the results of this study showed that, under the same production conditions large frame Indigenous Veld Goat (IVG) could have a similar potential for goat meat production. More significant differences in carcass characteristics were observed between the wethers and bucks rather than between breed types. Large frame IVG bucks seemed particularly suited for higher meat yield that is leaner with lower subcutaneous and intramuscular fat (SCF and IMF), compared to the BG bucks and, in particular, the wethers of both breed types. The latter tend to accumulate more SCF and IMF. In contrast, wethers produce a meat product (chevon) with increased SCF and IMF contents that could satisfy another consumer market segment that prefer a somewhat juicier and flavorsome carcass - these aspects warrant further research. Development of the formal commercial market for goat meat would offer more diversity of species for red meat producers and especially benefit smallholder farmers who typically produce most of the goats in the world.

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CHAPTER 4

Muscle profiling of large frame Indigenous Veld Goat and Boer Goat wethers and bucks of Southern Africa

Abstract

*The objective was to describe the factors influencing the tenderness, and colour attributes of six muscles (Longissimus thoracis et lumborum (LTL), Semimembranosus (SM), Biceps femoris (BF), Supraspinatus (SS), Infraspinatus (IS), Semitendinosus (ST)) from large frame Indigenous Veld Goats (IVG) and Boer Goats (BG). Weaner male Boer Goats (BG; n = 18; 10 bucks and 8 wethers) and large frame Indigenous Veld Goats (IVG; n = 19; 9 bucks and 10 wethers) were raised on hay and natural grass ad libitum and the recommended amount of commercial pelleted diet to a live weight of between 30 and 35 kg. All carcasses were electrically stimulated 10 minutes post-mortem. All dressed carcasses were chilled at 4°C within 1 hour post-mortem. The six different muscles were dissected from both sides and aged for 1- and 4-days post-mortem. Variations in meat characteristics such as pH, temperature, water holding capacity (WHC), % drip loss (DL), myofibril fragment length (MFL), intramuscular fat (IMF), connective tissue characteristics, and Warner-Bratzler shear force (WBSF) between the muscles were found. The IS muscle had the highest total collagen, whereas the LTL and SM muscles were the muscles with the lowest values observed for insoluble collagen and soluble collagen. The % solubility seems similar for all the muscles. The LTL muscle had the highest shear force values (>40.0 N), followed by BF, ST, SM, SS and IS at 1- and 4-days post-mortem. The LTL and SM had similar colour attributes. Bucks had higher L * and Hue angle values, whereas wethers had increased a*, b* and Chroma values. Muscle profile data will allow informed decisions to support muscle-specific strategies, which may be used to improve consumer acceptability of chevon.*

Keywords: Cape Lob Ear and Cape Speckled, meat tenderness, meat colour, collagen, boar goat, chevon

4.1. Introduction

Indigenous Veld Goats (IVG) are a group of specific pure-bred indigenous eco-types represented by the IVG-Association that define specific standards that a goat must adhere to before it can be classified as one of the eco-types such as the Cape Lob Ear and the Cape Speckled goats (registered as a breed at Studbook). Both of these eco-types have large frames and can compete with the Boer Goat (BG) in terms of meat yield, with advantages such as adaptability to harsh climates and disease resistance. The increasing global human population and the threat of global warming, makes it important to promote the production of goat meat (chevon) from adapted eco-

types such as the IVG. Although chevon is popular amongst the larger population of Southern Africa, chevon is not available on the commercial shelves in South Africa, the major reason being that there are insufficient commercial slaughter numbers to ensure a constant supply to the commercial retail market. Although Southern Africa has relatively large numbers of meat goats (703 892 head) (FAOSTAT, 2020), most are produced in the informal sector and traded within this sector thereby making it challenging obtaining official statistics of the volumes of goat meat produced and traded. Available goats are either sold alive for traditional slaughtering practices or exported to Middle Eastern and Asian countries. Small and emerging Southern African farmers are interested in IVGs as they do not require intensive management to be productive. For chevon, quality fresh meat is the most economically profitable, however the scientific knowledge on meat quality of these breed types is scarce, compared to that of the well-known "improved" BG breed and the non-defined "indigenous" goats that are usually used in comparison studies (Tshabalala *et al.,* 2003; Simela, 2005; Webb *et al.,* 2005; Pophiwa *et al.,* 2016; 2017; 2020).

The term "meat quality" includes many attributes; texture and colour are important attributes to consumers, with texture the most important. Tenderness and mechanical properties of meat are influenced by the connective tissue, myofibrils, and their interactions (Sacks *et al.,* 1988; Listrat *et al.,* 2016). The goat carcass consists of over a hundred different muscles with different properties, which affect processing characteristics and could influence consumer acceptability (Font-i-Furnols and Guerrero, 2014). There has been a continued trend in the retail sector to separate muscles, based on perceived connective tissue characteristics, to better market them and apply the knowledge in terms of the users' requirements. Notable studies on the physical and compositional traits of BG muscles have been conducted over the years (Reviewed by Webb *et al*., 2005). These range from carcass measurements and commercial yields (Sheridan *et al.*, 2003), cooking and juiciness related quality characteristics (Schönfeldt *et al.,* 1993), including studies to understand the impact of carcass handling on the texture, mainly determined by the Warner-Bratzler shear force (WBSF) on different muscles (Schönfeldt *et al.,* 1993; Pophiwa *et al.,* 2016; 2017). Most studies evaluating chevon are conducted on the *Longissimus thoracis et lumborum* (LTL) and *Semimembranosus* (SM) muscles in terms of tenderness and sensory quality attributes (Tshabalala *et al.,* 2003; Simela, 2005; Pophiwa *et al.,* 2017; 2020). This chapter focuses on muscle collagen characteristics, myofibril fragment length (MFL), WBSF and meat colour (CIE *L**, *a**, *b**, Chroma and Hue-angle), and the effect of breed (IVG vs. BG) and sex (bucks and wethers) in six different muscles (e.g., *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST) to establish baseline for these eco-types. The comparison of connective tissue content from different muscle sources within the same goat species have not been studied before.

4.2. Materials and Methods

4.2.1. Animal and experimental design

This research was approved by the Agricultural Research Council – Animal Production (ARC-AP) Ethics Committee (ref no. APIEC16/021). Weaner Boer Goats (BG; n = 18; 10 bucks and 8 wethers) and large frame Indigenous Veld Goats (IVG; n = 19; 9 bucks and 10 wethers) were purchased from commercial breeders at three months of age (17 kg on average for IVG and 20 kg on average for BG). The commercial breeder when bought had already castrated the male animals on the farm. The animals were reared at the Small Stock Section of the ARC-AP facility situated in Irene, in the Gauteng province of South Africa. During the rearing phase, the goats were randomly placed (breed and sex mixed) in two similar large grazing camps (~1500 m^2) with similar natural grass available during the summer rainfall areas in South Africa, with enough space to move and graze without affecting each other. They were moved to other camps, when the grass seem to be withered and to lessen the chance of worm infestation. The aim was to simulate a small farm situation that is typical in the grassland areas. The natural grass diet was supplemented with hay *ad libitum* and an average of 250 g commercial “Ram, lamb and ewe - 13” pellets (protein 130 g/kg, fat 25 - 70 g/kg, fiber 150 g/kg, moisture 120 g/kg, calcium 15 g/kg, phosphorus 3 g/kg, urea 10 g/kg; Meadow Feeds, Lanseria Corporate Estate, Malibongwe Drive, Lanseria, Gauteng, South Africa) per day per animal. Pellets were spread evenly along 20 m long narrow feeding troughs, giving all goats in the camps an equal opportunity to feed. Water was provided *ad libitum*. The duration spent under these farming conditions was on average 6 to 8 months until the goats had attained a live weight (LW) of between 30 and 35 kg. After weighing (LW), the goats were transported for 3 km to the abattoir of the ARC-AP on the day of slaughter. The experimental design is presented in Figure 4.1.

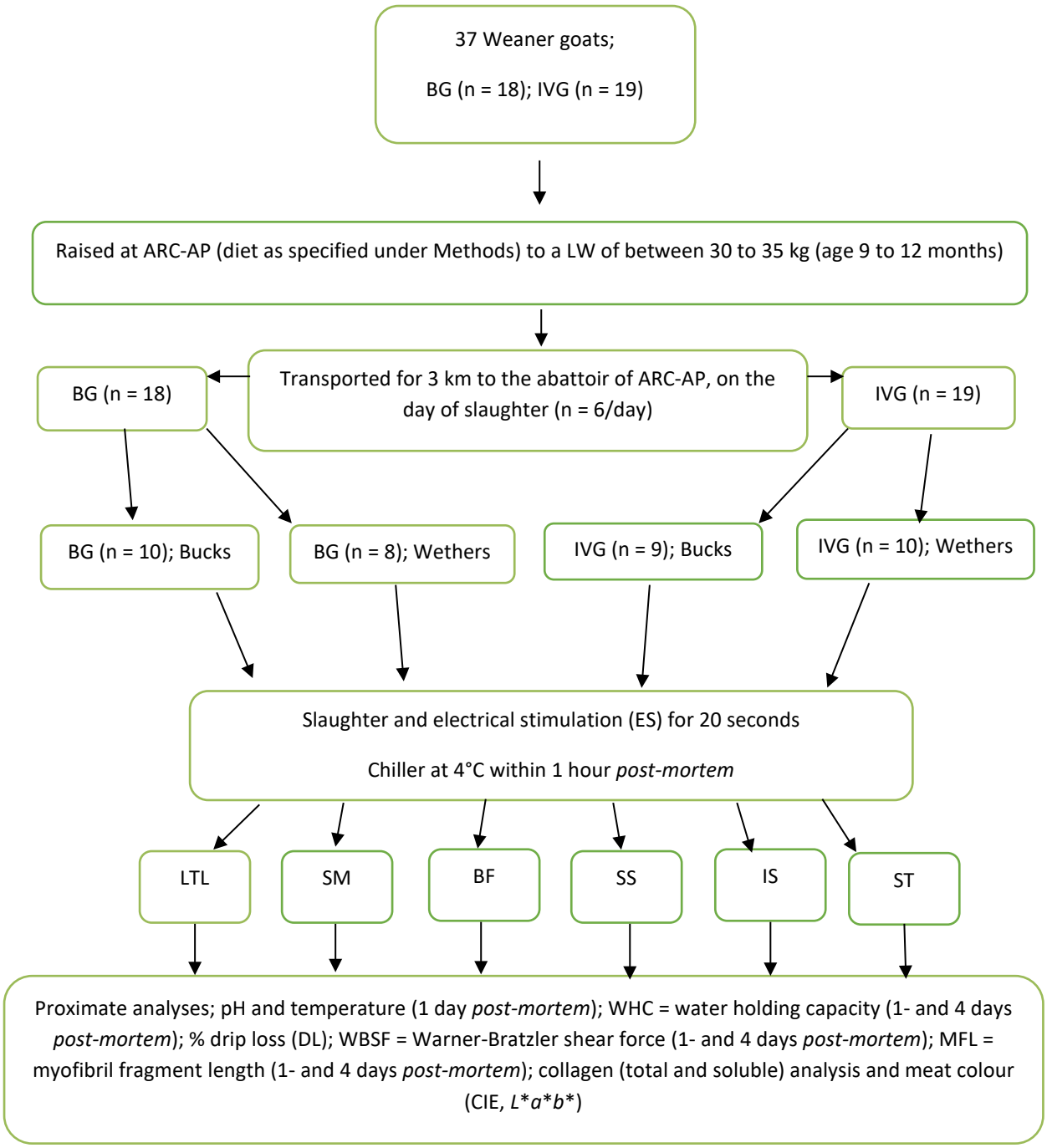

Figure 4.1. Experimental design to evaluate the effect of breed; large frame Indigenous Veld Goats (IVG, Cape Speckled and Cape Lob Ear) and Boer Goats (BG) of Southern Africa, on tenderness factors, colour attributes and connective tissue characteristic of *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)). ARC-AP = Agricultural Research Council - Animal Production, Irene, South Africa.

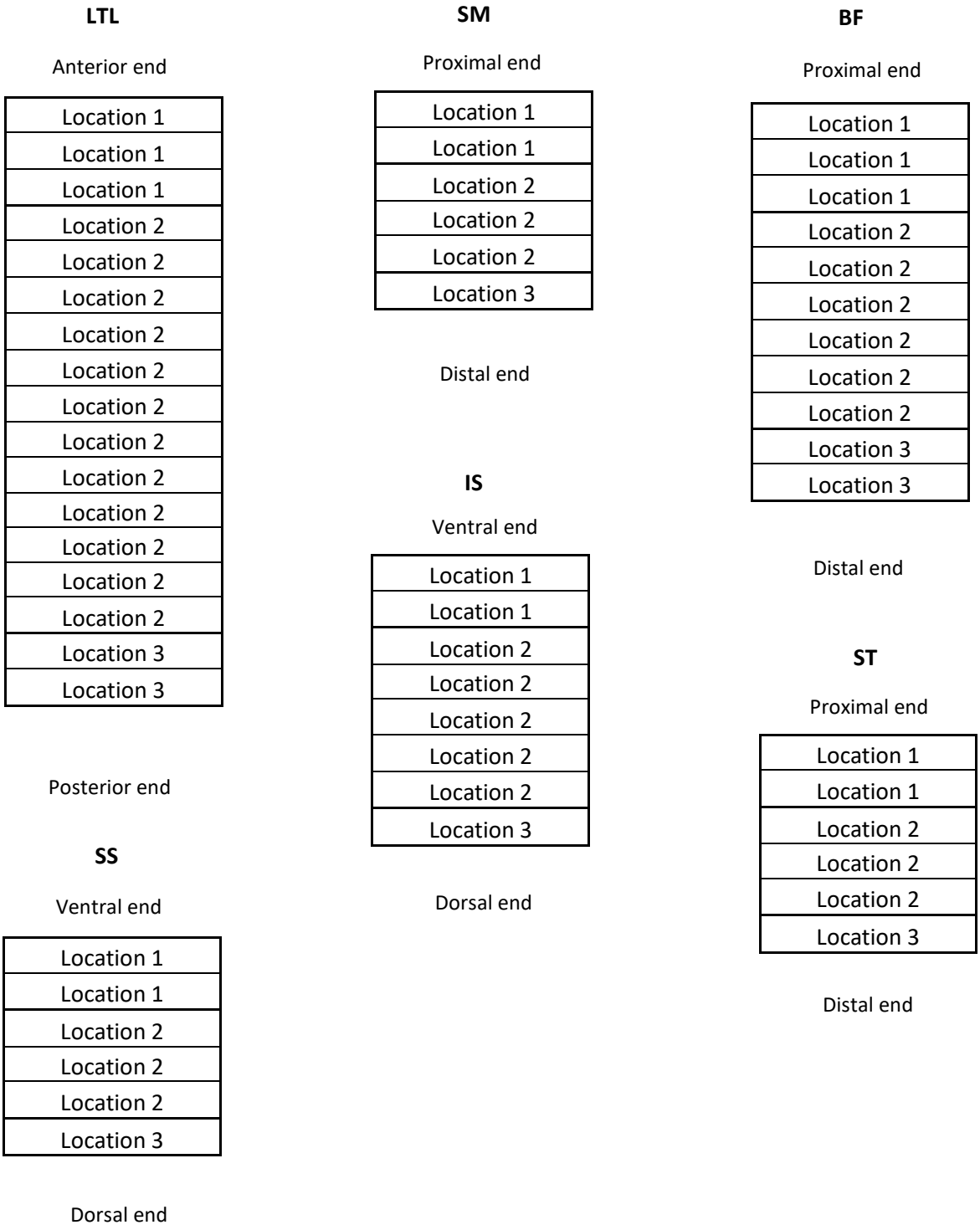

Figure 4.2. Sampling locations of the six different muscles (e.g., *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)). Left side of carcass for 1 day samples for location 1 (meat colour (CIE, *L*a*b**), water holding capacity (WHC), myofibril fragment length (MFL), location 2 (Warner-Bratzler shear force (WBSF)) and location 3 (collagen (total and soluble) analysis); Right side of carcass for 4 days samples for location 1 (meat colour (CIE, *L*a*b**), water holding capacity (WHC), myofibril fragment length (MFL)), location 2 (Warner-Bratzler shear force (WBSF)) and location 3 (collagen (total and soluble) analysis, proximate analysis). Proximal = nearest the vertebral column. Each horizontal section represents a 2.0 cm-thick steak.

4.3. Laboratory analysis

4.3.1. Proximate analysis

The proximate composition (moisture, protein, fat (representing chemical determined intramuscular fat – IMF) and ash) of the muscles were analysed using the procedures of the Association of Official's Analytical Chemist (AOAC, 1990) at the ARC-AP Analytical Laboratories. The moisture content (% wet weight) was determined according to method 934.01 (AOAC, 1990) by drying samples of 2.5 g of homogenized meat at 100 - 105°C for 24 hours. The ash content (% wet weight) was determined by incinerating the moisture-free samples at 500°C for a minimum of 6 hours according to AOAC (1990) method 942.05. The fat content was determined on 5 g of homogenized sample using a 1:2 chloroform/methanol solution for fat extraction as described in Lee *et al.* (1996). The protein content of the defatted sample was determined using the LECO combustion / Dumas method. The defatted samples were dried and ground to a fine powder, 0.5 g of which was weighed off into LECO™ foil cups and analysed for nitrogen content. This nitrogen content was multiplied by a factor of 6.25 in order to obtain the protein content of the sample, which was subsequently converted to a value per gram wet meat (AOAC, 1990, method 922.15). The LECO was recalibrated after every ten test samples using an EDTA calibration sample (LECO Corporation, St Joseph, MI, USA).

4.3.2. Drip loss (DL) and water holding capacity (WHC) of fresh meat

Drip loss (DL) was measured using a 10 mm thick slice of the six different muscles (LTL, SM, BF, SS, IS, and ST), vacuumed and aged for 4 days at 4°C. Water holding capacity (WHC) of the six muscles were determined using the filter paper press method as described by Strydom *et al.* (2005). Briefly, 400 to 500 mg meat sample was placed on filter paper (Whatman 4), contained between two perspex plates. Constant pressure was applied using a hand-operated screw for 5 minutes. The borders of meat and fluid expressed were marked out and their areas measured using a video image analyser (Soft Imaging System, Olympus Japan), according to Irie *et al.* (1996). Water holding capacity was expressed as a ratio of meat area to fluid area.

4.3.3. Myofibril fragmentation length (MFL)

Samples used for MFL were aged for 1- and 4-days *post-mortem*. Sub-samples of ca. 3 g were taken, blended with a blunt blade in cold potassium phosphate extraction buffer at 4˚C to arrest any further proteolysis (Culler *et al.,* 1978), and determined according to Heinze and Bruggemann (1994). The droplets of extracted MFL solution were mounted on slides, covered with a cover slip, and viewed under a microscope attached to a video image analysis (VIA). One hundred myofibril fragments per sample were examined and measured at a magnification of 40X.

4.3.4. Warner-Bratzler shear force (WBSF)

The frozen vacuumed packed muscle samples (LTL, SM, BF, SS, IS, and ST) were placed in a cold room of 4°C to thaw for 24 hours before cooking. Whole cuts were prepared according to an oven-broiling method (dry heat cooking) using direct radiant heat (AMSA, 2016). Calibrated electric ovens (Mielé ovens, model H217, Miele & Cie. KG, Gütersloh, Germany) were set on "broil" 10 minutes prior to cooking at 160°C. The samples were placed on an oven pan on a rack and broiled for approximately 20 minutes until they reached an internal core temperature of 70˚C. The internal temperature was monitored by placing an iron-constant thermocouple (T-type) (Hand-model Kane-Mane thermometer, Kane International Ltd, Hertfordshire, England) in the approximate geometric centre of each sample. The cooked meat + pan + drip was weighed. The cooked samples were cooled for 2 hours at room temperature before shear force measurement. For shear force measurements, six cylindrical samples (12.5 mm core diameter) were bored parallel to the direction of the muscle fibres. Each core was sheared perpendicular to the myofibrils using a Warner-Bratzler device fitted to an Instron Universal Testing Machine (Model 4301, Instron Ltd, Buckinghamshire, England) at a crosshead speed = 200 mm/min with one shear in the centre of each core (Honikel, 1998). The toughness of the meat was the average maximum force (N) required to shear through the cores.

4.3.5. Connective tissue characteristics (Total collagen and % collagen solubility)

Soluble, insoluble, and total collagen were determined in fresh minced samples.

4.3.5.1. Total collagen extraction

Total collagen content in the six muscles (LTL, SM, BF, SS, IS, and ST) was determined by measuring the total hydroxyl-proline nitrogen content in hydrolysed samples according to a modified method of Bergman and Loxley (1963). Aproximatly 1 g of fresh sample was weighed into a hydrolysed tube and mixed with 15 ml of 6 N HCl. The samples were hydrolysed at 120°C for 16 hours, 0.5 g active carbon was added to each tube, stirred, and filtered through Whatman 4 filter paper. The aliquots were collected in a 100 ml volumetric flask and filled up to a volume with distilled water. An aliquot of 50 ml was used for the determination of total collagen. The total nitrogen content in the muscles were determined after samples had been digested in a micro Kjeldahl system (Analytical Laboratory ARC-AP).

4.3.5.2. Soluble and insoluble collagen extractions

The solubility of the intramuscular collagen (hydroxy-proline nitrogen content of soluble collagen) was determined according to the method of Hill (1966) with some modifications. About 2 g of fresh sample was stirred in 10 ml of 1 % NaCl. The samples were heated in a shaking water bath at 78°C for 60 minutes. The cooled samples were centrifuged at 10 000 RPM for 15 minutes. The

supernatants were poured into hydrolysing tubes, marked as soluble. The pellet was poured into another hydrolysing tube and marked insoluble. To each tube, 7.5 ml of 6 N HCl (19.2 %) was added and hydrolysed overnight at 120°C. The following day, 0.5 g of active carbon was added to the cooled tubes, stirred, and the homogenates filtered into 50 ml volumetric flasks and filled to the mark with distilled water. Aliquots of 50 ml were used for determination of both soluble and insoluble collagen.

4.3.5.3. Procedure for determination of soluble, insoluble, and total collagen

Hydroxy-proline concentrations were determined calorimetrically according to a modified method of Boccard *et al*. (1979). About 1 ml of the final sample was added into the test tubes where 1 ml of 10 % KOH solution was added (to neutralise the acid in the sample, this is always a 2X dilution that must be included in all sample calculations). A blank consisting of 2 ml distilled water was prepared. Standard solutions were prepared containing zero to 7.5 µg/ml and 2 ml hydroxy-proline.

To each test tube (including standards and blanks), 1 ml of the oxidant solution (1.41 g Chloramine-T in a 100 ml, pH 6.8 buffer solution consisting of: 26 g citric acid monohydrate, 14 g sodium hydroxide, 78 g Anhydrous sodium acetate and 250 ml propan-1-ol) was added. The tubes were vortexed for 5 seconds and left for 20 minutes at room temperature. After 20 minutes, 1 ml of the colour reagent (10 g para-dimethylaminobenzaldehyde, 35 ml perchloric acid solution (60 %), 65 ml propan-2-ol, prepared fresh) was added and the tubes vortexed. The tubes were heated to 62°C ± 5°C for 30 minutes, then vortexed. Thereafter, they were cooled to room temperature (a strong aromatic pink liquid with a white salt residue form in the tubes). The top transparent pink liquid was pipetted into disposable micro cuvettes and read on a spectrophotometer at 558 nm (± 2 nm). Cuvette content were scanned between 480 nm and 620 nm.

Total collagen content was expressed as hydroxy-proline nitrogen per total protein nitrogen (Hypro N x 10^3/ total protein N) by calculating hydroxy-proline nitrogen from hydroxy-proline MM 131.13 and nitrogen atom number 14.0067. Collagen values can be expressed as mg collagen/g of sample by using the hydroxy-proline conversion of 7.25 and 7.53 for insoluble and soluble collagen respectively (Cross *et al.* 1973).

4.3.6. Minolta meat colour

Colour of muscle samples ca. 15 mm thickness were measured fresh at 1- and 4-days *post-mortem*. On samples that were vacuumed packed and aged for 4 days at 4°C, the meat samples were allowed to bloom for 60 minutes at ± 4˚C before the meat colour values were recorded. The surface absorbance was measured at three different positions on the meat samples from 400 to 730 nm in increments of 10 nm. A Konica-Minolta 600d spectrophotometer (Konica-Minolta Inc. Osaka, Japan) with the software package Spectra Magic NX Pro was used to record the three components; lightness, *L** (dark [0] to light [100]) and the two chromatic components; *a** (green [-60, 180˚] to red [+60, 0˚]) and *b** (blue [-60, 270˚] to yellow [+60, 90˚]) which represented the myoglobin levels in the meat (CIE, 1986). The spectrophotometer configuration consisted of illuminate (A), with an observer

angle of 10˚ and the spectral component excluded after calibration using a white reference (Krzywicki, 1978). Chroma (saturation index ((S) = $(a^{*2}+b^{*2})^{1/2}$); (MacDougall, 1977)) and Hue-angle (discolouration) = $\tan^{-1(b^*/a^*)}$; (Young *et al.,* 1999) were calculated from *a** and *b** values, Chroma measures colour intensity where the higher values indicate more intense red colour in meat. An increase in Hue-angle between 0˚ and 90˚ corresponds to a blending of yellowness or less of redness, probably due to metmyoglobin formation in fresh meat.

4.3.7. Statistical analysis

The data were subjected to analysis of variance (SAS, 1999) using a two-way ANOVA to test the effect of the two goat breeds (BG and IVG) and the two sex-types (bucks and wethers) and interactions on the six muscles with the following factors: pH and temperature (24 hours *post-mortem,* pH_u and T_u), WHC (1 and 4 days *post-mortem*), % DL, meat colour (CIE *L**, *a**, *b**, Chroma and Hue-angle; 1 and 4 days *post-mortem*), MFL (1 and 4 days *post-mortem*), WBSF (1 and 4 days *post-mortem*) and connective tissue characteristics. The two ageing periods (1- and 4-days *post-mortem)* were set as subplots for CIE *L**, *a**, *b**, Chroma and Hue angle. Least square means were compared if a significant F statistic (5 % level of probability) was detected by analyses of variance (Snedecor and Cochran, 1980). Slaughter day had no effect on the outcome of the results, therefore the data applicable to slaughter day was pooled within the main treatments and interactions of sex and breed treatments with ageing.

Prior to analyses, a Shapiro-Wilk test for normality was performed on the data (Shapiro and Wilk, 1965) and where applicable, outliers (classified as such when the standardized residual for an observation deviated with more than three SDs from the model value) were removed. Statistical significance (Fisher's t-test, least significant difference) was calculated at a 5 % level to compare means. $P \leq 0.05$ was considered statistically significant, although in some instances' data with a $P \leq 0.1$ (10 % level) was considered as a trend worth wile to discuss. Where applicable, the closeness of the linear relationships between the measured variables was determined using Pearson' correlation coefficient (r).

4.4. Results and Discussions

Generally, the evaluation of carcass characteristics of the two breed types (BG vs. IVG) showed more differences between the sexes (bucks vs. wethers) with no significant differences observed between the breeds (Table 4.1). Only live weight (LW) showed a breed x sex interaction; the average LW of large frame IVG wethers were lighter ($P = 0.032$) compared to that of the IVG bucks and BG bucks and wethers. In contrast, a tendency ($P = 0.095$) an interaction between breed x sex for the WCW was observed. The average WCW of the BG wethers was higher compared to BG bucks; whilst no significant differences were noted between sexes.

Table 4.1. Least square means and standard error (SE) of means for carcass characteristics of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed						
	BG		IVG		Significance (P – Values)		
Carcass characteristics	Bucks n = 10	Wethers n = 8	Bucks n = 9	Wethers n = 10	Breed	Sex	Breed x Sex
Live weight (kg)	35.40^{ab} ± 4.01	36.13^{a} ± 3.02	36 67^{a} ± 2.68	32.8^{b} ± 2.39	0.293	0.118	**0.032**
Warm carcass weight (kg)	15.77 ± 2.36	16.70 ± 1.71	16.40 ± 1.91	15.27 ± 1.00	0.531	0.826	0.095
Cold carcass weight (kg)	15.26 ± 2.31	16.25 ± 1.66	15.88 ± 1.83	14.86 ± 0.97	0.541	0.938	0.094
Chilling loss (%)	3.20^{a} ± 0.34	2.71^{b} ± 0.35	3.17^{a} ± 0.91	2.62^{b} ± 0.47	0.578	**0.009**	0.875
Dressing (%)	42.99^{a} ± 2.44	44.95^{b} ± 1.08	43.28^{a} ± 3.23	45.42^{b} ± 2.49	0.508	**0.017**	0.912

^{a,b} Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

Similar results was also recorded with respect to the CCW. Boer Goats (BG, both sexes) presented higher (P = 0.009) chilling losses (≥3.1 %) compared to IVG wethers (2.62 %), but similar to IVG bucks (2.71 %) (Table 4.1). Chilling losses in goat carcasses are normally in the range of 2.0 % to 3.0 % and tend to be higher compared to sheep carcasses at comparable ages and sexes (Webb *et al.,* 2005). This phenomenon can be attributed to the absence of thinner subcutaneous fat cover (SCF) found in goats (Webb *et al.,* 2005). The goat carcasses were all classified as having fat codes between -1 and 1 according to the South African Carcass Classification for Small Stock (Government Notice No. R863). The specific depth of the SCF was however not measurable in the present investigation. Goats are late maturing compared to sheep and grow at a slower rate thus fat is only deposited as they progress in physiological age and / or weight (Dhanda *et al.,* 1999; Webb *et al.,* 2005; Brand *et al.,* 2009; 2020). Goat meat is generally considered lean meat that is an ideal protein source for health-conscious groups that try to limit their fat intake. Nonetheless, IVG wethers had the lowest chilling loss (Table 4.1) This result supports the findings of the second phase of the present study (Chapter 3, and Van Wyk *et al.,* 2020) and supports the argument that higher levels of SCF reduce chilling losses (Ragni *et al.,* 2015; Rotondi *et al.,* 2018; Colonna *et al.,* 2020). High chilling losses are undesirable as they reduce the weight and the economic value of the carcasses as seen between the BG bucks and IVG wethers. The mean dressing percentage varied between 42.9 % and 45.4 %, which agrees with the values reported for BG, large frame IVG and undefined South African indigenous goats (Tshabalala *et al.,* 2003; Chapter 3, and Van Wyk *et al*., 2020). Castration normally slows down animal growth by increasing the rate of deposition of adipose tissue (fat) to the detriment of the muscular tissue (meat) on the carcass at slaughter (Mahgoub *et al.,* 2011). In addition, it is likely one of the main reasons for differences (P = 0.017) in dressing percentage between the two sexes. Means and standard errors of chemically determined moisture, protein, fat, and ash content, in the six muscles (LTL; SM; BF; SS; IS, and ST) of BG and large frame IVG (bucks and wethers) are presented in Table 4.2.

Table 4.2. Least square means and standard error (SE) of means for chemical composition of the six different muscles (LTL, SM, BF, SS, IS, and ST) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Muscle														
Proximate Analysis (%)	**LTL**		**SM**		**BF**		**SS**		**IS**		**ST**		**Significance (P-Values)**		
	Bucks	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Muscle**	**Sex**	**Muscle x Sex**
Moisture	76.2^{bc} ± 1.0	75.4^{cd} ± 1.4	77.3^{ab} ± 1.3	76.6^{ab} ± 1.08	74.9^{bc} ± 2.0	71.4^{e}± 5.2	77.6^{a} ± 0.9	77.3^{ab} ± 0.6	78.0^{a} ± 0.96	77.3^{ab} ± 1.36	75.4^{cd} ± 1.7	74.1^{d} ± 2.4	**<.0001**	**<.0001**	**0.002**
Protein	20.2^{c} ± 1.2	20.7^{c} ± 1.4	19.2^{d} ± 1.4	19.4^{d} ± 0.8	21.6^{b} ± 1.6	23.1^{a} ± 3.3	18.4^{e} ± 1.2	18.1^{e} ± 0.7	18.5^{e} ± 0.9	18.6^{e} ± 1.0	21.0^{b} ± 1.2	21.2^{b} ± 1.8	**<.0001**	**0.039**	0.194
Fat*	1.7^{cd} ± 1.0	2.6^{b} ± 1.0	1.6^{d} ± 1.5	1.6^{d} ± 0.5	2.3^{bc} ± 1.6	4.1^{a} ± 1.9	1.9^{cd} ± 1.2	2.9^{b} ± 1.2	1.4^{d} ± 1.0	2.4^{bc} ± 0.8	2.6^{b} ± 2.5	2.8^{b} ± 1.1	**<.0001**	**<.0001**	**0.007**
Ash	1.0^{a} ± 0.2	1.0^{a} ± 0.1	0.9^{a} ± 0.2	1.0^{a} ± 0.1	1.0^{a} ± 0.4	1.2^{b} ± 0.2	0.9^{a} ± 0.2	0.9^{a} ± 0.2	0.9^{a} ± 0.2	1.0^{a} ± 0.1	1.0^{a} ± 0.2	1.1^{ab} ± 0.1	**<.0001**	**<.0001**	**0.017**

Longissimus thoracis et lumborum (LTL); Semimembranosus (SM); Biceps femoris (BF); Supraspinatus (SS); Infraspinatus (IS); Semitendinosus (ST); Intramuscular fat (IMF)

**Fat % = chemically determined intramuscular fat (IMF)*

^{a,b,c,d,e} *Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)*

The choice of the particular six muscles (LTL, SM, BF, SS, IS, and ST) studied, was to obtain a set of muscles representing a variation in tenderness and originating from different areas of the carcass. Moisture, protein, and IMF contents were in the range of 71.4 - 78.0 %, 18.1 - 23.1 %, and 1.4 - 2.8 %, respectively. The muscles showed interactions between muscle and sex ($P \leq 0.05$) for moisture, IMF, and ash content. No significant effect was observed for protein content for the interaction between the muscle and sex. Bucks showed higher moisture content compared to wethers, however wethers had higher fat and ash contents in the muscles studied. In the SS muscle, while bucks had a higher protein, content whereas wethers had a higher protein content in the LTL, SM, BF, IS, and ST muscles. Typically, lean skeletal muscles generally have a biochemical composition of approximately 75 g/100 g meat moisture, 20 g/100 g meat protein, 1 - 10 g/100 g meat IMF and 1 g/100 g meat carbohydrates, vitamins, and minerals, with the latter usually analysed as ash (Huff-Lonergan and Lonergan, 2005; Listrat *et al.,* 2016). Previous studies on the moisture content of goat meat were limited to the LTL muscle, thus making it difficult to compare the proximate values obtained for all muscle types. Wethers of both breeds had higher IMF content compared to that of bucks. The highest IMF content was measured in the wethers' BF (~4 %) and the lowest in the bucks' IS (~1.1 %). Although goat meat is considered lean, the % IMF determined in this study is high for small stock especially in wethers. In agreement with results of the current study, Mahgoub *et al.* (2002, 2004) reported faster rate of deposition for carcass and non-carcass fat and total fat for Jebel Akhdar Omani does and wethers raised under intensive management as compared to bucks. Goats tend to deposit most of their fat in the visceral rather than carcass depot and produce leaner carcasses (Devendra and Owen, 1983). The present study proximate composition ranges are higher to that reported by Tshabalala *et al.* (2003) for undefined indigenous goats. This could probably be due to differences between breed, age, nutritional plane, and sample size.

No interactions between the breed x sex were observed for pH_u, T_u, WHC, DL, MFL and IMF content within the six muscles (results not shown). Means and standard errors of breed and sex on pH_u, T_u, WHC, DL, MFL, WBSF and IMF content of the six muscles (LTL, SM, BF, SS, IS, and ST) of BG and large frame IVG are presented in Table 4.3. Breed had a significant ($P \leq 0.05$) influence on pH_u with large frame IVG presenting higher pH_u values compared to that of BG for LTL, SM, BF, SS, and ST muscles. The pH_u measured in the IS muscle did not differ between BG and large frame IVG. The IS and SS muscles had the highest pH_u values, followed by BF and ST. The lowest pH_u were measured in the LTL and SM muscles. Wethers of both breeds (BG and IVG) had significant higher pH_u values compared to bucks for the SS and ST muscles. The ST muscle had a higher T_u 1 day *post-mortem* compared to the other muscles. In terms of T_u, bucks of both breeds (BG and IVG) tended to have a higher T_u 1 day *post-mortem* (LTL and SM) compared to that of wethers.

Table 4.3. Least square means and standard error (SE) of means of breed and sex on ultimate pH (pH_u), temperature 24 hours *post-mortem* (T_u), water holding capacity (WHC), % drip loss, myofibril fragment length (MFL), Warner-Bratzler shear force (WBSF) and Intramuscular fat (IMF) of the *Longissimus thoracis et lumborum (LTL), Semimembranosus (SM), Biceps Femoris (BF), Supraspinatus (SS), Infraspinatus (IS), and Semitendinosus (ST)* muscles of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed						
	BG		IVG		Significance (P – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed x sex
LTL							
pH_u	$5.54^{a} \pm 0.18$	$5.60^{a} \pm 0.05$	$5.67^{b} \pm 0.11$	$5.72^{b} \pm 0.18$	**0.011**	0.241	0.944
T_u (°C)	11.93 ± 2.02	10.53 ± 1.71	11.57 ± 2.01	10.53 ± 2.45	0.681	0.087	0.791
WHC 1 day *pm*[#]	0.41 ± 0.03	0.39 ± 0.06	0.38 ± 0.04	0.37 ± 0.05	0.101	0.384	0.642
WHC 4 days *pm*	$0.38^{a} \pm 0.04$	$0.45^{b} \pm 0.08$	$0.39^{a} \pm 0.08$	$0.43^{b} \pm 0.07$	0.979	**0.018**	0.515
Drip loss (%)	1.71 ± 0.84	1.86 ± 0.78	2.00 ± 1.02	1.96 ± 0.79	0.495	0.836	0.721
WBSF 1 day *pm* (N)	58.5 ± 1.10	59.0 ± 1.17	57.4 ± 1.15	59.5 ± 1.05	0.958	0.752	0.834
WBSF 4 days *pm* (N)	46.5 ± 1.14	40.5 ± 1.12	43.3 ± 0.88	42.9 ± 1.22	0.842	0.395	0.499
MFL 1 day *pm* (µm)	37.16 ± 5.46	35.55 ± 4.83	35.26 ± 5.05	37.42 ± 5.04	0.351	0.220	0.319
MFL 4 days *pm* (µm)	33.62 ± 6.21	29.63 ± 2.01	30.32 ± 5.07	29.85 ± 6.14	0.471	0.332	0.426
Fat*	$1.97^{a} \pm 1.11$	$2.58^{b} \pm 1.35$	$1.49^{a} \pm 0.94$	$2.59^{b} \pm 0.70$	0.620	**0.017**	0.473
SM							
pH_u	$5.57^{a} \pm 0.09$	$5.56^{a} \pm 0.09$	$5.68^{b} \pm 0.18$	$5.78^{b} \pm 0.14$	**0.001**	0.266	0.216
T_u (°C)	$11.69^{y} \pm 2.37$	$9.90^{x} \pm 2.05$	$10.56^{y} \pm 2.22$	$9.30^{x} \pm 2.91$	0.221	0.068	0.742
WHC 1 day *pm*	0.41 ± 0.03	0.40 ± 0.07	0.39 ± 0.06	0.37 ± 0.04	0.126	0.401	0.723
WHC 4 days *pm*	$0.37^{a} \pm 0.05$	$0.40^{b} \pm 0.08$	$0.37^{a} \pm 0.05$	$0.43^{b} \pm 0.07$	0.379	0.054	0.536
Drip loss (%)	1.90 ± 0.71	2.41 ± 0.64	2.29 ± 0.53	2.48 ± 1.31	0.367	0.236	0.580
WBSF 1 day *pm* (N)	$51.4^{b} \pm 0.98$	$41.4^{a} \pm 0.91$	$45.2^{a} \pm 0.83$	$50.6^{b} \pm 1.47$	0.706	0.569	**0.041**
WBSF 4 days *pm* (N)	19.0 ± 0.71	22.9 ± 0.48	23.0 ± 0.54	24.8 ± 0.65	0.116	0.171	0.608
MFL 1 day *pm* (µm)	42.25 ± 6.69	39.49 ± 4.94	37.56 ± 4.85	38.17 ± 3.91	0.076	0.558	0.355
MFL 4 days *pm* (µm)	$35.68^{a} \pm 6.12$	$30.11^{b} \pm 2.46$	$31.60^{a} \pm 3.97$	$29.46^{b} \pm 4.55$	0.079	**0.017**	0.265
Fat*	1.41 ± 0.91	1.53 ± 0.49	1.27 ± 0.90	1.73 ± 0.48	0.838	0.234	0.476
BF							
pH_u	$5.74^{a} \pm 0.11$	$5.71^{a} \pm 0.14$	$5.82^{b} \pm 0.13$	$5.91^{b} \pm 0.16$	**0.003**	0.477	0.204
T_u (°C)	11.66 ± 2.45	10.76 ± 1.49	11.19 ± 1.99	10.65 ± 2.47	0.622	0.328	0.804
WHC 1 day *pm*	$0.38^{y} \pm 0.04$	$0.38^{y} \pm 0.05$	$0.36^{x} \pm 0.04$	$0.35^{x} \pm 0.05$	0.096	0.550	0.686
WHC 4 days *pm*	0.35 ± 0.04	0.41 ± 0.06	0.37 ± 0.04	0.37 ± 0.06	0.647	0.167	0.074
Drip loss (%)	0.96 ± 0.34	1.00 ± 0.40	0.97 ± 0.27	0.70 ± 0.35	0.182	0.282	0.188
WBSF 1 day *pm* (N)	55.8 ± 1.06	47.1 ± 1.52	49.9 ± 1.09	47.6 ± 1.43	0.444	0.211	0.455
WBSF 4 days *pm* (N)	44.5 ± 0.82	34.4 ± 0.78	40.9 ± 0.96	42.1 ± 1.36	0.652	0.213	0.102
MFL 1 day *pm* (µm)	$43.57^{a} \pm 9.93$	$35.01^{b} \pm 5.51$	$40.81^{a} \pm 6.80$	$38.89^{b} \pm 6.50$	0.989	**0.046**	0.188
MFL 4 days *pm* (µm)	$35.11^{a} \pm 5.76$	$28.26^{b} \pm 3.54$	$33.29^{a} \pm 7.04$	$32.21^{b} \pm 5.27$	0.724	**0.044**	0.128
Fat*	$2.75^{a} \pm 1.85$	$4.18^{b} \pm 2.46$	$1.88^{a} \pm 1.29$	$3.74^{b} \pm 0.74$	0.345	**0.005**	0.694

[a,b] Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

[#]pm = post-mortem

**Fat % = chemically determined intramuscular fat (IMF)*

Table 4.3. (Continued). Least square means and standard error (SE) of means of breed and sex on ultimate pH (pH_u), temperature 24 hours *post-mortem* (T_u), water holding capacity (WHC), % drip loss, myofibril fragment length (MFL), Warner-Braztler shear force (WBSF) and Intramuscular fat (IMF) of the *Longissimus thoracis et lumborum (LTL), Semimembranosus (SM), Biceps Femoris (BF), Supraspinatus (SS), Infraspinatus (IS), and Semitendinosus (ST)* muscles of Boer- (BG) and large frame Indigenous Veld Goat (IVG).

	Breed						
	BG		IVG		Significance (P – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed x Sex
SS							
pH_u	$5.89^{a} \pm 0.27$	$5.98^{b} \pm 0.11$	$5.91^{a} \pm 0.12$	$6.17^{b} \pm 0.25$	0.092	**0.017**	0.267
T_u (°C)	$12.98^{a} \pm 1.70$	$10.99^{ab} \pm 2.23$	$11.66^{ab} \pm 2.26$	$9.80^{b} \pm 2.54$	0.059	**0.012**	0.926
WHC 1 day *pm*[#]	$0.35^{x} \pm 0.03$	$0.35^{x} \pm 0.03$	$0.35^{x} \pm 0.06$	$0.31^{y} \pm 0.04$	0.205	0.078	0.165
WHC 4 days *pm*	$0.35^{ab} \pm 0.03$	$0.35^{ab} \pm 0.04$	$0.36^{a} \pm 0.06$	$0.41^{b} \pm 0.03$	**0.019**	**0.026**	0.185
Drip loss (%)	1.89 ± 0.48	2.21 ± 1.12	1.60 ± 1.03	1.92 ± 1.00	0.384	0.306	0.999
WBSF 1 day *pm* (N)	37.6 ± 0.44	37.4 ± 0.60	39.7 ± 0.50	35.8 ± 0.71	0.908	0.415	0.230
WBSF 4 days *pm* (N)	33.1 ± 0.43	31.9 ± 0.84	34.7 ± 0.49	30.0 ± 0.69	0.968	0.177	0.420
MFL 1 day *pm* (µm)	41.06 ± 5.85	45.03 ± 5.03	44.08 ± 4.74	42.13 ± 2.73	0.883	0.560	0.066
MFL 4 days *pm* (µm)	38.64 ± 6.78	37.85 ± 5.78	40.22 ± 3.62	35.46 ± 4.60	0.803	0.130	0.276
Fat*	$1.94^{a} \pm 1.09$	$3.05^{b} \pm 1.53$	$1.76^{a} \pm 1.05$	$2.76^{b} \pm 0.80$	0.689	**0.008**	0.888
IS							
pH_u	5.97 ± 0.26	6.11 ± 0.10	6.09 ± 0.24	6.12 ± 0.21	0.324	0.247	0.446
T_u (°C)	12.32 ± 2.86	11.51 ± 2.04	12.08 ± 2.32	10.66 ± 2.57	0.448	0.182	0.713
WHC 1 day *pm*	0.36 ± 0.05	0.38 ± 0.07	0.34 ± 0.05	0.34 ± 0.05	0.195	0.791	0.606
WHC 4 days *pm*	0.35 ± 0.05	0.39 ± 0.06	0.38 ± 0.04	0.37 ± 0.05	0.686	0.419	0.199
Drip loss (%)	$0.97^{a} \pm 0.35$	$1.20^{a} \pm 0.57$	$0.82^{b} \pm 0.49$	$0.62^{b} \pm 0.23$	**0.015**	0.960	0.129
WBSF 1 day *pm* (N)	33.8 ± 0.63	31.9 ± 0.45	29.9 ± 0.40	30.0 ± 0.68	0.155	0.641	0.588
WBSF 4 days *pm* (N)	26.9 ± 0.37	28.9 ± 0.42	25.7 ± 0.39	24.8 ± 0.54	0.083	0.726	0.331
MFL 1 day *pm* (µm)	46.53 ± 6.51	42.70 ± 4.59	44.63 ± 5.51	44.43 ± 8.29	0.886	0.367	0.403
MFL 4 days *pm* (µm)	41..41 ± 7.32	39.36 ± 6.25	38.78 ± 4.06	37.46 ± 5.89	0.232	0.407	0.856
Fat*	$1.49^{a} \pm 0.59$	$2.70^{b} \pm 1.10$	$1.10^{a} \pm 0.66$	$2.09^{b} \pm 0.41$	0.092	**<.0001**	0.641
ST							
pH_u	$5.66^{a} \pm 0.11$	$5.69^{a} \pm 0.06$	$5.71^{b} \pm 0.13$	$5.89^{b} \pm 0.18$	**0.004**	**0.021**	0.091
T_u (°C)	13.55 ± 2.12	12.79 ± 1.73	12.72 ± 1.64	12.24 ± 2.31	0.265	0.354	0.833
WHC 1 day *pm*	0.37 ± 0.04	0.35 ± 0.05	0.38 ± 0.03	0.37 ± 0.04	0.432	0.394	0.705
WHC 4 days *pm*	0.38 ± 0.07	0.39 ± 0.06	0.39 ± 0.04	0.41 ± 0.05	0.265	0.421	0.750
Drip loss (%)	1.49 ± 0.97	1.62 ± 0.83	1.93 ± 1.53	1.54 ± 0.92	0.624	0.708	0.479
WBSF 1 day *pm* (N)	$50.8^{a} \pm 0.51$	$44.8^{b} \pm 0.48$	$44.8^{b} \pm 0.48$	$44.1^{b} \pm 1.19$	0.440	**0.047**	0.736
WBSF 4 days *pm* (N)	47.3 ± 0.61	41.4 ± 0.32	43.0 ± 0.64	40.8 ± 1.23	0.288	0.137	0.483
MFL 1 day *pm* (µm)	46.48 ± 4.56	45.63 ± 3.40	44.06 ± 5.03	46.66 ± 5.38	0.662	0.553	0.274
MFL 4 days *pm* (µm)	40.58 ± 5.24	38.44 ± 4.41	40.12 ± 6.19	38.51 ± 8.17	0.864	0.371	0.899
Fat*	$2.12^{a} \pm 1.53$	$2.76^{b} \pm 1.50$	$1.84^{a} \pm 1.07$	$2.93^{b} \pm 0.68$	0.980	**0.040**	0.590

^{a,b} Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

[#]pm = post-mortem

**Fat % = chemically determined intramuscular fat (IMF)*

Pophiwa *et al.* (2016), in contrast, did not report pH_u breed differences, which strengthens the theory that the breeds used in their study were from a similar genotype. Interpretation of the results from the present study should consider that all the carcasses were ES, preventing cold shortening, causing lower pH_u and a lower-than-expected WBSF. Although the WBSF on a muscle level did not vary according to the IMF content, in general, the IMF content correlated with WBSF and DL measured at 4 days *post-mortem* ($r = 0.319$, $P \leq 0.0001$ and $r = -0.392$, $P \leq 0.0001$, respectively). Indicating that it does contribute to the juiciness and aroma of the meat. Starkey *et al.* (2016) found that the main factors, which influenced shear force of the LL and SM, were IMF, sarcomere length and protein degradation.

Different muscles will not show the same pH_u, WHC, DL, WHC and WBSF effects, due to their different intrinsic characteristics (Adeyemi and Sazili, 2014). Nevertheless, a general correlation of $r = -0.314$ ($P \leq 0.0001$), and $r = -0.440$ ($P \leq 0.0001$) were observed between pH_u and WHC 1 day *post-mortem* and DL measured 4 days *post-mortem*, respectively, between all muscles studied. *Post-rigor* T_u and WHC 4 days *post-mortem* correlated with an $r = -0.350$ ($P \leq 0.0001$) and with WBSF ($r = 0.308$; $P \leq 0.0001$). Lower pH_u values can be expected compared to pH_u reported for carcasses that was not ES but rapidly chilled. Pophiwe *et al.* (2016), reported on average pH_u of 5.7 to 5.8 for LTL and SM with no differences between breeds and treatments, which included similar ES conditions, but delayed chilling for non-stimulated (NS) carcasses. A pH_u >5.8 for LTL in goat carcasses were reported by Hogg *et al.* (1992), Swan *et al.* (1998), and Kannan *et al.* (2001) and their conclusion was that DFD is the cause. According to Monin and Sellier (1985), and Scheffler *et al.* (2011), the energy status of muscle *post-slaughter* affects meat tenderness and colour, which in our case is represented by *post-rigor* pH_u and T_u. Although significant ($P \leq 0.0001$), very low general correlations were found between pH_u and T_u and CIE L^*, a^*, b^*, Chroma and Hue-angle measured at 1 day *post-mortem* and even less at 4 days *post-mortem*.

Results of pH_u showed a definite sex effect with higher pH_u in wethers compared to bucks. The pH_u in IS (~6.1) showed on average the highest pH_u. The SS measured a pH_u of ~5.9, followed by BF and ST with pH_u between 5.7 and 5.9. LTL and SM muscles showed similar but lower pH_u values from 5.5 to 5.7. Pophiwa *et al.* (2016) and Safari *et al.* (2009) reported higher pH_u values for LTL and SM. In general, the rate and extent of *post-mortem* glycolysis and ultimate pH of the muscle are critical factors that determine goat meat quality (Casey and Webb, 2010). It is well known that the rate of *post-mortem* pH reduction is an important determinant of other physical meat quality parameters, e.g., WHC and meat colour. According to Simela *et al*. (2004), goat carcasses with a lower pH_u tend to be more tender, with lower shear force values and better colorimetric meat colour than those with a high pH_u values. According to Immonen *et al.* (2000), darker meat in beef occurs with muscle glycogen levels below 50 µmol/g at slaughter. The darker meat colour in goat meat could indeed indicate towards lower glycogen levels, but it could also be a species characteristic linked to myoglobin concentrations, species activity (Neethling *et al.,* 2017). Further research towards this reason should be investigated. Lower pH_u values did not result in lower WBSF in this

study – no correlation was found between pH_u and WBSF, although a slight significant correlation was found between pH_u and MFL measured at 1- and 4-days *post-mortem* (r = 0.170; P = 0.011 and r = 0.122; P = 0.069, respectively). In addition, shear force has been widely variable depending on experimental conditions like animal management regime, species, muscle temperature, muscle pH decline, and meat ageing (Tshabalala *et al.,* 2003; Schönfeldt and Strydom, 2011). A more significant general correlation between T_u and MFL 1 day *post-mortem* was observed (r = 0.225; P = 0.0007) indicating that temperature in the muscle had a higher effect on proteolytic activity. Most BG muscles (LTL; SM, BF and ST) had lower pH_u than the corresponding IVG muscles, although the WBSF did not differ between breed for these muscles (Table 4.3).

A significant (P ≤ 0.05) interaction between breed x sex was observed in the SM muscle for WBSF (1 day *post-mortem*) with no significant interactions observed for WBSF in the other muscles studied at 1- or 4-days *post-mortem* (Table 4.3). In terms of the main effects the only significant breed differences observed were in the SS (WHC 4 days *post-mortem*, P = 0.019) and IS (DL, P = 0.015) muscles (Table 4.3). A tendency to differ (P ≤ 0.10) was observed in the BF muscle (WHC 1 day *post-mortem*), SM muscle (MFL 1- and 4-days *post-mortem*) and in the IS muscle (IMF and WHC 4 days *post-mortem*). Sex differences were observed in the following muscles: LTL muscle (WHC at 4 days *post-mortem*, P = 0.018), SM muscle (MFL at 4 days *post-mortem,* P = 0.017), BF muscle (MFL at 1-day, P = 0.046 and at 4-days *post-mortem,* P = 0.044), SS muscle (WHC at 4 days *post-mortem*, P = 0.026) and the ST muscle (WBSF at 1 day *post-mortem*, P = 0.047) as depicted in Table 4.3. At 1 day *post-mortem* the WHC of LTL and SM muscles was the highest and the lowest in the SS muscle (Table 4.3). At 4 days *post-mortem* LTL muscle had the highest WHC. The SM muscle had significantly higher DL compared to that of the other muscles, followed by LTL, SS and ST muscle, with the BF and IS displaying the lowest DL values.

When evaluating the average WBSF at 1- and 4-days *post-mortem* it was observed that, the LTL muscle had the highest WBSF compared to the other muscles (Table 4.3). The IS muscle presented the lowest WBSF values at 1 day *post-mortem* as well as the SM muscle at 4 days *post-mortem*. The toughest muscles were LTL, BF and ST with about 50.0 N to 60.0 N at 1 day *post-mortem* and with some tenderisation (~40.0 N) at 4 days *post-mortem*. In contrast, SM tenderisation was more effective developing from a tougher 50.0 N at 1 day *post-mortem* to a very tender 20.0 N. In contrast, the IS and SS that showed high pH_u were tender (~37.0 N and ~30.0 N; respectively) at 1 day *post-mortem* and did not tenderise further when measured at 4 days *post-mortem* (~32.0 N and ~26.0 N; respectively). Figure 4.3 is a visual representation of how little the BF, IS, SS, and ST goat muscles tenderised over a period of 3 days whilst the LTL and SM had the ability to tenderise over a 3-day period.

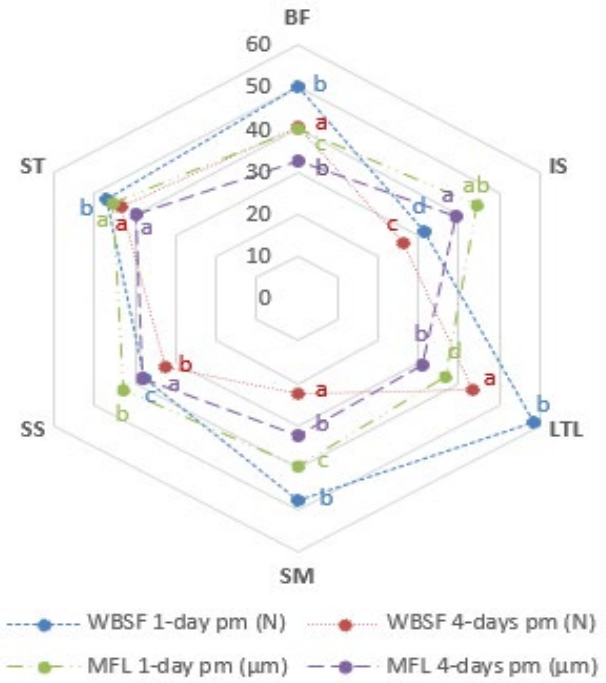

Figure 4.3. Ranking of *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps Femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST) based on Warner-Bratzler shear force values (WBSF, 1- and 4-days *post-mortem, pm*) and myofibril fragment length (MFL, 1- and 4-days *post-mortem, pm*) on a scale of 0 to 60 N and 0 to 60 µm, respectively. [a,b,c,d] Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$).

Myofibril fragmentation is a representative of proteolytic activity and explains the WBSF measured in the LTL, ST, IS and SS that correspond with 1 to 4 days *post-mortem* MFL differences (Figure 4.3). For MFL at 4 days *post-mortem* the LTL and SM muscle had on average the shortest MFL versus the other muscles and ST the longest that was similar to that of the SS and IS muscles. Surprisingly, the most proteolytic activity as reflected in MFL differences between 1- and 4-days *post-mortem* followed by SM, was detected in BF. According to the MFL measured in the LTL, this muscle should have been more tender compared to most of the other muscles, indicating that other factors must have influenced the tenderising process at slaughter or as a result of *post-mortem* procedures that could include ineffective ES, chilling, or cooking methods. Wethers seem to have a more effective proteolytic activity *post-mortem* compared to bucks in BF and SM (larger 1- and 4-days *post-mortem* differences), but none of the other muscles showed the same effect. Nonetheless, MFL measured at 1- and 4-days *post-mortem* generally correlated with WBSF measured at 4 days *post-mortem* ($r = 0.270$, $P \leq 0.0001$ and $r = 0.407$, $P \leq 0.0001$, respectively), although no significant correlation could be established with WBSF measured at 1 day *post-mortem*.

Differences and interactions between the breed x sex were not observed for connective tissue characteristics among the six muscles. Means and standard errors of muscle-type on the average connective tissue characteristics for the six muscles (LTL, SM, BF, SS, IS, and ST) from bucks and wethers of BG and large frame IVG are presented in Table 4.4.

Table 4.4. Least square means and standard error (SE) of means of muscle-type on the average connective tissue characteristics for six muscles (*Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps Femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

Connective tissue characteristics	**Muscle**						
	LTL	**SM**	**BF**	**SS**	**IS**	**ST**	**Significance (*P*-Values)**
Total collagen (Hypro N x 10^3 / Total N)	$1.73^{e} \pm 0.38$	$1.68^{e} \pm 0.267$	$2.76^{c} \pm 0.76$	$3.21^{b} \pm 0.58$	$3.53^{a} \pm 0.76$	$2.06^{d} \pm 0.42$	**<.0001**
Insoluble collagen (Hypro N x 10^3 / Total N)	$1.09^{d} \pm 0.31$	$1.09^{d} \pm 0.23$	$1.75^{b} \pm 0.40$	$2.14^{a} \pm 0.34$	$2.20^{a} \pm 0.50$	$1.34^{c} \pm 0.31$	**<.0001**
Soluble collagen (Hypro N x 10^3 / Total N)	$0.64^{c} \pm 0.22$	$0.59^{c} \pm 0.21$	$1.00^{b} \pm 0.56$	$1.07^{b} \pm 0.47$	$1.34^{a} \pm 0.52$	$0.72^{c} \pm 0.26$	**<.0001**
Collagen solubility (%)	$37.0^{a} \pm 10.3$	$35.1^{ab} \pm 1.0$	$34.6^{ab} \pm 12.8$	$32.4^{b} \pm 10.2$	$37.2^{a} \pm 10.1$	$34.8^{ab} \pm 9.2$	**<.0001**
Soluble collagen (mg/g[#])	$1.414^{cd} \pm 0.478$	$1.235^{d} \pm 0.415$	$2.392^{ab} \pm 1.317$	$2.126^{b} \pm 0.963$	$2.687^{a} \pm 1.042$	$1.647^{c} \pm 0.583$	**<.0001**
Insoluble collagen (mg/g)	$2.497^{c} \pm 0.647$	$2.361^{c} \pm 0.498$	$4.362^{a} \pm 0.887$	$4.376^{a} \pm 0.628$	$4.565^{a} \pm 0.966$	$3.163^{b} \pm 0.659$	**<.0001**
Total collagen (mg/g)	$3.821^{d} \pm 0.754$	$3.511^{d} \pm 0.516$	$6.598^{b} \pm 1.680$	$6.345^{b} \pm 1.155$	$7.088^{a} \pm 1.448$	$4.697^{c} \pm 0.879$	**<.0001**

[a,b,c,d,e] *Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)*

[#]*mg collagen/g of sample*

Significant differences (P ≤ 0.05) were observed between the muscles for all connective tissue characteristics measured. An interesting observation made is that the LTL and SM muscle had similar connective tissue characteristics in terms of total collagen, insoluble collagen, and soluble collagen. When evaluating total collagen, the IS muscle had the highest total collagen. The LTL and SM muscles were the muscles with the lowest values observed for insoluble collagen and soluble collagen; however, the solubility seems similar for all the muscles. Connective tissue and more specifically collagen characteristics such as total collagen and collagen solubility contribute to the so-called "background" toughness of meat (Dransfield, 1977), and the intrinsic tenderness characteristic of a muscle. The contribution of collagen characteristics to the background toughness is emphasised in the correlations showed between WBSF measured at 1-day *post-mortem* and the different collagen related measurements; % solubility (r = -0.285; P ≤ 0.0001), soluble collagen (r = -0.325; P ≤ 0.0001), insoluble collagen (r = -0.371; P ≤ 0.0001), and total collagen (r = 0.377; P ≤ 0.0001). The lower WBSF of IS and SS can be explained by collagen solubility whilst the lower collagen solubility levels could contribute to the higher WBSF noted in the LTL, SM (1 day *post-mortem*) and ST. On the other hand, BF seems to have high soluble collagen levels, but is also one of the tougher muscles analysed (Figure 4.4). The ratio of collagen solubility to total collagen represented by % collagen solubility (34.6 %) plays a role and, according to Starkey *et al.* (2016), soluble collagen and animal age influenced shear force in BF muscle in sheep carcasses.

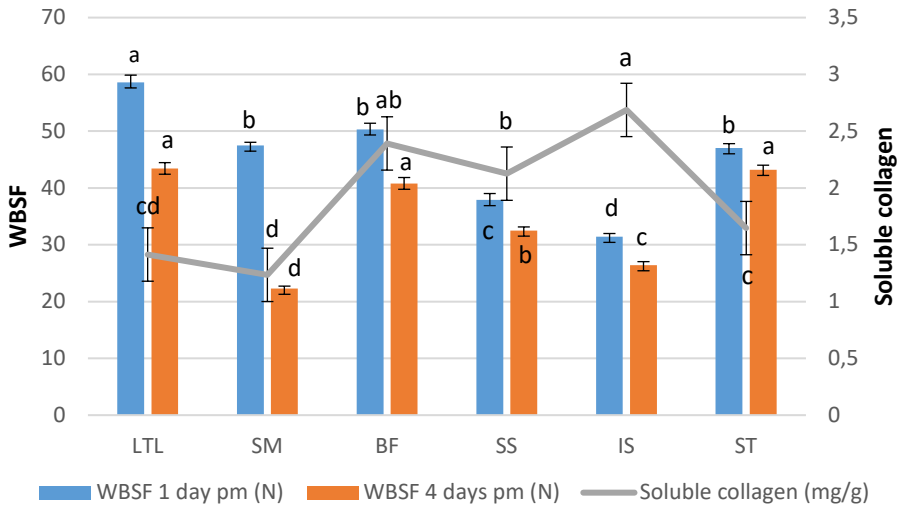

Figure 4.4. Ranking of *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps Femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST) based on Warner-Bratzler shear force values (WBSF, 1- and 4-days *post-mortem*, *pm*) and Soluble collagen. [a,b,c,d] Means within the same parameter with different letters differ (P ≤ 0.05).

The WBSF measured at 4-days *post-mortem* cannot be explained by the lower collagen solubility and is mainly attributed to proteolytic activity. The general accepted hypothesis is that collagen is the major determinant of the texture differences of meat in different muscles in the carcass (Jeremiah

et al., 2003). Dransfield (1977) showed a clear correlation between total collagen content and muscle toughness. According to Baily and Light (1989), the subtle variations in texture between muscles are rather dependent on the collagen quality (solubility) rather than the quantity of collagen. Although collagen concentration does not change significantly during growth until slaughter, collagen solubility decreases with animal weight and age (Baily and Light, 1989). In beef carcasses, Cross *et al.* (1973) indicated that soluble collagen contributed to toughness characteristics and that tenderness differs among muscles from various anatomical locations. This seems to be true for small livestock and the same muscle differences were found between bucks and wethers of BG and large frame IVG for the six different muscles studied. The data from the current study suggest that the total collagen content varies from 1.68 Hypro N x 10^3 / Total N (SM) to 3.53 Hypro N x 103 / Total N (IS) for BG and large frame IVG. In agreement to Starkey *et al.* (2016), various factors across different muscles affect their tenderness characteristics, and one model to predict their tenderness is not possible.

Means and standard errors of muscle and sex on colour attributes for six different muscles (LTL, SM, BF, SS, IS, and ST) of bucks and wethers (BG and large frame IVG) are presented in Table 4.5. No significant interactions between breed x sex were observed nor were differences between breeds noted for the various colour attributes of the six different muscles. An interaction between muscle x sex (P = 0.004) was observed for *L** (lightness) at 1-day *post-mortem* and a tendency (P = 0.077) to differ was observed for *b** (yellowness) at 4-day *post-mortem*. Significant differences in terms of muscle effect were observed for the six different muscles for *L**, *a**, *b**, Chroma and Hue-angle 1- and 4-days *post-mortem*. The ST muscle had the highest *L** value from 1 to 4 days *post-mortem* followed by IS, BF, SS, LTL, and SM. The highest *a** values (redness) were observed in the SS and SM muscles of wethers, whereas the lowest value measured was in the ST muscle of bucks. Overall, the *b** values increased over the storage period for all the muscles studied, except for a decrease that was measured in the BF muscle of bucks. The highest *b** values were exhibited in the ST and SS muscles. The data from Chroma values demonstrated a similar trend to that of the *a** values, where the highest values were observed in the SS and SM muscles of wethers, and the lowest values measured in the ST muscle of bucks 4-days *post-mortem*. Hue-angle values increased between 1- and 4-days *post-mortem*. The ST muscle exhibited the highest Hue-angle values in both bucks and wethers. Sex effects were noticed in IS, LTL and SM for *L** and *a**, but not for *b**.

Table 4.5. Least square means and standard error (SE) of means of muscle and sex on colour (myoglobin) for six muscles (*Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps Femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Muscle													
	LTL		**SM**		**BF**		**SS**		**IS**		**ST**		**Significance (P- Values)**	
	Bucks	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Bucks**	**Wethers**	**Muscle**	**Muscle x Sex**
*L** 1-day *pm*[#]	35.38^{cde} ± 2.31	33.81^{f} ± 2.72	35.17^{de} ± 2.05	33.14^{f} ± 2.13	37.37^{b} ± 2.69	34.23^{ef} ± 2.88	36.46^{bc} ± 2.76	33.56^{f} ± 1.80	37.61^{b} ± 2.94	35.97^{cd} ± 2.58	39.45^{a} ± 2.30	39.57^{a} ± 2.92	**<.0001**	**0.004**
*L** 4-days *pm*	36.00^{de} ± 2.51	35.27^{efg} ± 3.26	35.7^{def} ± 2.89	34.24^{g} ± 2.90	37.38^{bc} ± 2.39	36.62^{cd} ± 3.38	36.64^{cd} ± 2.68	34.55^{fg} ± 3.29	37.90^{b} ± 2.88	36.66^{cd} ± 3.34	39.72^{a} ± 1.93	39.58^{a} ± 3.89	**<.0001**	0.311
*a** 1-day *pm*	9.65^{de} ± 1.24	10.85^{bc} ± 1.10	10.36^{cde} ± 0.89	11.53^{ab} ± 1.22	10.12^{ab} ± 1.37	11.37^{ab} ± 1.47	10.42^{cd} ± 1.33	12.02^{a} ± 1.67	8.33^{f} ± 1.74	9.60^{e} ± 1.95	8.07^{f} ± 1.47	8.10^{f} ± 1.83	**<.0001**	0.312
*a** 4-days *pm*	9.91^{bc} ± 1.10	10.49^{ab} ± 1.42	9.96^{bc} ± 1.14	11.03^{a} ± 1.27	9.23^{cd} ± 1.33	9.95^{bc} ± 1.48	10.48^{ab} ± 1.92	11.27^{a} ± 2.22	8.78^{d} ± 1.69	10.15^{b} ± 2.30	7.63^{e} ± 1.24	8.47^{d} ± 1.90	**<.0001**	0.787
*b** 1-day *pm*	11.14^{d} ± 1.56	11.75^{c} ± 1.34	11.85^{c} ± 1.29	12.28^{abc} ± 1.37	11.85^{c} ± 1.20	12.00^{bc} ± 1.32	12.10^{bc} ± 1.05	12.06^{bc} ± 1.30	11.09^{d} ± 1.61	11.04^{d} ± 1.18	12.61^{ab} ± 0.83	12.78^{a} ± 0.88	**<.0001**	0.591
*b** 4-days *pm*	12.81^{abc} ± 0.92	12.55^{abcd} ± 0.78	12.53^{abcd} ± 0.97	12.77^{abc} ± 0.82	11.78^{e} ± 1.19	12.08^{de} ± 1.16	12.98^{ab} ± 1.00	12.45^{bcd} ± 1.10	12.44^{cd} ± 1.22	12.07^{de} ± 1.14	12.62^{abc} ± 1.07	13.01^{a} ± 0.88	**<.0001**	0.077
Chroma 1-day *pm*	14.79^{fgh} ± 1.61	16.05^{bcd} ± 1.20	15.78^{cde} ± 1.22	16.89^{ab} ± 1.48	15.63^{def} ± 1.45	16.58^{abc} ± 1.55	16.04^{bcd} ± 1.22	17.08^{a} ± 1.85	13.99^{h} ± 2.09	14.72^{gh} ± 1.87	15.09^{efg} ± 0.99	15.26^{defg} ± 1.19	**<.0001**	0.589
Chroma 4-days *pm*	16.23^{abc} ± 1.10	16.41^{abc} ± 1.18	16.03^{bcd} ± 1.23	16.91^{a} ± 1.15	15.00^{ef} ± 1.62	15.74^{cde} ± 1.52	16.75^{ab} ± 1.86	16.89^{a} ± 1.88	15.33^{def} ± 1.63	15.90^{cd} ± 2.00	14.81^{f} ± 1.36	15.66^{cde} ± 1.10	**<.0001**	0.716
Hue-angle 1-day *pm*	49.20^{c} ± 4.97	47.17^{de} ± 4.52	48.71^{cd} ± 3.60	46.73^{e} ± 3.84	49.54^{c} ± 4.10	46.69^{e} ± 4.24	49.50^{c} ± 4.21	45.30^{e} ± 3.53	54.23^{b} ± 4.73	49.66^{c} ± 5.01	57.95^{a} ± 5.30	58.26^{a} ± 6.40	**<.0001**	**0.006**
Hue-angle 4-days *pm*	52.31^{c} ± 3.36	50.39^{cd} ± 3.89	51.58^{c} ± 3.08	49.24^{de} ± 3.29	51.96^{c} ± 2.80	51.06^{cd} ± 4.36	51.59^{c} ± 3.91	48.25^{e} ± 5.60	55.24^{b} ± 4.85	50.84^{cd} ± 5.99	59.19^{a} ± 3.50	57.42^{a} ± 6.56	**<.0001**	0.201

^{a,b,c,d,e} *Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)*

[#]*pm = post-mortem*

Although breed did not influence the colour attributes of the goat meat studied, the colour attributes did differ between muscles and in some cases, there were differences between the bucks and wethers. In a previous study (Argüello *et al.,* 1998), the LTL muscle was darker ($P \leq 0.05$) than the SM or *Triceps Brachii* (TB) of Caprine kids. Compared to extensive studies on the influence of muscle source on colour attributes in other livestock, only limited studies examined this phenomenon in chevon meat; with the focus mainly being on the LTL and SM muscles (Babiker *et al.,* 1990; Dhanda *et al.,* 1999; Pophiwa *et al.,* 2016). The differences found between muscles sampled might be explained by differences in the concentration of sarcoplasmic proteins, IMF, muscle myoglobin (Mg), and/ or muscle fibre type (Babiker *et al.,* 1990). According to the review of Seideman *et al.* (1984), some muscles will remain bright red for longer periods of time than other muscles and are said to have higher metmyoglobin reducing activity (MRA), as well a higher concentration of iron, which promotes oxidation leading to a decline in the colour stability (Farouk *et al.,* 2007; Purchas *et al*., 2010). The conclusion made was that muscles (BF, SM, and ST) had greater percentages of metmyoglobin and therefore a lower MRA than the *Longissimus* muscle. Neethling *et al.* (2016) investigated muscle-specificity in fresh meat from blesbok (*Damaliscus pygargus phillipsi*) and observed that the blesbok *Infraspinatus* muscle is more colour-stable than the LTL and BF. This observation is very different from that previously reported for fresh beef and suggests that the game species have a unique biology and that the influence of muscle source on colour stability is species dependent. The current study supports the observation from Neethling *et al.* (2016).

Further, according to Seideman *et al.* (1982), meat from intact male animals (bulls and rams) are generally darker compared to females and castrated males. This is in contrast to the present study, where the wethers had darker meat (L^* <35.0) compared to bucks (L^* >36.9). In addition, wethers' muscles were less red, displayed lower Chroma and higher Hue angle than bucks for BF, IS, LTL, SM, and SS muscles at 1 day *post-mortem* with corresponding higher pH_u in comparison to bucks. In general, the meat colour differences between bucks and wethers disappeared after 4 days *post-mortem* except for the IS, SM and SS that maintained their colour differences in terms of lightness, redness, Chroma, and Hue-angle. It is known that energy status immediately after slaughter has an influence on meat colour and tenderness (Monin and Sellier, 1985; Scheffler *et al.,* 2011). In the present study, the wethers may have had less muscle energy at slaughter than bucks, suggesting that the amount of muscle glycogen depleted during the *pre-slaughter* phase which could be largely associated with stress and adrenaline releases (Gardener *et al.,* 1999), was higher in the wethers. An argument could be that wethers have been previously exposed to stressors (e.g., handling during castration) and / or sex playing a role? – An aspect warranting further research.

4.5. Conclusion

Differences between breeds (BG and IVG) are minimal for collagen characteristics and proteolytic activity leading to similar tenderness and meat colour. On the contrary, sex was the main factor determining the tenderness results of all the muscles studied. *Post-slaughter* ES could be the reason why no one attribute measured could be identified as being the cause of the meat quality (tenderness and meat colour) differences between the different muscles. The exogenous and endogenous factors affecting tenderness, colour and colour stability are not exclusive, but are rather interrelated. In addition, it could be suggested that IVG (wethers) are more prone to *ante-mortem* stress as most muscles had higher pH_u and appeared darker in colour. Further studies are required on *pre-slaughter* procedures that are more adapted for minimising stress in goats, particularly on IVG (wethers). The data from the current study could be used to support more muscle-specific strategies, which may be used to improve colour stability and marketing.

4.6. References

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Addendum: Supplementary data

Table 4.6. Pearson correlation coeffiicents of ultimate pH (pH_u), temperature 24 hours *post-mortem* (T_u), water holding capacity (WHC), % drip loss, myofibril fragment length (MFL), Warner-Bratzler shear force (WBSF) and Intramuscular fat (IMF) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats

	pH_u	T_u (°C)	WHC 1 day *pm*[##]	WHC 4 days *pm*	Drip loss (%)	WBSF 1 day *pm* (N)	WBSF 4 days *pm* (N)	MFL 1 day *pm* (µm)	MFL 4 days *pm* (µm)	Collagen solubility (%)	Soluble collagen (mg/g[#])	Insoluble collagen (mg/g)	Total collagen (mg/g)
pH_u													
T_u (°C)	-0.019;												
	0.086*												
WHC 1 day *pm*[##]	-0.314;	-0.175;											
	<.0001*	**0.008***											
WHC 4 days *pm*	0.126;	-0.350;	0.322;										
	0.062*	**<.0001***	**<.0001***										
Drip loss (%)	-0.440;	-0.180;	0.171;	-0.021;									
	<.0001*	**0.007***	**0.010***	0.755*									
WBSF 1 day *pm* (N)	-0.452;	0.087;	0.237;	0.045;	0.141;								
	<.0001*	0.198*	**0.0003***	0.460*	**0.036***								
WBSF 4 days *pm* (N)	0.075;	0.308;	-0.170;	-0.064;	-0.631;	0.411;							
	0.269*	**<.0001***	**0.011***	0.342*	**<.0001***	**<.0001***							
MFL 1 day *pm* (µm)	0.169;	0.224;	0.019;	-0.057;	-0.225;	-0.008;	0.269;						
	0.011*	**0.0007***	0.775*	0.394*	**0.0007***	0.907*	**<.0001***						
MFL 4 days *pm* (µm)	0.122;	0.240;	-0.006;	-0.146;	-0.392;	0.040;	0.406;	0.742;					
	0.068*	**0.0003***	0.932*	**0.029***	**<.0001***	0.549*	**<.0001***	**<.0001***					
Collagen solubility (%)	0.114;	-0.018;	-0.187;	-0.004;	-0.072;	-0.285;	0.018;	-0.036;	-0.048;				
	0.091*	0.789*	**0.005***	0.955*	0.285*	**<.0001***	0.796*	0.601*	0.482*				
Soluble collagen	0.341;	0.051;	-0.030;	-0.148;	-0.320;	-0.325;	-0.131;	0.121;	0.187;	-0.078;			
(mg/g[#])	**<.0001***	0.452*	0.662*	**0.026***	**<.0001***	**<.0001***	0.0511*	0.073*	**0.005***	0.245*			
Insoluble collagen	0.512;	0.232;	-0.324;	-0.214;	-0.490;	-.371;	0.109;	0.099;	0.235;	0.044;	0.693;		
(mg/g)	**<.0001***	**0.0005***	**<.0001***	**0.001***	**<.0001***	**<.0001***	0.104*	0.144*	**0.0004***	0.512*	**<.0001***		
Total collagen (mg/g)	0.508;	0.219;	-0.302;	-0.214;	-0.486;	-0.377;	0.086;	0.104;	0.237;	0.032;	0.748:	0.997;	
	<.0001*	**0.001***	**<.0001***	**0.001***	**<.0001***	**<.0001***	0.202*	0.123*	**0.0004***	0.635*	**<.0001***	**<.0001***	
Fat**	0.229;	0.078;	0.121;	0.231;	-0.363;	0.128;	0.319;	0.070;	0.024;	0.018;	-0.009;	0.077;	0.070;
	0.0006*	0.246*	0.072*	**0.0005***	**<.0001***	0.056*	**<.0001***	0.296*	0.722*	0.782*	0.886*	0.252*	0.300*

**Significance (P-Values) with significant P-values presented in bold;*

***Fat % = chemically determined intramuscular fat (IMF);*

[##]pm = post-mortem;

[#]mg collagen/g of sample

CHAPTER 5

Effect of goat breed, castration and electrical stimulation on water binding and tenderness related characteristics of *Longissimus thoracis et lumborum* and *Semimembranosus* muscles

Abstract

This study seeks to determine if pre- and post-slaughter procedures such as castration and electrical simulation (ES) influence chevon tenderness and related physiological characteristics in weaner male Boer Goats (BG; n = 36; 21 bucks and 15 wethers) and large frame Indigenous Veld Goats (IVG; n = 41; 21 bucks and 20 wethers). Half of the carcasses were electrical stimulated (ES) 10 minutes post-mortem and the other half not (NS). All dressed carcasses were chilled at 4°C within 1 hour post-mortem. Muscle pH and temperature were measured at 1-, 3-, 6- and 24-hours post-mortem in the Longissimus thoracis et lumborum (LTL) and Semimembranosus (SM) muscles. Myofibril fragment length (MFL), water holding capacity (WHC), % thawing- and cooking loss at 1- and 4-days post-mortem as well as sarcomere length (SL), drip loss (DL), Warner-Bratzler shear force (WBSF) and sensory attributes (tenderness and juiciness) were determined in both muscles. Calpains-1, -2 and calpastatin activities were determined at 1- and 24-hours post-mortem. Both LTL and SM muscles of buck were less tender ($P \leq 0.05$) compared to wethers. The LTL were more tender with ES ($P \leq 0.001$) while SM was less affected ($P = 0.055$). Calpain-2 played a greater role in tenderisation than is normally found in beef and could suggest that the activation of the system occurred at a later stage than in other species.

Keywords: Chevon quality, sex, cold shortening, *post-mortem* proteolytic activity, calpastatin, electrical stimulation

5.1. Introduction

Globally, there is a renewed interest in goat farming for meat production as a tool to encourage an increase in the numbers of small farmers as well as improving profitability of their farming enterprises in order to alleviate poverty and give a means for self-support to rural communities. In order to maximise income, carcasses need to meet the quality criteria, especially tenderness, applicable to fresh meat, particularly as pertaining to the traditionally more expensive muscles/cuts preferred by Western consumers. Some challenges of goat meat (chevon) are multiple factors involved in ensuring consistent good eating quality (meat tenderness) (Simela, 2005). Tough goat meat can be minimised by controlling the energy levels in muscle by means of *pre-slaughter* management (breed,

sex, age, body condition, feed withdrawal, and animal handling, etc.) (Guerrero *et al*., 2013; Nikbin *et al*., 2016), *ante-mortem* management (stunning method, bleeding time, etc.) and *post-slaughter* management (electrical stimulation procedures and / or carcass temperature control, carcass suspension and meat ageing, etc.) (Hutchison *et al*., 2014). Castration is one of many management strategies in animal production applied for several reasons, including the ease of controlling / reducing male aggression, early undesired mating activity of young bucks, and removal of undesirable odour (Needham *et al.,* 2017). In addition, castration can influence fat deposition in the carcass, influencing leanness (Paengkoum *et al.,* 2013) and reduce calpastatin levels (Koohmaraie, 1992). Electrical stimulation was primarily developed to accelerate *post-mortem* glycolysis so that muscles are prevented from excessive shortening when they enter *rigor* (Swatland, 1981; Ferguson and Gerrard, 2014). The technique has proved to be useful beyond just the prevention of cold-induced sarcomere shortening and the resultant toughness, and depending on the parameters applied, it improves tenderness through the physical disruption of muscle fibres and acceleration of proteolysis (Hwang *et al.,* 2003).

Fresh meat tenderness refers to the ease of mastication, associated with the initial ease of penetration by the teeth, the ease with which the fragments are broken down and the remaining residue left after the mastication (Lawrie, 1958). Tenderness is a principal factor considered by numerous consumers as they tend to discriminate against meat that is not tender (Maltin *et al.,* 2003). Meat tenderness is determined by three factors: background toughness, the toughening phase and tenderisation phase (Luciano *et al.,* 2007). The background toughness is inherent to a specific animal / muscle at slaughter and does not change during the storage stage. Whereas the toughening phase and tenderisation phase occurs during the process of *post-mortem* storage (Koohmaraie and Geesink, 2006). During the process of *rigor-mortis*, sarcomere shortening leads to the toughening phase and a strong negative correlation is obtained between sarcomere length and meat tenderness (Purchas, 1979; Wheeler *et al.,* 2000).

The calpain proteolytic system, responsible for the *post-mortem* tenderisation of beef and mutton (Koohmaraie, 1992; Dransfield, 1999; Ferguson and Gerrard, 2014) has not been studied in goat meat. Previous research on the response of muscle to different *rigor* temperatures differs between sheep and cattle (Savell *et al.,* 2005; Behkit *et al.,* 2007) and therefore it is expected that this knowledge cannot be extrapolated to goats. The proteolytic degradation of cytoskeletal proteins primarily by the calcium activated calpain system is typically quantified by myofibril fragment length (MFL) or better-known myofibril fractionation index (MFI) (Volpelli *et al.,* 2005). Some meat tenderness research on goat meat were previously done on BG and related “indigenous” goats under different *pre-* and *post-slaughter* conditions (Simela, 2005; Pophiwa *et al.,* 2016; 2017). Pophiwa *et al.* (2016) studied the effects of carcass ES compared to stepwise chilling on meat tenderness of BG and BG related “indigenous goat” wethers and bucks, but the effect on the calpain system was not quantified. Therefore, the purpose of this study is to establish the effect of castration and electrical stimulation followed by immediate chilling on meat tenderness of the *Longissimus thoracis et*

lumborum (LTL) and *Semimembranosus* (SM) of large frame Indigenous Veld Goats (IVG; Cape Speckled and Cape Lob Ear), compared to the Boer Goats (BG). The study includes the effect of cold shortening and calpain system on the meat tenderness outcome.

5.2. Material and methods

5.2.1. Animals and experimental design

Please refer to Chapter 3 (and Van Wyk *et al.,* 2020) regarding the experimental animals and ethical clearance, etc. The experimental design is presented in Figure 5.1.

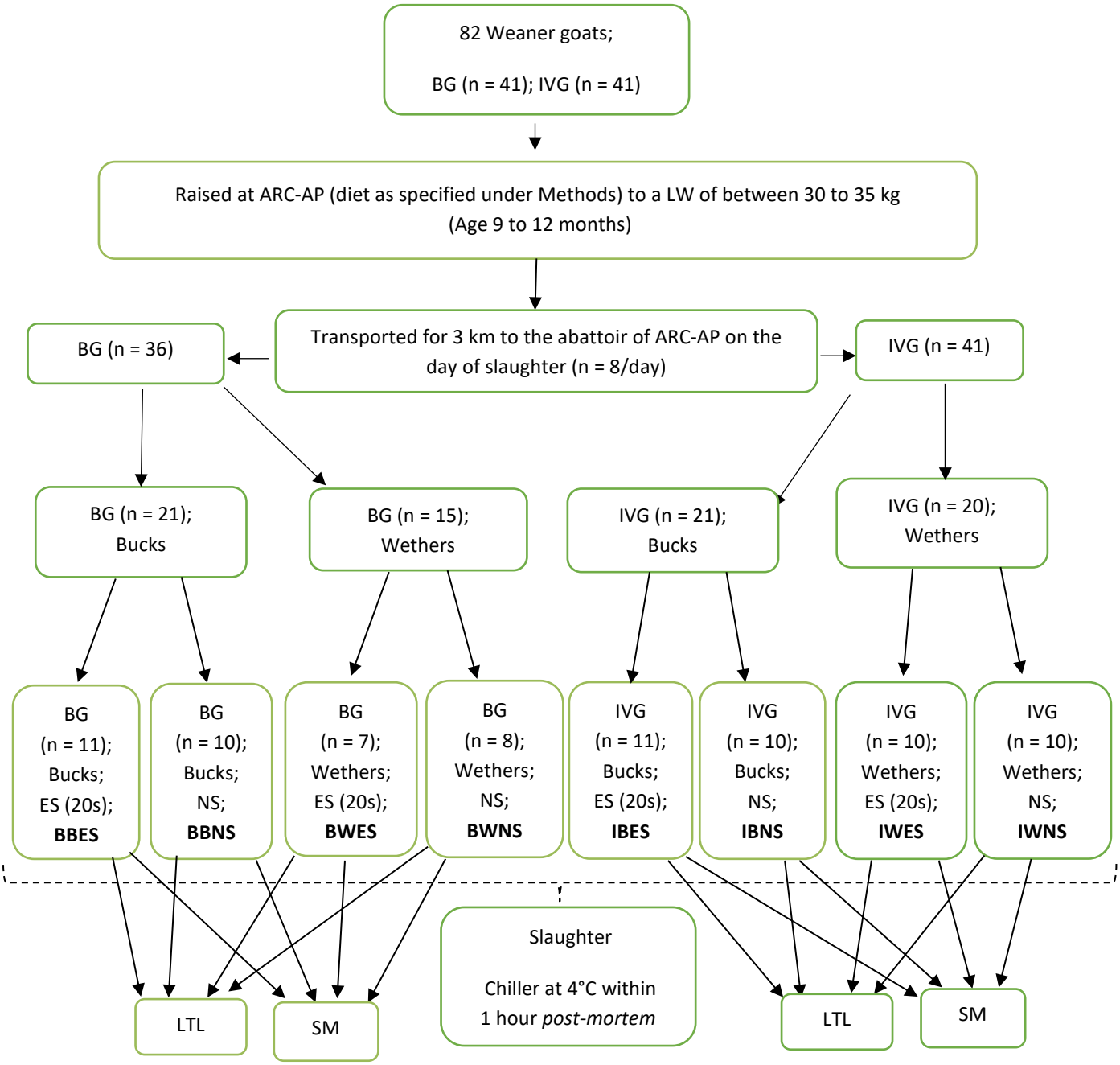

Figure 5.1. Experimental design to evaluate the effect of breed; large frame Indigenous Veld Goats (IVG, Cape Speckled and Cape Lob Ear) and Boer Goats (BG) of Southern Africa, on meat tenderness and calpain system related ageing of *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM). Electrical stimulation (ES); No-electrical stimulation (NS). Electrical Stimulated Boer Goat Carcasses of Bucks (BBES); No-

Stimulated Boer Goat Carcasses of Bucks (BBNS); Electrical Stimulated Boer Goat Carcasses of Wethers (BWES); No-Stimulated Boer Goat Carcasses of Wethers (BWNS); Electrical Stimulated Large frame Indigenous Veld Goat Carcasses of Bucks (IBES); No-Stimulated Large frame Indigenous Veld Goat Carcasses of Bucks (IBNS); Electrical Stimulated Large frame Indigenous Veld Goat Carcasses of Wethers (IWES); No-Stimulated Large frame Indigenous Veld Goat Carcasses of Bucks (IWNS).

5.2.2. Slaughter and sampling procedures

A maximum of eight goats per day representing all experimental groups were slaughtered over an 11-week period starting with the heaviest of each group (total animals slaughtered: BG; n = 36, 21 bucks and 15 wethers; IVG; n = 41; 21 bucks and 20 wethers). This gave the less dominant animals a chance to catch-up in weight as the dominant animals were removed, although measures were taken to give animals an equal chance to feed (see Chapter 3, and Van Wyk *et al.,* 2020). The carcasses were subjected to either of the following treatments: electrical stimulation (ES - 20 seconds, 400 Volts peak, 5ms pulses at 15 pulses/second), 10 minutes after stunning and exsanguination or no-electrical stimulation (NS), where after all the carcasses were placed in the chiller at 4°C within 60 minutes *post-mortem*. Carcass characteristics were determined as described in Chapter 3 (and Van Wyk *et al.,* 2020) and experimental design shown in Figure 5.1. Temperature and pH were measured with a portable pH meter (Eutech Instruments, Cyber Scan pH 11, Keppel Logistic, Singapore) on the left side of the carcass in the *Longissimus thoracis et lumborum* (LTL) (Lumbar 5 position), and the *semimembranosus* (SM) muscles at 1-, 3-, 6- and 24-hours *post-mortem*. Left side LTL and SM samples for the determination for calpain and calpastatin levels were taken at 1- and 24-hours *post-mortem* at the 5th lumbar vertebra position and snap frozen in liquid nitrogen and stored at -80°C. The myofibril fragment length (MFL; 1- and 4-days *post-mortem*), water holding capacity (WHC; 1- and 4-days *post-mortem*), and sarcomere length (SL) samples were dissected from a slice of the left side of LTL and SM after colour measurements were taken after 1 hour of blooming (reported under Chapter 6). LTL and SM steaks from the carcasses' right side were vacuumed packed and aged for 4 days *post-mortem* at 4°C. Drip in the bag (drip loss) 4 days *post-mortem* and WHC were measured, and the myofibril fragment length (MFL) sample was snap frozen with liquid nitrogen and stored at -80°C until analysed. Samples for Warner-Bratzler shear force (WBSF) were collected 1 day *post-mortem* (left LTL and SM). As goat muscles are small, it was decided to use day 4 aged muscles (right side) stored at -20°C for the sensory analyses (e.g., tenderness and juiciness).

5.2.3. Drip loss (DL) and water holding capacity (WHC) of fresh meat

Drip loss (DL) was measured using a 10 mm thick slice of the muscles (LTL and SM), vacuumed, and aged for 4 days at 4°C. Water holding capacity (WHC) of both LTL and SM samples were determined using the filter paper press method as described by Strydom *et al.* (2005). Briefly, 400 to 500 mg meat sample was placed on filter paper (Whatman 4), contained between two Perspex plates. Constant pressure was applied using a hand-operated screw for 5 minutes. The borders of meat and fluid expressed were marked out and their areas measured using a video image analyser

(Soft Imaging System, Olympus Japan), according to Irie *et al.* (1996). Water holding capacity was expressed as a ratio of meat area to fluid area.

5.2.4. Sarcomere length (SL)

For measuring SL, extracts of LTL and SM were prepared according to the method decribed by Hegarty and Naudé (1970). Approximately 5 g were cut from the fresh sample and homogenised in ca. 15 ml of distilled water using an Ultra-Turrax blender at low speed until all the individual fibres were separated. A few drops of homogenate were mounted onto the slide and covered with a cover slip. The slides were immediately viewed under a microscope linked to a CC12 video camera (Olympus, Tokyo, Japan) and fifty measurements of 5 sarcomeres at a time were made at a magnification of 31000X. Data was processed using the life sciences software package (soft imaging systems Gimbh, Munster, Germany) and the mean length per sarcomere was used for statistical analysis.

5.2.5. Myofibril fragmentation length (MFL)

Samples used for MFL were from the steaks (see section 5.2.2) aged for 1- and 4-days *post-mortem*. Sub-samples of ca. 3 g were blended with a blunt blade in potassium phosphate extraction buffer at 4˚C to arrest any further proteolysis (Culler *et al.,* 1978), and determined as described by Heinze and Bruggemann (1994). The droplets of extracted MFL solution were mounted on slides, covered with a cover slip, and viewed under a microscope attached to a video image analysis (VIA). One hundred myofibril fragments per sample were examined and measured at a magnification of 40X.

5.2.6. Thawing and cooking losses, Warner-Bratzler shear force (WBSF)

A day before the muscles (LTL and SM) were cooked, the vacuum-sealed frozen samples were placed in a cold room at 4°C to thaw for 24 hours before cooking. The LTL samples (whole) were prepared according to an oven-broiling method (dry heat cooking) using direct radiant heat and SM samples (whole) were prepared using a moist heat cooking method (AMSA, 2016). Calibrated electric ovens (Mielé ovens, model H217, Miele & Cie. KG, Gütersloh, Germany) were set on “broil’’ at 160˚C for 10 minutes prior to preparation. The LTL samples were placed on an oven pan on a rack and broiled for approximately 20 minutes until they reached an internal core temperature of 70˚C, whereas the SM samples were prepared in covered casserole dishes by adding 100 ml water and oven cooked until an internal core temperature of 70˚C was reached. The internal temperature was monitored by placing an iron-constant thermocouple (T-type) (Hand-model Kane-Mane thermometer, Kane International Ltd, Hertfordshire, England) in the approximate geometric centre of each sample. The cooked meat + pan + drip was there after all weighed. The cooked samples were cooled for 2 hours at room temperature. Thawing loss was expressed as a % of pre-thawed weight and cooking loss was expressed as a % of pre-cooked weight (Molette *et al.,* 2003).

For shear force measurements, six cylindrical samples (12.5 mm core diameter) were bored parallel to the direction of the muscle fibres. Each core was sheared perpendicular to the myofibrils using a Warner-Bratzler device fitted to an Instron Universal Testing Machine (Model 4301, Instron Ltd, Buckinghamshire, England); crosshead speed = 200 mm/min with one shear in the centre of each core (Honikel, 1998). The toughness of the meat was the average maximum force (N) required to shear through the cores.

5.2.7. Descriptive sensory attributes

Descriptive sensory attributes (DSA) of the LTL and SM muscles (4 days *post-mortem*) were performed by ten female members with experience in the sensory evaluation of meat (Sensory Analytical Laboratory, Meat Industry Centre, ARC-AP), assessing the juiciness and tenderness on an 8-point scale (Table 5.1).

Table 5.1. Scoring of sensory panels on an eight-point scale.

Reference standard	**Description of attributes presented**	**Scale**		
Impression of juiciness	The impression of juiciness that you form as you start chewing	1 = Extremely dry	5 = Slightly juicy	8 = Extremely juicy
Muscle fibre and overall tenderness	Chew sample with a light chewing action	1= Extremely tough / stringy	5 = Slightly tough / stringy	8 = Extremely tender

5.2.8. Calpain system

Calpain-1, Calpain-2 and calpastatin were extracted from 3 g frozen (1- and 24-hours *post-mortem*) LTL and SM muscles and their activity determined according to Geldenhuys *et al.* (2015). Calpain activity were determined using the azo-casein assay according to Dransfield (1996); the use of azo-casein eliminated the problem of background absorbance of non-specific proteins in the extracts (Dransfield, 1996). One unit of calpastatin was defined as the amount that inhibited one unit of Calpain-2 activity, where one unit of calpain activity is defined as an increase in absorbance of 1.0 at 366 nm/h at 25˚C. Data were expressed as units/g of muscle.

5.2.9. Statistical analysis

The data were subjected to analysis of variance (SAS, 1999) using a three-way ANOVA to test the effect of the two goat breeds (BG and IVG), two sex-types (bucks and wethers), two treatments (ES and NS) and interactions as factors on pH and temperature (1, 3, 6 and 24 hours *post-mortem*), WHC (1 and 4 days *post-mortem*), % DL (4 days *post-mortem*), SL (1 day *post-mortem*), calpain system (1 and 24 hours *post-mortem*), MFL (1 and 4 days *post-mortem*), % thawing loss (1 and 4 days *post-mortem)*, % cooking loss (1 and 4 days *post-mortem)*, WBSF (1 day *post-mortem*) and

sensory attributes (4 days *post-mortem*) from the LTL and SM muscles. Least square means were compared if a significant F statistic (5 % level of probability) was detected (Snedecor and Cochran, 1980). Slaughter day had no effect on the outcome of the results (thus data not shown and mentioned further), therefore the data applicable to slaughter day was pooled within the main treatments and interactions of sex and breed treatments with ageing.

Prior to analyses, a Shapiro-Wilk test for normality was performed on the data (Shapiro and Wilk, 1965) and where applicable, outliers (classified as such when the standardized residual for an observation deviated with more than three SDs from the model value) were removed. Statistical significance (Fisher's t-test, least significant difference) was calculated at a 5 % confidence level to compare means. $P \leq 0.05$ was considered statistically significant, although in some instances' data with a $P \leq 0.1$ (10 % confidence level) was considered as a trend worth discussing.

5.3. Results and Discussion

To understand the processes that affect meat quality of chevon, it was important to study the mechanisms involved with meat tenderness; amongst others the muscle contraction and *post-mortem* proteolytic (calpain system) ageing characteristics. The carcass characteristics are presented in Table 5.2 to assist in clarity during the discussion. Although the quality of the carcass and meat can be influenced by different factors as reviewed in Chapter 2, a detailed discussion of these pertinent factors is presented in Chapter 3 (and Van Wyk *et al.,* 2020). In summary, although BG is the most popular goat breed across the world for meat production, the results of this study showed that under the same production conditions IVG could be considered to have a similar potential for chevon production as was also supported by Simela and Merkel (Review, 2008). More significant differences in carcass characteristics were observed between the wethers and bucks rather than between breed-types.

Table 5.2. Least square means and standard error (SE) of means for carcass characteristics of Boer (BG) and large frame Indigenous Veld (IVG) buck and wether goats (number of outliers removed indicated in brackets); (refer to Chapter 3 and Van Wyk *et al.,* 2020).

	Breed						
	BG		IVG		Significance (P – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed × Sex
Live weight (kg)	35.5^{xy} ± 3.26 (1)	35.7^{xy} ± 2.91 (1)	36.4^{x} ± 2.09	34.3^{y} ± 2.38 (1)	0.748	0.114	0.070
Warm carcass weight (kg)	15.4^{y} ± 1.48	16.4^{x} ± 2.08	15.7^{xy} ± 0.73	15.9^{xy} ± 1.20	0.918	0.063	0.130
Cold carcass weight (kg)	14.8^{y} ± 0.48 (2)	15.8^{x} ± 1.40	15.2^{xy} ± 0.72 (1)	15.4^{xy} ± 1.19	0.774	0.055	0.164
Chilling loss	3.5^{a} ± 0.52 (2)	3.5^{a} ± 0.57	3.34^{ab} ± 0.50 (1)	3.01^{b} ± 0.56	**0.011**	0.221	0.125
Dressing percentage	41.9^{b} ± 2.69 (1)	44.2^{a} ± 1.12 (1)	41.9^{b} ± 2.49	44.9^{a} ± 2.06 (1)	0.347	**<.0001**	0.580
Eye muscle area (μm^2)	1043^{xy} ± 265	1184^{x} ± 269	1049^{xy} ± 242	964^{y} ± 194	0.101	0.732	0.053

^{a,b} Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.10)

The significance (P-values) of the effect of breed (BG vs. IVG), sex (bucks vs. wethers), ES treatment (ES vs. NS) and their interactions and the means and standard error of means of pH and temperature, WHC, % DL, SL, MFL, WBSF, sensory attributes (tenderness and juiciness), % thawing loss and % cooking loss of the LTL and SM are presented in Table 5.3, Table 5.4 and Table 5.5 respectively.

The significance (P-values) for the main effects and interactions between breed, sex, and treatment for the calpain system *post-mortem* ageing measured 1- and 24-hours *post-mortem* of the LTL and SM of BG and large frame IVG are presented in Table 5.6 and the means in Tables 5.7 and 5.8 respectively.

Table 5.3. The significance (P-values) of the main effects of breed (BG vs. IVG), sex (bucks vs. wethers), treatment (ES vs. NS) and their interactions on pH and temperature, water holding capacity (WHC), % drip loss (DL), sarcomere length (SL), myofibril fragment length (MFL), Warner-Bratzler shear force (WBSF), tenderness, juiciness, % thawing loss and % cooking loss of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles.

	Significance (P- Values)						
	Breed	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**
***Longissimus thoracis et lumborum* (LTL)**							
pH 1 hour *pm*[#]	0.086	0.247	**<.0001**	0.884	0.386	0.304	0.183
pH 3 hours *pm*	0.231	0.223	**<.0001**	0.438	0.640	0.485	0.160
pH 6 hours *pm*	0.625	0.818	**<.0001**	0.986	0.758	0.811	0.864
pH 24 hours *pm*	0.808	0.543	**<.0001**	0.147	0.567	0.545	0.889
Temperature 1 hour *pm*	**0.007**	**0.003**	0.773	0.591	0.537	0.199	0.069
Temperature 3 hours *pm*	0.106	**0.001**	0.438	0.167	0.645	0.877	0.954
Temperature 6 hours *pm*	**0.013**	0.214	0.837	**0.002**	0.975	0.304	0.534
Temperature 24 hours *pm*	0.187	**<.0001**	0.843	0.449	0.253	0.585	0.836
WHC 1 day *pm*	0.067	**0.045**	0.059	0.333	0.665	0.312	0.471
WHC 4 days *pm*	0.923	0.092	0.998	0.741	0.612	0.896	0.599
Drip loss (%)	0.593	**0.007**	0.101	0.158	0.184	0.635	0.651
SL (µm)	**0.049**	0.381	0.099	0.239	0.663	0.335	0.218
MFL 1 day *pm* (µm)	0.547	**0.039**	0.865	0.059	0.981	0.139	0.626
MFL 4 days *pm* (µm)	0.956	**0.002**	0.387	0.953	0.744	0.344	0.940
WBSF 1 day *pm* (N)	0.632	**<.0001**	**<.0001**	0.450	0.140	0.652	0.906
Tenderness 4 days *pm*	0.151	0.388	0.763	0.327	0.077	0.382	0.655
Juiciness 4 days *pm*	0.129	0.254	0.914	0.672	0.557	0.747	0.613
Thawing loss (%) 1 day *pm*	0.076	0.280	**0.025**	0.598	0.876	0.811	**0.007**
Thawing loss (%) 4 days *pm*	0.555	0.161	0.516	0.342	0.570	0.527	0.516
Cooking loss (%) 1 day *pm*	0.478	**0.050**	0.580	0.113	0.415	**0.012**	0.263
Cooking loss (%) 4 days *pm*	0.274	0.322	0.640	0.346	0.054	**0.012**	0.762
***Semimembranosus* (SM)**							
pH 1 hour *pm*	0.270	0.239	**<.0001**	0.601	0.917	0.236	0.137
pH 3 hours *pm*	0.958	0.222	**<.0001**	0.789	0.232	0.554	0.195
pH 6 hours *pm*	0.298	0.460	**<.0001**	0.702	0.360	0.832	0.872
pH 24 hours *pm*	0.133	0.824	**0.003**	0.311	0.645	0.847	0.929
Temperature 1 hour *pm*	0.641	**0.006**	0.102	0.558	0.384	0.203	0.724
Temperature 3 hours *pm*	**0.012**	**0.001**	0.309	0.122	0.778	0.397	0.464
Temperature 6 hours *pm*	0.076	**0.007**	0.665	0.092	0.531	0.314	0.617
Temperature 24 hours *pm*	**0.001**	**0.012**	0.649	0.956	0.494	0.584	0.177
WHC 1 day *pm*	**0.005**	0.114	0.410	0.332	0.904	0.518	0.203
WHC 4 days *pm*	0.260	0.172	0.334	0.994	0.305	0.618	0.294
Drip loss (%)	0.084	0.647	0.691	0.404	0.918	0.482	0.473
SL (µm)	**0.026**	0.446	0.077	0.682	0.966	0.237	0.426
MFL 1 day *pm* (µm)	0.160	**<.0001**	0.174	0.891	0.599	0.162	0.626
MFL 4 days *pm* (µm)	0.081	**0.030**	**0.032**	0.244	0.860	0.760	0.506
WBSF 1 day *pm* (N)	**0.038**	**0.011**	0.055	0.985	0.588	0.135	0.489
Tenderness 4 days *pm*	0.127	0.076	**0.005**	0.314	0.369	0.685	0.808
Juiciness 4 days *pm*	0.076	0.084	**0.025**	0.993	0.275	0.811	0.610
Thawing loss (%) 1 day *pm*	0.814	0.893	0.427	0.513	0.594	0.841	0.993
Thawing loss (%) 4 days *pm*	0.952	0.544	**0.013**	0.325	0.287	**0.049**	0.253
Cooking loss (%) 1 day *pm*	0.520	0.208	0.637	**0.033**	0.318	0.503	0.863
Cooking loss (%) 4 days *pm*	0.703	**0.001**	0.529	0.689	0.590	0.636	0.561

Significant P-values are presented in bold; [#]pm = *post-mortem*

Table 5.4. Least square means and standard error (SE) of means of breed, sex and treatment on pH and temperature, water holding capacity (WHC), % drip loss (DL), sarcomere length (SL), myofibril fragment length (MFL), Warner-Bratzler shear force (WBSF), tenderness, juiciness, % thawing loss and % cooking loss of the *Longissimus thoracis et lumborum* (LTL) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		Sex		Treatment	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
pH						
1 hour *pm*[#]	$6.32^{x} \pm 0.38$	$6.23^{y} \pm 0.32$	6.30 ± 0.36	6.24 ± 0.34	$6.01^{a} \pm 0.21$	$6.54^{b} \pm 0.24$
3 hours *pm*	6.14 ± 0.38	6.07 ± 0.32	6.13 ± 0.36	6.07 ± 0.35	$5.83^{a} \pm 0.20$	$6.38^{b} \pm 0.25$
6 hours *pm*	5.90 ± 0.30	5.92 ± 0.30	5.90 ± 0.29	5.92 ± 0.30	$5.71^{a} \pm 0.18$	$6.11^{b} \pm 0.25$
24 hours *pm*	5.64 ± 0.15	5.64 ± 0.13	5.65 ± 0.14	5.63 ± 0.13	$5.58^{a} \pm 0.11$	$5.70^{b} \pm 0.13$
Temperature						
1 hour *pm*	$27.43^{a} \pm 2.46$	$28.93^{b} \pm 2.55$	$27.41^{a} \pm 2.44$	$29.21^{b} \pm 2.50$	28.13 ± 2.68	28.13 ± 2.56
3 hours *pm*	13.46 ± 2.19	14.32 ± 2.68	$12.98^{a} \pm 2.13$	$15.04^{b} \pm 2.43$	13.69 ± 2.72	14.15 ± 2.23
6 hours *pm*	$10.77^{a} \pm 3.06$	$9.09^{b} \pm 2.67$	9.55 ± 2.77	10.26 ± 3.18	9.91 ± 3.07	9.84 ± 2.90
24 hours *pm*	7.59 ± 1.81	7.08 ± 2.14	$6.46^{a} \pm 1.77$	$8.35^{b} \pm 1.78$	7.33 ± 2.05	7.31 ± 1.97
WHC 1 day *pm*	$0.422^{x} \pm 0.04$	$0.444^{y} \pm 0.04$	$0.444^{a} \pm 0.56$	$0.422^{b} \pm 0.05$	0.422 ± 0.051	0.436 ± 0.56
WHC 4 days *pm*	0.411 ± 0.05	0.411 ± 0.42	$0.411^{x} \pm 0.05$	$0.400^{y} \pm 0.03$	0.415 ± 0.053	0.416 ± 0.042
Drip loss (%)	2.071 ± 0.62	2.154 ± 0.86	$1.904^{a} \pm 0.72$	$2.362^{b} \pm 0.72$	2.242 ± 0.790	1.982 ± 0.701
SL (µm)	$1.87^{a} \pm 0.10$	$1.82^{b} \pm 0.10$	1.85 ± 0.11	1.83 ± 0.09	$1.86^{x} \pm 0.11$	$1.82^{y} \pm 0.09$
MFL 1 day *pm* (µm)	35.67 ± 3.99	35.19 ± 3.03	$36.18^{a} \pm 3.43$	$34.50^{b} \pm 3.42$	35.52 ± 3.23	35.31 ± 3.80
MFL 4 days *pm* (µm)	29.52 ± 4.55	29.57 ± 4.51	$30.98^{a} \pm 4.81$	$27.83^{b} \pm 3.43$	29.18 ± 4.34	29.93 ± 4.69
WBSF 1 day *pm* (N)	63.40 ± 1.52	64.70 ± 1.55	$69.00^{a} \pm 1.57$	$58.30^{b} \pm 1.27$	$55.40^{a} \pm 0.95$	$73.00^{b} \pm 1.50$
Tenderness 4 days *pm*	4.18 ± 1.27	3.96 ± 1.19	4.00 ± 1.24	4.12 ± 1.21	4.03 ± 1.18	4.09 ± 1.27
Juiciness 4 days *pm*	4.62 ± 0.92	4.48 ± 0.90	4.51 ± 0.92	4.59 ± 0.91	4.55 ± 0.93	4.54 ± 0.90
Thawing loss (%) 1 day *pm*	6.34 ± 1.52	6.47 ± 1.55	$6.90^{a} \pm 1.57$	$5.83^{b} \pm 1.27$	$5.54^{a} \pm 0.95$	$7.30^{b} \pm 1.50$
Thawing loss (%) 4 days *pm*	0.42 ± 0.04	0.44 ± 0.04	$0.44^{a} \pm 0.56$	$0.42^{b} \pm 0.05$	0.42 ± 0.05	0.44 ± 0.56
Cooking loss (%) 1 day *pm*	14.68 ± 3.23	15.16 ± 3.16	$15.53^{a} \pm 3.61$	$14.23^{b} \pm 2.44$	15.14 ± 3.48	14.73 ± 2.87
Cooking loss (%) 4 days *pm*	3.02 ± 1.36	3.21 ± 1.35	3.32 ± 1.41	2.89 ± 1.25	3.23 ± 1.26	3.01 ± 1.44

[a,b] Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

[#]pm = post-mortem

Table 5.5. Least square means and standard error (SE) of means of breed, sex and treatment on pH and temperature, water holding capacity (WHC), % drip loss (DL), sarcomere length (SL), myofibril fragment length (MFL), Warner-Bratzler shear force (WBSF), tenderness, juiciness, % thawing loss and % cooking loss of the *Semimembranosus* (SM) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		Sex		Treatment	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
pH						
1-hour *pm*[#]	6.34 ± 0.33	6.29 ± 0.26	6.34 ± 0.32	6.28 ± 0.26	6.34^{a} ± 0.32	6.28^{b} ± 0.26
3-hours *pm*	6.12 ± 0.33	6.12 ± 0.29	5.91 ± 0.18	6.33 ± 0.26	5.91^{a} ± 0.18	6.33^{b} ± 0.26
6-hours *pm*	5.90 ± 0.28	5.96 ± 0.30	5.73 ± 0.17	6.13 ± 0.25	5.73^{a} ± 0.17	6.13^{b} ± 0.25
24-hours *pm*	5.62 ± 0.10	5.65 ± 0.11	5.60 ± 0.10	5.67 ± 0.10	5.60^{a} ± 0.10	5.67^{b} ± 0.10
Temperature						
1-hour *pm*	31.98 ± 2.28	32.24 ± 2.73	32.54^{a} ± 2.44	31.69^{b} ± 2.56	31.40 ± 2.79	32.99 ± 1.84
3-hours *pm*	16.97^{a} ± 2.72	15.47^{b} ± 2.80	16.41^{a} ± 2.80	15.90^{b} ± 2.91	15.26 ± 2.98	17.23 ± 2.29
6-hours *pm*	8.55^{x} ± 2.97	7.34^{y} ± 3.08	7.72^{a} ± 2.99	8.10^{b} ± 3.18	7.15 ± 2.36	8.81 ± 3.57
24-hours *pm*	8.43^{a} ± 2.12	6.59^{b} ± 2.62	7.54^{a} ± 2.43	7.36^{b} ± 2.72	6.85 ± 2.28	8.17 ± 2.29
WHC 1 day *pm*	0.400^{a} ± 0.04	0.433^{b} ± 0.05	0.433 ± 0.05	0.411 ± 0.04	0.414 ± 0.052	0.420 ± 0.056
WHC 4 days *pm*	0.387 ± 0.06	0.398 ± 0.04	0.392 ± 0.05	0.385 ± 0.04	0.385 ± 0.041	0.394 ± 0.05
Drip loss (%)	2.844^{x} ± 1.20	2.422^{y} ± 0.83	2.582 ± 1.14	2.661 ± 0.92	2.573 ± 1.032	2.692 ± 1.05
SL (µm)	1.88^{a} ± 0.10	1.83^{b} ± 0.11	1.86 ± 0.11	1.84 ± 0.11	1.88^{x} ± 0.12	1.83^{y} ± 0.10
MFL 1-day *pm* (µm)	38.10 ± 4.37	39.48 ± 5.03	40.78^{a} ± 4.66	36.50^{b} ± 3.74	38.28 ± 4.23	39.41 ± 5.23
MFL 4-days *pm* (µm)	31.18^{x} ± 4.90	29.32^{y} ± 4.62	31.31^{a} ± 5.12	28.85^{b} ± 4.11	29.08^{a} ± 4.97	31.33^{b} ± 4.44
WBSF 1-day *pm* (N)	50.00^{a} ± 1.17	56.00^{b} ± 1.22	55.90^{a} ± 1.13	49.40^{b} ± 1.25	50.60^{x} ± 1.10	55.30^{y} ± 1.30
Tenderness 4-days *pm*	3.61 ± 1.11	3.25 ± 1.33	3.28 ± 1.23	3.57 ± 1.25	3.67^{a} ± 1.25	3.16^{b} ± 1.18
Juiciness 4-days *pm*	4.12 ± 0.88	3.88 ± 1.05	3.91 ± 0.97	4.09 ± 0.99	4.16^{a} ± 0.92	3.83^{b} ± 1.01
Thawing loss (%) 1-day *pm*	5.00^{a} ± 1.17	5.60^{b} ± 1.22	5.59^{a} ± 1.13	4.94^{b} ± 1.25	5.06 ± 1.10	5.53 ± 1.30
Thawing loss (%) 4-days *pm*	0.40^{a} ± 0.04	0.43^{b} ± 0.05	0.43 ± 0.05	0.41 ± 0.04	0.41 ± 0.05	0.42 ± 0.05
Cooking loss (%) 1-day *pm*	75.26 ± 4.43	76.02 ± 5.83	74.96 ± 5.36	76.51 ± 4.96	75.89 ± 5.51	75.43 ± 4.93
Cooking loss (%) 4-days *pm*	30.18 ± 4.81	30.56 ± 4.42	31.95^{a} ± 4.19	28.51^{b} ± 4.36	30.15 ± 4.36	30.63 ± 4.84

[a,b] Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)

[#]pm = post-mortem

Table 5.6. The significance (P-values) of the main effects of breed (BG vs. IVG), sex (bucks vs. wethers), treatment (ES vs. NS) and their interactions on the calpain systems of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles.

	Significance (P- Values)													
	***Longissimus thoracis et lumborum* (LTL)**							***Semimembranosus* (SM)**						
	Breed	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**	**Breed**	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**
Calpain system activity 1 hour *pm*														
Calpastatin (U/g)	0.334	**0.039**	0.806	**0.033**	0.396	0.526	0.791	0.121	0.244	0.393	0.332	0.886	0.431	0.872
Specific calpastatin	0.270	**0.001**	0.585	**0.022**	0.452	0.704	0.565	0.150	**0.004**	0.805	0.314	0.898	0.725	0.811
Calpain-1 (U/g)	0.067	0.717	0.080	0.752	0.086	0.117	0.142	0.469	0.190	0.162	0.590	0.779	0.453	0.396
Specific Calpain-1	**0.039**	0.059	0.170	0.311	0.092	0.080	0.828	0.700	0.337	0.489	0.546	0.976	0.285	0.358
Calpain-2 (U/g)	0.446	0.591	0.268	0.099	0.237	0.831	0.731	**0.042**	0.902	0.987	0.984	0.066	0.969	0.758
Specific Calpain-2	0.545	0.111	0.487	**0.033**	0.328	0.853	0.158	0.106	**0.010**	0.528	0.884	0.165	0.791	0.636
Calpastatin/Calpain-1	0.586	0.066	0.112	0.135	0.579	0.155	0.374	0.165	**0.007**	0.443	0.111	0.577	0.496	0.171
Calpastatin/Calpain-1+ Calpain-2	0.887	**0.028**	0.182	0.171	0.741	0.309	0.759	0.522	**0.038**	0.855	0.155	0.432	0.447	0.308
Calpain system activity 24 hours *pm*														
Calpastatin (U/g)	0.859	0.096	0.273	0.069	0.056	0.934	0.725	0.440	0.141	0.922	**0.013**	0.341	0.082	0.956
Specific calpastatin	0.924	**0.014**	0.626	**0.047**	0.051	0.970	0.980	0.352	**0.007**	0.908	**0.009**	0.378	0.116	0.976
Calpain-1 (U/g)	0.583	0.920	**0.029**	0.080	0.928	0.825	0.150	0.754	0.917	0.259	0.290	0.844	0.547	0.134
Specific Calpain-1	0.661	0.406	0.088	**0.044**	0.883	0.777	0.303	0.210	0.283	0.601	0.180	0.447	0.184	0.582
Calpain-2 (U/g)	**0.003**	0.711	0.299	0.289	**0.037**	0.338	0.299	0.054	0.462	0.120	0.244	**0.003**	0.845	0.467
Specific Calpain-2	**0.008**	**0.006**	0.808	0.789	0.056	0.475	0.054	0.083	**0.0002**	0.200	0.567	**0.017**	0.929	0.475
Calpastatin/Calpain-1	0.116	0.085	0.798	0.633	0.834	0.539	0.432	0.867	0.639	0.496	0.918	0.484	0.120	0.651
Calpastatin/Calpain-1+ Calpain-2	0.230	**0.051**	0.932	0.313	0.037	0.832	0.867	0.608	0.295	0.305	**0.042**	0.172	0.286	0.558

Significant P-values are presented in bold; post-mortem = pm

Table 5.7. Least square means and standard error (SE) of means of breed, sex and treatment on the calpain system of the *Longissimus thoracis et lumborum* (LTL) muscle of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		Sex		Treatment	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
Calpain system activity 1 hour *pm*[#]						
Calpastatin (U/g)	1.140 ± 0.208	1.097 ± 0.188	1.161^{a} ± 0.188	1.065^{b} ± 0.188	1.125 ± 0.202	1.109 ± 0.195
Specific calpastatin	0.025 ± 0.005	0.024 ± 0.004	0.026^{a} ± 0.004	0.022^{b} ± 0.004	0.025 ± 0.005	0.024 ± 0.004
Calpain-1 (U/g)	1.003^{x} ± 0.111	0.948^{y} ± 0.150	0.971 ± 0.139	0.978 ± 0.131	0.948^{x} ± 0.157	1.001^{y} ± 0.103
Specific Calpain-1	0.022^{a} ± 0.003	0.021^{b} ± 0.003	0.022 ± 0.003	0.020 ± 0.002	0.021 ± 0.003	0.021 ± 0.002
Calpain-2 (U/g)	0.826 ± 0.092	0.809 ± 0.102	0.812 ± 0.104	0.823 ± 0.088	0.805 ± 0.103	0.830 ± 0.090
Specific Calpain-2	0.018 ± 0.003	0.017 ± 0.003	0.018 ± 0.003	0.017 ± 0.002	0.017 ± 0.002	0.018 ± 0.002
Calpastatin/Calpain-1	1.148 ± 0.240	1.178 ± 0.250	1.209 ± 0.208	1.110 ± 0.274	1.210 ± 0.264	1.117 ± 0.215
Calpastatin/Calpain-1+ Calpain-2	0.624 ± 0.113	0.628 ± 0.117	0.652^{a} ± 0.102	0.595^{b} ± 0.123	0.645 ± 0.122	0.607 ± 0.105
Calpain system activity 24 hours *pm*						
Calpastatin (U/g)	0.804 ± 0.271	0.814 ± 0.243	0.852 ± 0.233	0.757 ± 0.274	0.781 ± 0.254	0.838 ± 0.256
Specific calpastatin	0.017 ± 0.006	0.017 ± 0.005	0.018^{a} ± 0.005	0.015^{b} ± 0.005	0.017 ± 0.006	0.017 ± 0.005
Calpain-1 (U/g)	0.739 ± 0.179	0.713 ± 0.229	0.724 ± 0.211	0.727 ± 0.204	0.675^{a} ± 0.176	0.777^{b} ± 0.224
Specific Calpain-1	0.016 ± 0.004	0.015 ± 0.004	0.015 ± 0.004	0.014 ± 0.004	0.014^{x} ± 0.004	0.016^{y} ± 0.004
Calpain-2 (U/g)	0.825^{a} ± 0.086	0.764^{b} ± 0.089	0.798 ± 0.091	0.786 ± 0.095	0.782 ± 0.088	0.803 ± 0.097
Specific Calpain-2	0.017^{a} ± 0.002	0.016^{b} ± 0.002	0.017^{a} ± 0.002	0.016^{b} ± 0.002	0.016 ± 0.002	0.016 ± 0.002
Calpastatin/Calpain-1	1.075 ± 0.357	1.287 ± 0.706	1.286 ± 0.686	1.071 ± 0.386	1.177 ± 0.444	1.200 ± 0.692
Calpastatin/Calpain-1+ Calpain-2	0.515 ± 0.167	0.563 ± 0.189	0.575^{x} ± 0.187	0.499^{y} ± 0.163	0.544 ± 0.187	0.537 ± 0.174

[a,b] *Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)*

[x,y] *Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)*

[#]*pm = post-mortem*

Table 5.8. Least square means and standard error (SE) of means of breed, sex and treatment on the calpain system of the *Semimembranosus* (SM) muscle of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		Sex		Treatment	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
Calpain system activity 1 hour *pm*[#]						
Calpastatin (U/g)	1.111 ± 0.215	1.039 ± 1.1181	1.100 ± 0.206	1.040 ± 0.190	1.054 ± 0.182	1.092 ± 0.217
Specific calpastatin	0.025 ± 0.005	0.023 ± 0.004	0.026^{a} ± 0.005	0.022^{b} ± 0.004	0.024 ± 0.004	0.024 ± 0.005
Calpain-1 (U/g)	0.986 ± 0.154	0.960 ± 0.160	0.951 ± 0.161	0.977 ± 0.151	0.946 ± 0.157	0.999 ± 0.155
Specific Calpain-1	0.018 ± 0.002	0.017 ± 0.002	0.022 ± 0.003	0.021 ± 0.003	0.021 ± 0.003	0.022 ± 0.003
Calpain-2 (U/g)	0.815^{a} ± 0.102	0.763^{b} ± 0.110	0.788 ± 0.111	0.787 ± 0.108	0.787 ± 0.105	0.787 ± 0.115
Specific Calpain-2	0.018 ± 0.002	0.017 ± 0.002	0.018^{a} ± 0.002	0.017^{b} ± 0.002	0.018 ± 0.002	0.017 ± 0.002
Calpastatin/Calpain-1	1.165 ± 0.233	1.095 ± 0.224	1.193^{a} ± 0.231	1.049^{b} ± 0.205	1.149 ± 0.242	1.105 ± 0.218
Calpastatin/Calpain-1+ Calpain-2	0.624 ± 0.107	0.608 ± 0.115	0.640^{a} ± 0.111	0.586^{b} ± 0.104	0.619 ± 0.116	0.612 ± 0.106
Calpain system activity 24 hours *pm*						
Calpastatin (U/g)	0.845 ± 0.234	0.809 ± 0.197	0.859 ± 0.215	0.786 ± 0.209	0.826 ± 0.195	0.826 ± 0.235
Specific calpastatin	0.018 ± 0.005	0.017 ± 0.004	0.018^{a} ± 0.004	0.015^{b} ± 0.004	0.017 ± 0.004	0.017 ± 0.005
Calpain-1 (U/g)	0.736 ± 0.182	0.722 ± 0.199	0.727 ± 0.167	0.731 ± 0.217	0.704 ± 0.161	0.754 ± 0.216
Specific Calpain-1	0.018 ± 0.019	0.014 ± 0.004	0.018 ± 0.018	0.014 ± 0.004	0.017 ± 0.018	0.015 ± 0.004
Calpain-2 (U/g)	0.840^{x} ± 0.081	0.798^{y} ± 0.112	0.826 ± 0.101	0.807 ± 0.101	0.800 ± 0.093	0.835 ± 0.106
Specific Calpain-2	0.017^{x} ± 0.002	0.016^{y} ± 0.002	0.018^{a} ± 0.002	0.016^{b} ± 0.002	0.017 ± 0.002	0.017 ± 0.002
Calpastatin/Calpain-1	1.223 ± 0.459	1.243 ± 0.533	1.258 ± 0.472	1.205 ± 0.529	1.274 ± 0.480	1.192 ± 0.516
Calpastatin/Calpain-1+ Calpain-2	0.557 ± 0.182	0.538 ± 0.145	0.565 ± 0.171	0.525 ± 0.151	0.567 ± 0.172	0.526 ± 0.152

[a,b] *Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)*

[x,y] *Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.1)*

[#]*pm = post-mortem*

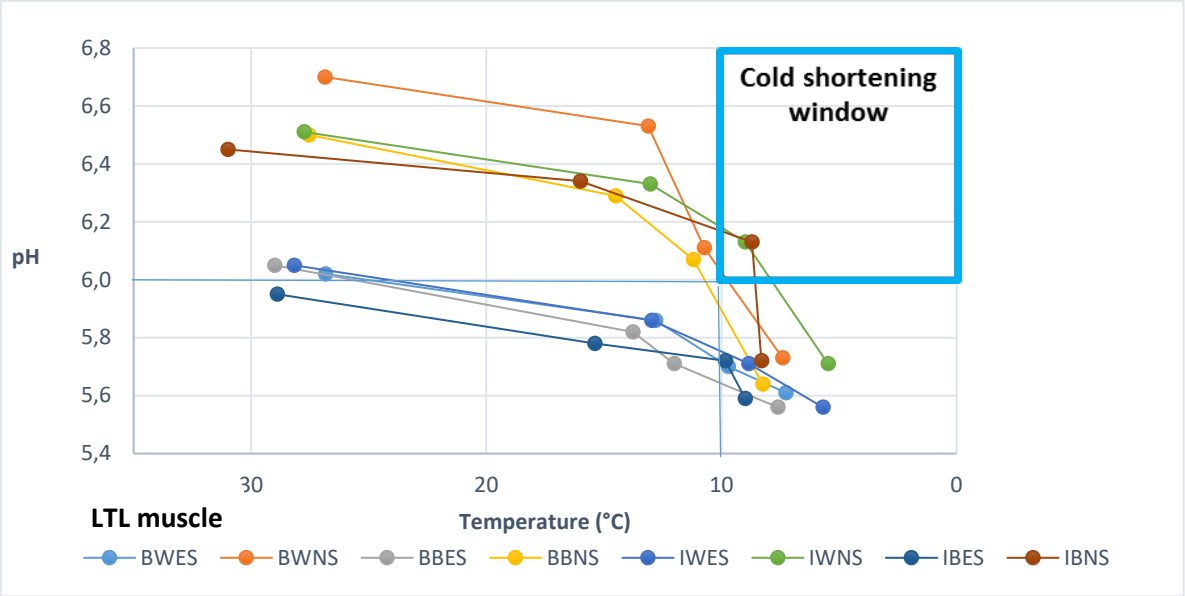

Figure 5.2. Average temperature and pH decline of the *pre-* and *post-mortem* interventions for the LTL muscle; BWES, BWNS, BBES, BBNS, IWES, IWNS, IBES, IBNS (See Figure 5.1 for treatment group descriptions). Cold shortening window according to Pearson and Young (1989), as discussed in the review of Thompson (2002).

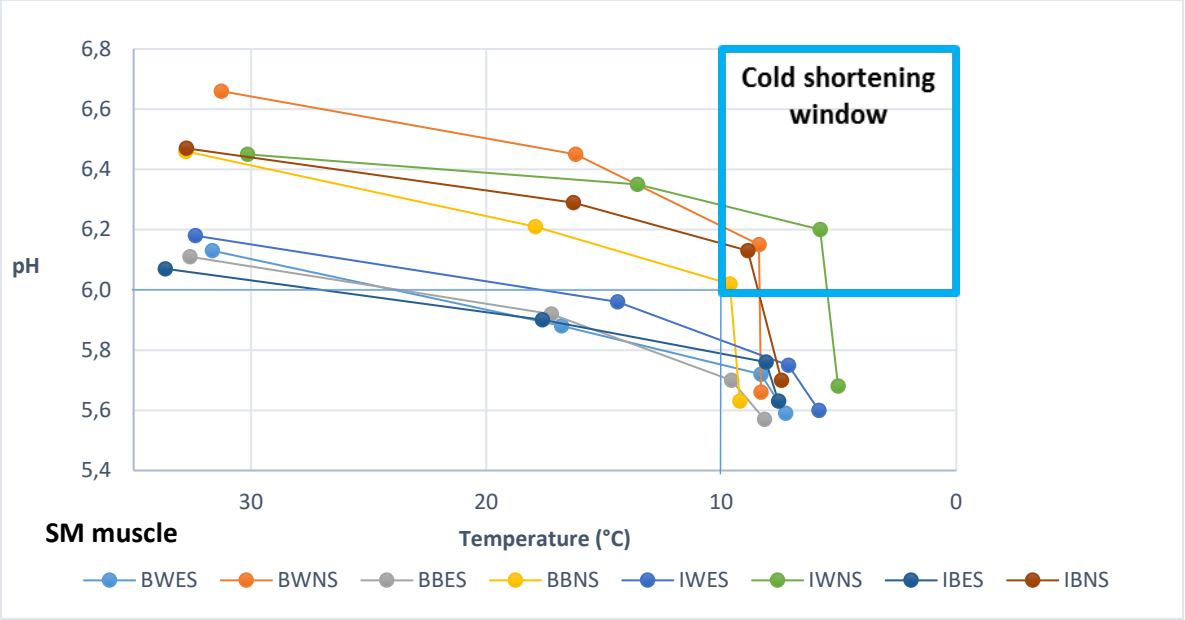

Figure 5.3. Average temperature and pH decline of the *pre-* and *post-mortem* interventions for the SM muscle; BWES, BWNS, BBES, BBNS, IWES, IWNS, IBES, IBNS (See Figure 5.1 for treatment group descriptions). Cold shortening window according to Pearson and Young (1989), as discussed in the review of Thompson (2002).

Tornberg (1996) studied the biophysical aspects of meat tenderness and concluded that the minimal shortening region for beef LTL is 10 to 15°C and for SM 7 to 13°C. In the present investigation (Figure 5.3), it could be suggested that there is a possible relationship between percentage shortening and ultimate tenderness both in the warm and cold-shortening region, but for the LTL muscle (Figure 5.2), this was only aplicable in the cold-shortening region. Reasons why the *longissimus* muscle is sensitive to cold shortening is likely the attached structure, whereby the fibres are firmly anchored to

the skeletal framework at one end only (Buege and Marsh, 1975) and secondly, the LTL is a more enzymatically active muscle than SM (Tornberg, 1996). Jeacocke (1993) suggested that individual carcasses or even individual muscle fibres within carcasses could be subjected to cold shortening as not all fibres enter *rigor* at exactly the same time and thus partial cold shortening could have taken place in some of the treatment groups (e.g., IWNS, BWNS, BBNS, IBNS) as presented in Figure 5.2 and Figure 5.3. In both muscles (LTL and SM) the pH decline was accelerated by ES (Table 5.4 and Table 5.5) resulting in the pH differing significantly ($P \leq 0.05$) between ES and NS at all time points evaluated (1-, 3-, 6- and 24-hours *post-mortem*, Table 5.3). Both LTL and SM muscles from the ES carcasses avoided the cold shortening window and had reached a pH_u before the temperature of the carcass had decreased to 10°C. The fact that the higher pH_u were measured in NS muscles might indicate that *rigor-mortis* was not yet concluded at the time of measurement. By using a stepwise chilling strategy, Pophiwa *et al.* (2016) avoided the risk window for cold shortening on BG and non-defined indigenous goat for NS carcasses. Furthermore, the present results suggested that the ES treatment caused an acceleration of glycolysis (Chapter 6) and subsequent early *rigor-mortis* development. The difference between the current study and that of Pophiwa *et al*. (2016), is that the ES conditions differed e.g., 20 seconds, 400 Volts peak, 5 milli seconds pulses at 15 pulses/second (current study) vs. 30 seconds, 220 Volts peak at 9.5 pulses/second (Pophiwa *et al.,* 2016). The mode of action of ES relies on its ability to accelerate *post-mortem* glycolysis resulting in a more rapid pH decline via rapid depletion of muscle glycogen (Adeyemi and Sazili, 2014). Therefore, the choice of using only 20 seconds of ES proved to be too short in the current study and is deduced to be the cause of the tougher meat in this study, however, an ideal ES regime for goat carcasses still needs to be developed.

5.3.1.2. Physical and sensory characteristics

Boer Goats (SM muscle) had lower WHC than IVG (0.400 vs. 0.433; $P \leq 0.05$), 1-day *post-mortem* which corresponds to the higher % DL tendency of BG compared to IVG (2.844 vs. 2.422; $P \leq 0.10$). In addition, WHC, DL and SL measurements support the lower WBSF of BG (SM only). In the LTL muscle, bucks had higher WHC than wethers (0.444 vs. 0.422; $P \leq 0.05$, 1-day *post-mortem* and 0.411 vs. 0.400; $P \leq 0.1$, 4-days *post-mortem*) which corresponds to the lower % DL of bucks compared to wethers (1.9 vs. 2.4; $P \leq 0.05$). In the current study, breed had a significant effect ($P \leq 0.05$) on SL with longer average SL measurements measured in BG (LTL; 1.87 µm) vs. IVG 1.82 µm; SM (1.88 µm vs. 1.83 µm) thus, an average of about 0.05 µm between breeds. It is a surprisingly small difference and is debatable if it would have a noticeable effect on other attributes such as WHC, DL and tenderness, of which some does have showed a slight tendency ($P \leq 0.10$) towards a breed effect (Table 5.3).

Short SL could be an indication of excessive muscle contraction caused by high energy at very low muscle temperature (cold shortening) resulting in tougher meat. This phenomenon is frequently a major cause of goat meat toughness during commercial *post-slaughter* chilling (<4°C)

conditions (Webb *et al.,* 2005; Kannan *et al.,* 2014). Studies in other species have further shown that muscles with longer sarcomeres tend to be more tender than those with shorter sarcomeres (Kerth *et al.,* 1999; Smulders *et al.,* 1990; Veiseth *et al.,* 2004). Marsh and Leet (1966) reported that 20 % shortening in sarcomeres caused negligible effects on beef tenderness and relates to 1.8 µm if resting sarcomere is assumed to be 2.2 µm long (according to Herring *et al.* (1967) for bovine *semitendinosus*) and used by various studies (Wheeler and Koohmaraie, 1999; Simela, 2005; Pophiwa *et al.,* 2016) on ovine *longissimus* muscle as reference. The sarcomeres in the present study were on average ~1.85 µm (Table 5.4) and had shortened by 15 to 18 %. This differs from that reported for goats in South Africa that shortened between 5 to 10 % (Pophiwa *et al.,* 2017) or 20 to 40 % (Simela, 2005). Simela (2005) reported sarcomeres shorter than 1.7 µm and concluded that it could be an explanation for muscle toughening as discussed by Marsh and Leet (1966).

According to Kadim *et al.* (2003), breed differences in goat meat tenderness may be due to variations in the connective tissue content (See Chapter 4) and / or proteolytic activity (Ferguson *et al.,* 2000). Breed differences, or lack thereof, in the tenderness depend on factors such as age, level of nutrition, ultimate pH, the type of muscle and temperature of cooking (Kadim *et al.,* 2003; Pophiwa *et al.,* 2017). However, variation of individual goat's muscles in WBSF values may be associated with their content and structure (degree of cross-links of collagen fibres) of connective tissue due to differential involvement in physical activities (Gonzalez *et al.,* 1983). Hozza *et al.* (2015) reported the shear force values for Small East African (SEA) Goats and Norwegian Crosses, *gluteobiceps* (66.0 N), *semimembranosus* (65.0 N) and *vastus lateralis* (58.0 N) which were regarded as objectionably tough and demonstrated that there are differences (caused by breed, nutrition, and management practices) in meat quality characteristics of meat from SEA goats and their crosses with Norwegian goats. Unfortunately, authors rarely describe the precise anatomical location from which samples are derived and further investigations are required on muscle profiling of different goat breeds present in Southern Africa (refer to Chapter 4).

As the loin is traditionally dry cooked in the Southern African culture, the aim of this study was to imitate normal consumer behaviour, hence the use of a dry heat cooking technique (section 5.2.6). The cooking method could however influence the tenderness measured as it was expected that the LTL would be more tender than the SM; the opposite was found (Table 5.5 and 5.6). In the present study, the average values measured in the LTL muscle for cooking losses were marginally similar in value for the LTL muscle of Spanish and cross breed goats (15 to 16 %) (Gadiyaram *et al.,* 2008). Kadim *et al.* (2003) reported cooking losses of 29.9 to 33.6 % for the LTL and SM muscles of three Omani goat breeds whilst Pratiwi *et al.* (2007) reported cooking losses as high 40 % for the LTL of Feral goats. Marginally higher cooking losses were measured in the current study for the SM muscle (74 - 76 %). No significant differences were presented for thawing losses; there is limited information on thawing losses of goat meat, although Schnöfeldt *et al*. (1993b) reported thawing losses of <1 % in LTL and SM muscles of Angora and Boer Goats. The current study confirmed the findings of Pophiwa *et al.* (2016) with losses of 2 - 3 % for the LTL and 5 - 6 % for the SM muscles,

respectively. Overall, the variation in cooking losses reported in different studies can be attributed to the method, time and temperature of cooking, pH_u of the muscle and the muscle used; these factors can also change the nutritional value, flavour and tenderness of meat resulting in varied perceptions of goat meat (Hoffman and Wiklund, 2006).

Juiciness of meat is directly related to the intramuscular lipids and moisture content of the meat (Cross *et al.,* 1986), while the water remaining in the cooked product is the major contributor to the sensation of juiciness during eating (Forrest *et al.,* 1975). The moisture cooking method used for the SM would ensure a more tender outcome as this method counteract all the connective tissue drawbacks for example, as moist heat is applied over time, the collagen is transformed into a water-soluble gel and the muscle softens. Contrasting, Rhee *et al.* (2004) concluded that among the biochemical traits expected to be related to tenderness, proteolysis was more highly correlated with tenderness rating in the LTL of beef. The traits related to tenderness and shear force, however, are highly variable in individual muscles, and numerous factors are associated with meat tenderness. Tender beef is defined as being <55.0 N by Shackelford *et al*. (1991). Taking this as a reference the SM from both BG and IVG would be considered relative tender in contrast to the LTL that measured >60.0 N. In contrast, Pophiwa *et al.* (2017) found the SM to be much tougher compared to this study and LTL more tender (~41.5 N) than measured in this study (~64.0 N). In agreement with this study, Pophiwa *et al.* (2017) found that the SM of IVG had higher WBSF values (86.7 N) compared to BG (79.0 N) 1 day *post-mortem*, which are both regarded as very tough compared to what thie current study measured for both BG (50.0 N) and IVG (56.0 N) (Table 5.5). The contradictory WBSF, sensory attributes and related results found between the current study and that of Pophiwa *et al.* (2016) although performed in the same laboratory, were not unexpected and can be attributed to different *pre-* and *post-slaughter* conditions applied (undefined indigenous goats, ES for 30 seconds and stepwise chilling).

Differences in WHC, DL and SL were not found between bucks and wethers and ES and NS SM muscles. Ndakeva *et al.* (2018), reported lower DL values for sex (does) in both LTL and SM which could be due to the stepwise chilling / delayed chilling applied in their study compared to the current study. The mechanism of WHC is very complex and only partly understood (as reviewed in Ertbjerg and Puolani, 2014). Knowledge on mechanisms to control the amount of available water in meat is essential as meat is sold on weight, thus it is important to minimize water losses (Den Hertog-Meischke *et al.,* 1997). Proteolytic activity *post-mortem* could affect WHC and DL (Huff-Lonergan and Lonergan, 2005), as there is a great body of evidence that demonstrates a direct effect of pH, ionic strength, and oxidation on the ability of myofibrillar protein and myofibrils and muscle cells to entrap water. Independent of these effects, the same factors (pH decline, ionic strength, and oxidation) also affect proteolysis of key cytoskeletal proteins in *post-mortem* muscle (Huff-Lonergan and Lonergan, 2005). Variation in water holding capacity at any given pH and temperature of storage is proposed to be at least partially due to variation in proteolysis and the resulting muscle cell shrinkage and mobilization of water to the extracellular space and could explain the higher WBSF

measured *post-mortem* for buck LTL compared to LTL of wethers (67.7 N vs. 57.2 N, respectively; P ≤ 0.05) including for buck SM compared to SM of wethers (55.9 N vs. 49.42 N, respectively; P ≤ 0.05). The LTL muscle (Table 5.7) showed higher calpastatin levels for bucks (1.611 U/g) compared to wethers (1.065 U/g) for 1 hour *post-mortem* and this trend was repeated at 24 hours *post-mortem* with higher specific calpastatin for bucks (0.018 U/g) compared to wethers (0.015 U/g). Similarly, in the SM muscle, higher calpastatin levels for bucks (1.100 U/g) compared to wethers (1.040 U/g) at 1 hour *post-mortem* was recorded and this trend was repeated at 24 hours *post-mortem* with higher specific calpastatin for bucks (0.018 U/g) compared to wethers (0.015 U/g). The calpain system play a major role in *post-mortem* tenderisation (Koohmaraie.1992; Boehm *et al*., 1998). When low level of calpastatin is produced, the more calpain protease is produced relating to an increase in meat tenderness, therefore the higher calpastatin levels observed for bucks demonstrate that weathers is more tender compared to bucks and as established by the WBSF values observed in Table 5.5.

5.3.1.3. Proteolytic enzyme system

Proteolytic activity can be assessed by measuring MFL that is associated with *post-mortem* proteolysis, as during *post-mortem* storage as proteases weaken myofibrils by causing fragmentation (Koohmaraie, 1994; Kannan *et al.,* 2014). At 4-days *post-mortem* in the SM muscle, MFL tended to differ (P ≤ 0.10) between breed, sex and treatment, indicating that muscles react differently to *pre*-and *post-slaughter* treatments (Table 5.3). Boer Goats' (BG) MFL at 4 days *post-mortem* were longer than IVG's (31.19 µm and 29.32 µm, respectively, P ≤ 0.05). Myofibril fragment length (MFL) in the LTL muscle differed (P ≤ 0.05) between wethers and bucks at 1- and 4-days *post-mortem* where bucks (SM muscle) had longer MFL (40.78 µm; 1 day and 31.31 µm, respectively; 4 days *post-mortem*) compared to wethers (36.50 µm, 28.85 µm, respectively).

Differences in MFL (1 day *post-mortem*) were not found between ES and NS carcasses, but in the SM muscle at 4 days *post-mortem*, NS carcasses had longer MFL (31.33 µm) compared to ES carcasses (29.08 µm). Physically the SL averages did not differ much from each other (~1.8 µm) and could explain the tenderising effect of ES (Wheeler and Koohmaraie, 1999). These results also indicate that ES did not affect the SM in the same way as with the LTL muscle. Further, a tendency to differ (P ≤ 0.10) was observed for WHC and DL between ES and NS carcasses. ES improves meat tenderness, particularly within the first few days *post-mortem* (Takahashi *et al.,* 1987; Ho *et al.,* 1997; Kadim *et al.,* 2006). One of the detrimental effects of ES can however be a significant increase in % DL, lower WHC and protein degradation (Kahraman and Ergun, 2009). When proteins degrade *post-mortem*, they lose the ability to bind water in muscles (Den Hertog-Meischke *et al.,* 1997). In the current investigation, ES had no negative effects on the ability of both muscles to retain water (WHC and % DL) but did increase (P ≤ 0.05) the tenderness of the LTL muscle. The SM was however more tender compared to both ES and NS LTL muscles (Table 5.4 and Table 5.5). It is important to apply ES and temperature conditions to control any possible negative effects, whilst still benefiting

from the tenderising effect. King *et al.* (2004) reported that *post-mortem* ES improves many quality factors in caprito (very young kids) whilst Kannan *et al*. (2014) ascribed these improvements to earlier activation of proteases, physical disruption of muscle fibres, or both. Shorter MFL values were only measured in the ES group for the SM muscles at 4 days *post-mortem*. The reason for the lack of shorter MFL in the ES LTL is unclear as it was expected that these muscles would show higher levels of myofibrillar breakage. This result could not be explained.

Significant ($P \leq 0.05$) interactions between breed x sex were recorded for LTL calpastatin and specific calpastatin 1 hour *post-mortem* with similar interactions being noted at 24 hours *post-mortem* (Table 5.7). Contrary, IVG calpastatin related measurements between bucks and wethers did not differ significantly. Calpain-1, 1 hour *post-mortem* showed a tendancies ($P \leq 0.10$) to differ between breed and treatment as well as a sex x treatment interaction. The trend for breed become significant ($P \leq 0.05$) when calculating specific Calpain-1. On average BG measured a higher Calpain-1 level in the LTL compared to that of IVG (~1 U/g vs. 0.9 U/g). This changed at 24 hours *post-mortem* where Calpain-1 showed a significant difference ($P \leq 0.05$) between treatment and a trend ($P \leq 0.10$) in the breed x sex interaction, which became significant ($P \leq 0.05$) when calculating specific Calpain-1. The percentage decrease of Calpain-1 activity of approximately 28 - 34 % and 30 - 37 % recorded in the LTL and SM respectively of all goat eco-types by 24-hours *post-mortem* were within the range previously reported by Dransfield (1993) of about 20 - 70 % decrease by 24-hours *post-mortem*. Ndakeva (2018) reported similar values of 29 - 39 % and 24 - 36 % in LTL and SM, respectively as measured for different goat eco-types. Calpain-2, 1 hour *post-mortem* showed an interaction trend ($P \leq 0.10$) between breed and sex and its corresponding specific Calpain-2, a significant ($P \leq 0.05$) interaction between breed and sex in the LTL muscle, but after 24 hours *post-mortem* Calpain-2 ($P \leq 0.05$) and specific Calpain-2 ($P < 0.10$) showed sex x treatment interactions (Table 5.6). Specific Calpain-2 higher values were observed in BG bucks for both ES and NS carcasses while for IVG for bucks of NS carcases. Calpastatin / Calpain-1 ratio at 1- and 24-hours *post-mortem* showed slight sex differences ($P \leq 0.10$), however the calpastatin ratio to both Calpain-1 and Calpain-2 at 1 and 24 hours differed significantly ($P \leq 0.05$) between the sexes. It can, therefore, be expect that Calpain-2 in combination with calpastatin, played a greater role in *post-mortem* interactions in the LTL compared to what Calpain-1. Measurements that eliminate the extractable protein factor showed more significant differences than *vice versa*. Calpastatin and Calpain-1 activities in the LTL decreased from 1 hour to 24 hours *post-mortem*, but Calpain-2 stayed relatively stable (Table 5.7). These findings correspond with the normal activity pattern for other species, such as beef (North *et al.,* 2015).

In contrast to the LTL, the SM showed no interactions between breed, sex, or treatment at 1 day *post-mortem* for calpastatin related measurements but followed the same pattern at 24 hours *post-mortem* (Tables 5.7 and 5.8) than the LTL. In the SM muscle (Table 5.8), BG, bucks (ES and NS carcasses) had significantly ($P \leq 0.05$) higher calpastatin and specific calpastatin values,

whereas the BG wethers (ES carcasses) had the lowest calpastatin and specific calpastatin values. Calpain-1, 1- and 24-hours *post-mortem* and the corresponding specific Calpain-1 in the SM muscle showed no breed, sex or treatment differences. In contrast, Calpain-2 1 hour *post-mortem* showed a tendency for a breed difference ($P \leq 0.10$) while specific Calpain-2 showed a significant interaction between sex in the SM muscle at 1 hour *post-mortem*. Similar results for calpastatin / Calpain-1 ratio and calpastatin ratio to both Calpain-1 and Calpain-2 at 1 hour *post-mortem* were oberved. Similar breed x sex interactions were found for calpastatin and specific calpastatin in the SM as was found in the LTL as well as for Calpain-2, specific Calpain-2 and calpastatin ratios to both Calpain-1 and Calpain-2 at 24 hours *post-mortem*. It is therefor clear that Calpain-1 did not play any role in the *post-mortem* differences in proteolytic action in the SM muscle. This observation does however not imply that Calpain-1 has not played a role during *post-mortem* tenderisation. It merely indicates that it was not influenced by breed, sex or ES as reflected by normal activity at 1 hour *post-mortem* (Tables 5.7 and 5.8).

There is limited information on the effects of goat eco-types on calpain and calpastatin activities. The calpastatin inhibitor and Calpain-1 activities decreased with the ageing period (Table 5.7 and Table 5.8). As expected, both Calpain systems components still seem to be active 24 hours *post-mortem*. North *et al.* (2019) studied these systems in springbok (*Antidorcas marsupialis* - an ungulate species similar in size to goats and having minimal subcutaneous fat) and reported similar results. The Calpain-2 component though seems to be stable throughout ageing and seems to be similar to other animal systems studied (Koohmaraie, 1994; Kemp *et al.,* 2010; Nowak, 2011). Observing the Calpain system components measured at 1 hour *post-mortem* and 24 hours *post-mortem*, only Calpain-2 activity appears to play a possible role in explaining the slight difference between WBSF measured in BG and IVG muscles, particularly as pertaining to the SM. Calpain-2 (SM) has a higher activity level in BG than IVG at both 1-hour *post-mortem* and 24 hours *post-mortem* (Table 5.8). North *et al.* (2015) suggested that in springbok meat, Calpain-2 played a greater role in tenderisation than is normally found in beef, which may partially explain the more rapid tenderisation found in their study and a faisable explaination for the current study.

Optimal activity of the calpain system is at pH 7 to 6 (Morgan *et al.,* 1993) with pH values for the current study ranging between 6.3 - 5.6 (Table 5.4 and Table 5.5). There is limited information on the interaction effects of sex on calpain and calpastatin activity. Male animals are usually known to have higher calpastatin levels than female or castrated animals (Morgan *et al.,* 1993). The current study agrees where the bucks had higher calpastatin levels compared to the wethers. The kinetics of the calpain system is an intricate system whose workings depend on numerous factors including intramuscular calcium levels and other control components (Morgan *et al.,* 1993). As mentioned, Calpain-1 seems to undergo minimum autolysis, implying that proteolytic activity by means of this enzyme could be minimal. Indications in BG suggest that proteolytic activity *post-mortem* should be higher in wethers than bucks, when comparing MFL and WBSF values. Although other factors such as carcass quality (e.g., carcass composition, fat and tenderness) and animal welfare, may play a

role, castration seems very effective in decreasing WBSF. A difference in WBSF of 11.0 N was measured in the LTL of wethers and bucks, which is substantial. The difference in WBSF between wethers and bucks in SM muscle was ~6.0 N, a tenderness difference that should be distinguishable by consumers as confirmed with numerically higher sensorial tenderness and juiciness scores for wethers compared to bucks (Table 5.4). The MFL results further supports these conclusions that proteolytic activity was involved in the more tender results for wethers than bucks. Although the kinetics of the Calpain system might differ from that of other species (Calpain-2 more involved than Calpain-1), the results support that this system is involved with the tenderisation process and could explain why wethers' muscles were overall more tender compared to mussle of bucks (WBSF and sensory attributes). The higher calpastatin inhibitor activity in bucks is in accordance with other research on sex differences (Nagaraj *et al.,* 2002).

The calpastatin activities in this study (Table 5.7 and Table 5.8) were lower than those found by Gadiyaram *et al.* (2008) with 6.8 - 7.6 U/g in ES and NS Spanish goats and their crossbreds that were aged for 1 and 4 days. The values of calpastatin and Calpain-1 activities in the present study was within the range of 0.83 - 2.49 U/g compared to 0.70 - 1.21 U/g reported by Nagaraj and Santhanam (2006) and Ndakeva (2018) in different muscles (e.g., LTL, BF, SM, and ST) and goat eco-types. Furthermore, Kemp *et al*. (2010) stated that high calpastatin levels in meat reduces calpain activity for proteolysis to occur resulting in less meat tenderisation and thus poor meat quality.

In addition, pH influences the decrease in calpastatin and calpains activities (Dransfield, 1993). A possible explanation for the lack of treatment effect observed in this study is that the response of calpastatin to ES is not as rapid as that of the calpains (Ducastaing *et al.,* 1985, Hwang and Thompson, 2001). In studies, where the temporal changes in the calpains and their inhibitor were monitored, differences in the concentration of these enzymes was observed later during chilling, even when there were no differences in the initial values (Uytterhaegen *et al.,* 1992; Geesink *et al.,* 1994). In the current study (Table 5.7), only the specific activity of Calpain-1 measured after 24 hours *post-mortem* in the LTL muscle showed differences ($P \leq 0.05$), where the NS had higher values compared to that of ES carcasses. This could explain the significant impact on WBSF and sensory attribute (tenderness) in ES vs. NS treatment groups and is consistent with studies that have demonstrated the beneficial effect of ES on tenderness (Hwang *et al.,* 2003; Devine *et al.,* 2004). The decline in Calpain-1 activity found, agrees with the results noted for other species (North *et al.,* 2015), however minimal ageing could be a factor in why the WBSF values in the current study was higher compared to values reported by Pophiwa *et al.* (2016).

5.4. Conclusion

Differences between BG and large frame IVG pertaining to LTL are minimal. In conctrast, IVG SM seems to be tougher than that of BG. Shorter SL were measured in IVG compared to BG, which

might explain some meat quality differences. It was expected that both BG and IVG reacted the same towards castration and electrical stimulation as *pre* and *post-mortem* factors that can normally be used to improve the tenderness of meat. Electrical stimulation has however been shown to be ineffectifive. Despite extensive research on ES, the fundamental mechanisms and the appropriate commercial applications remained obscured as applied to chevon, in terms of the effect on meat tenderness and calpain system characteristics. However, it must be kept in mind that the methodologies to measure calpains and calpastatin differ from laboratory to laboratory, and results can therefore not be directly compared. Further research is required to increase awareness of the role that the calpain system and other proteolytic systems play in different goat muscles and the factors affecting meat tenderness as in the current study it could suggest that the proteolytic activation occurred at a later stage than in other species.

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CHAPTER 6

Effect of breed (large frame Indigenous Veld Goat and Boer Goat of Southern Africa), castration and electrical stimulation on meat colour and the *pre-rigor* muscle energy profile of *Longissimus thoracis et lumborum* and *Semimembranosus muscles*

Abstract

Early post-slaughter muscle energy metabolism controlling chevon colour were studied in weaner male Boer Goats (BG; n = 36; 21 bucks and 15 wethers) and large frame Indigenous Veld Goats (IVG; n = 41; 21 bucks and 20 wethers). Half of the carcasses were electrically stimulated 10 minutes post-mortem (ES – 20 seconds, 400 Volts peak, 5ms pulses at 15 pulses/s) and the other half were not stimulated (NS). All dressed carcasses were chilled at 4°C within 1 hour post-mortem. Samples to determine muscle energy levels (1-, 3-, 6- and 24-hour's post-mortem) were taken whilst pH and temperature were measured in the Longissimus thoracis et lumborum (LTL) and Semimembranosus (SM) muscles. Meat colour were measured 1- and 4-days post-mortem. Only significant breed differences were observed for L and a* in the LTL; highest L* was observed for BG and lowest a* for IVG. The pH_u values of >5.6 were linked with meat being darker (L* <31), having lower 24 hours post-mortem muscle glycogen (18 µmol/g) and lactate levels (25 µmol/mg). Wethers had significantly darker meat and lower Hue-angle values than buck in both muscles. At 24 hours post-mortem, glycolytic potential (GP) values were 79 to 94 µmol/g muscle, with BG wethers presenting the group with the highest GP at 1-, 3-, 6- and 24-hours post-mortem in both muscles. A pH_u >5.6, high initial lactate concentration of >35 µmol/g (LTL muscle) and low glycolytic potential (GP) (<94 µmol/g), suggests that goats suffered from both chronic and acute stress during ante-mortem handling.*

Keywords: chevon quality; ultimate pH; meat colour; glycolic potential; glycolytic metabolites

6.1. Introduction

Development of a market for chevon in Southern Africa would offer more diversity of species for red meat producers and benefit emerging farmers who produce over 90 % of goats in Southern Africa. The browsing habits and adaptations to harsh climates of indigenous goats make them useful in semi-arid and harsh environmental conditions (Upton, 2004). It is reported that the Boer Goat (BG) originate from one of the large frame original indigenous breeds, the Cape Lob Ear (Williams, 2015). Various South African privately led breeding programmes resulted in a large number of non-descriptive crossbred "indigenous" goats (Ncube *et al*., 2020; described in Chapter 2) usually used

in comparative studies with the BG. Using these “indigenous” goats showed that quality meat products could be produced, when good farming and rearing practices are followed (Webb, 2014; Pophiwa *et al.,* 2016; 2017). Two of the large frame eco-types of original natural “indigenous” goats that survived the intensive breeding programmes of the early twentieth century, Cape Lob Ear and Cape Speckled, protected by the Indigenous Veld Goat Society of South Africa (Mdladla *et al.,* 2017), were used in this study to compare with the BG. Chevon being a controversial product, depending on consumer perception (Schönfeldt *et al.,* 1993a, 1993b), indicates that there is a need to optimise the *pre-* and *post-slaughter* procedures in order to regulate *post-mortem* glycolysis (Ferguson and Gerrard, 2014) and ensure acceptable visual and eating quality goat meat. *Pre-slaughter* factors such as breed, sex (male, female, castrate), feed withdrawal, stress during transport and handling, could have a negative impact on glycogen reserves at slaughter and subsequent meat quality characteristics such as colour stability and tenderness (Tarrant, 1989; Ilian *et al*., 2001; Kannan *et al*., 2003; Warner *et al*., 2010; Zhu *et al*., 2011; Frylinck *et al.,* 2013) in all species. Kruger *et al.* (2016) concluded that infrequent handling does elicit a more significant stress response in goats and is a more severe stressor than exposure to natural and environmental factors. This study recommended that extra efforts should be made to calm animals before slaughter procedures are to be performed. Such animals would not have a fear of the handlers and thus suffer less stress. The factors contributing to stress, can lead to too high (dark firm and dry; DFD) or too low (pale soft exudative; acid; PSE) ultimate pH and unfavourable meat quality (Troy and Kerry, 2010; Troy *et al.,* 2016). Pale soft exudative meat is more common in porcine. Studies on *pre-* and *post-slaughter* procedures for goat production and the effect on the subsequent meat product are scarce, but Pighin *et al.* (2014) defined DFD phenomenon in lamb as pH_u >6.0. Adapting *ante-slaughter* handling practises and *post-mortem* technologies aimed at maximising chevon quality (Troy *et al.,* 2016), could allow meat processors to optimise meat management systems based on specific quality traits of breed and / or sex.

Meat colour is an important characteristic by which consumers judge the quality and acceptability of meat (Lawrie, 1958; Review Behkit and Faustman, 2005). Colour of meat depends on the meat’s light scattering properties and the concentration and chemical state of myoglobin, which is determined by the energy status of the muscle *ante-* and *post-slaughter* (Brewer, 2004). Myoglobin is a water-soluble protein responsible for transporting and storing oxygen from the blood to the muscle (Wittenberg *et al*., 1975). Due to muscle variation in metabolism and energy demand, the myoglobin concentration differs not only between species, but also between muscles (Wittenberg, 1970). According to Neethling *et al.* (2017) who reviewed the exogenous and endogenous factors influencing the colour and colour stability of fresh meats from domestic and wild ungulates, pre- and post-harvest factors influencing meat colour and meat colour stability are interrelated and the effects of several of these factors are specific to species, breed, sex, and muscle source. Endurance muscles and muscles that are more fatigue resistant, such as muscles located near the bone, need oxygen, as they tend to be rich in mitochondria and utilize oxidative metabolism

as a source for energy production. Due to the muscles' need for oxygen, myoglobin is in high abundance and causes the muscle to have a deeper red colour (Seideman *et al.,* 1984). Glycolytic muscles are typically muscles used for quick bursts of energy, and because oxygen is not required for their function, myoglobin abundance is lessened (England *et al*., 2016), giving the muscles a lighter or paler appearance. In general, beef and other ruminants produce meat that is darker than their differing counterparts - monogastric animals. This difference has been largely attributed to differences in myoglobin content, or its lack thereof (Walters, 1975).

Electrical stimulation (ES) is an innovation used in the meat industry to improve colour and meat tenderness of beef, lamb, and goat meat (Biswas *et al.,* 2007; Kahraman and Ergun, 2009). Electrical stimulation is a procedure involving an electric current passing through a hot carcass immediately or a period after slaughter. The electric current flowing through the muscle tissue causes the muscles to contract and relax at high frequency (anaerobically) resulting in the release of energy causing a subsequent increase in the tempo of H_30^+ and muscle lactic acid accretion. This process is typically measured as a more rapid pH decline in the meat. Research on "indigenous" goat carcasses (Tshabalala *et al.,* 2003) and goat meat quality (Simela, 2005; Pophiwa *et al.,* 2016; 2017), and biochemical changes occurring in the meat immediately *post-mortem*, indicate that these changes are highly influential in determining the quality of the meat. Goats are generally characterised as being stress sensitive and having low glycolytic potential (Casey and Webb, 2010).

As stated, "indigenous" goats have not been well defined and can be described as Boer x indigenous cross goats. This is the first muscle energy study on well-defined IVG eco-types. The aim of this study was to investigate the effect of *pre-slaughter* (castration) and *post-slaughter* procedures (electrical stimulation (ES) vs. no-stimulation (NS)) on meat colour, pH / temperature, and *pre-rigor* muscle energy (glycolysis) of *Longissimus thoracis et lumborum* (LTL) and *Semimembranosus* (SM) muscles of Boer Goats (BG) and large framed Indigenous Veld Goats (IVG; Cape Lob Ear and Cape Speckled Goats) that were slaughtered under commercial conditions.

6.2. Material and methods

6.2.1. Animals and experimental design

Please refer to Chapter 3 (and Van Wyk *et al.,* 2020) regarding the experimental animals and Figure 5.1 for the experimental design. The following acronyms are used to describe the different treatment groups BBES, BBNS, BWES, BWNS, IBES, IBNS, IWES, IWNS (See Figure 5.1 for treatment group descriptions).

6.2.2. Slaughter and sampling procedures

A maximum of eight goats per day representing all experimental groups were slaughtered over an 11-week period starting with the heaviest of each group (total animals slaughtered; BG; n = 36, 21 bucks and 15 wethers; IVG; n = 41; 21 bucks and 20 wethers). This gave the less dominant animals

a chance to catch up in weight as the dominant animals were being removed, although measures were taken to give animals an equal chance to feed (see Chapter 3, and Van Wyk *et al.,* 2020). The carcasses were subjected to either of the following treatments: electrical stimulation (ES - 20 seconds, 400 Volts peak, 5ms pulses at 15 pulses/second), 10 minutes after stunning and exsanguination or no electrical stimulation (NS), where after all the carcasses were placed in the chiller at 4°C within 60 minutes *post-mortem*. Carcass characteristics were determined as described in Chapter 3 (and Van Wyk *et al.,* 2020) and experimental design shown in Figure 5.1. Temperature and pH were measured with a portable pH meter (Eutech Instruments, Cyber Scan pH 11, Keppel Logistic, Singapore) on the left side of the carcass in the *Longissimus thoracis et lumborum* (LTL) (Lumbar 5 position), and the *semimembranosus* (SM) muscles at 1-, 3-, 6- and 24-hours *post-mortem*. At the same time and muscle location, samples collected for the determination of glycolytic potential (glycogen, glucose, glucose-6-phosphate, and lactic acid), ATP and creatine-phosphate content, were snap frozen in liquid nitrogen, and stored at -80°C until analyses. Samples for colour measurement (1- and 4-days *post-mortem*) were taken from a slice of the left-side LTL and SM.

6.2.3. Muscle energy status early *post-mortem*

The concentration of lactate, glucose, glycogen, glucose-6-phosphate, ATP and creatine-phosphate in the LTL and SM samples were determined using a modified method of Dalrymple and Hamm (1973) at 1-, 3-, 6- and 24-hours *post-mortem*. A portion of 2 g was cut from the frozen muscle sample and homogenised in 10 ml of cold 0.6M perchloric acid using Ultra Turrax T5 blender (Janke and Kunkel IKA @ - Labortechnik, Germany). The homogenate was centrifuged for 15 minutes at the speed of 10 000 RPM at 4˚C. After centrifugation, 100 µl of aliquot samples obtained for the determination of muscle glucose and glycogen using the amyloglucosidase method (Keppler and Decker, 1974) were subjected to a water bath for 2 hours at 40˚C. A drop of methyl orange indicator was added to the remaining homogenized sample and was neutralised with a few drops of 5.4 M potassium hydroxide and precipitated out after 20 minutes through a Whatman 4 filter paper. The lactate concentration was determined using L-lactate dehydrogenase as described by Gutmann and Wahlefeld (1974). Glycogen concentration was determined as glycosyl units after hydrolysis with α-amyloglucosidase and correction for glucose concentration in the extract according to the method of Keppler and Decker (1974). Whereas the concentration of ATP, glucose-6-phosphate and creatine-phosphate were determined in the perchloric acid extracts according to Lamprecht *et al*. (1974). Glycolytic potential (GP) was calculated using Monin and Sellier's (1985) formula:

$$GP\ (\mu mol/g) = 2\ (glycogen + glucose + glucose\text{-}6\text{-}phosphate) + lactic\ acid$$

6.2.4. Minolta meat colour

Colour of muscle samples were measured fresh at 1- and 4-days *post-mortem* on samples that were vacuum packed and aged for 4 days at 4°C. The muscle slices of ca. 15 mm thickness were allowed

to bloom for 60 minutes at ± 4˚C before the meat colour values were recorded. The surface absorbance was measured on three different positions on the meat samples from 400 to 730 nm in increments of 10 nm. A Konica-Minolta 600d spectrophotometer (Konica-Minolta Inc. Osaka, Japan) with the software package Spectra Magic NX Pro was used to record the three components; lightness, *L** (dark [0] to light [100]) and the two chromatic components; *a**(green [-60,180˚] to red [+60,0˚]) and *b**(blue [-60,270˚] to yellow [+60,90˚]) which represented the myoglobin levels in the meat (CIE, 1986). The spectrophotometer configuration consisted of illuminate (A), with an observer angle of 10˚, a spectral component excluded after calibration using the included white reference (Krzywicki, 1978). Chroma (e.g., saturation index (S = $(a^{*2}+b^{*2})^{1/2}$); (MacDougall, 1977)) and Hue-angle (discolouration) = $\tan^{-1}(b^*/a^*)$ (Young *et al.,* 1999) were automatically calculated from *a** and *b**, Chroma measures colour intensity where the higher values indicate more intense red colour in meat. An increase in Hue-angle between 0˚ and 90˚ corresponds to a blending of yellowness or less of redness, probably due to metmyoglobin formation in fresh meat.

6.2.5. Statistical analysis

The data were subjected to analysis of variance (SAS, 1999) using a three way ANOVA to test the effect of the two goat breeds (BG and IVG), two sex-types (bucks and wethers), two treatments (ES and NS) and interactions as factors on pH and temperature (1, 3, 6 and 24 hours *post-mortem*), CIE *L**, *a**, *b**, Chroma and Hue-angle (1- and 4-days *post-mortem*) and energy metabolites (1-, 3-, 6- and 24-hours *post-mortem*) of the LTL and SM muscles. Least square means were compared if a significant F statistic (5 % level of probability) was detected by analyses of variance (Snedecor and Cochran, 1980). Slaughter date had no effect on the outcome of the results and thus will not be mentioned further.

Prior to analyses, a Shapiro–Wilk test for normality was performed on the data (Shapiro and Wilk, 1965) and where applicable, outliers (classified as such when the standardized residual for an observation deviated with more than three SDs from the model value) were removed. Statistical significance (Fisher's t-test, least significant difference) was calculated at a 5 % level to compare means. $P \leq 0.05$ was considered statistically significant, although in some instances data with a $P \leq 0.10$ (10 % level) was considered as a trend worth discussing.

6.3. Results and Discussion

Glycolysis is the key process in the conversion of muscle to meat (Scheffler and Gerrard, 2007). The energy status of muscle immediately *ante-* and *post-slaughter* affects meat tenderness and colour (Monin and Sellier, 1985; Scheffler *et al.,* 2011).

6.3.1. Biochemical changes in *post-mortem* muscles

Very few studies have attempted to investigate muscle metabolism controlling the development of goat meat quality (Pophiwa *et al.,* 2016; Simela *et al.,* 2004). This section discusses the biochemical

changes in *post-mortem* muscles of BG and large frame IVG as influenced by castration and ES. The significance (P-values) and the means and standard error of means (SE) of the main effects of breed, sex (bucks vs. wethers), treatment (ES vs. NS) and their interactions on pH and temperature of the LTL and SM of BG and large frame IVG are presented in Table 6.1 and Table 6.2.

Table 6.1. The significance (P-values) of the main effects of breed, sex (bucks vs. wethers), treatment (ES vs. NS) and their interactions on pH and temperature of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Significance (P- Values)						
	Breed	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**
***Longissimus thoracis et lumborum* (LTL)**							
pH 24 hours *pm*[#]	0.808	0.543	**<.0001**	0.147	0.567	0.545	0.889
Temperature 24 hours *pm*	0.187	**<.0001**	0.843	0.449	0.253	0.585	0.836
***Semimembranosus* (SM)**							
H 24 hours *pm*	0.133	0.824	**0.003**	0.311	0.645	0.847	0.929
Temperature 24 hours *pm*	**0.001**	**0.012**	0.649	0.956	0.494	0.584	0.177

Significant P-values are presented in bold
[#]*pm = post-mortem*

Table 6.2. Least square means and standard error (SE) of means of breed, sex and treatment on pH and temperature of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		**Sex**		**Treatment**	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
***Longissimus thoracis et lumborum* (LTL)**						
pH 24 hours *pm*[#]	5.64 ± 0.15	5.64 ± 0.13	5.65 ± 0.14	5.63 ± 0.13	5.58^{a} ± 0.11	5.70^{b} ± 0.13
Temperature 24 hours *pm*	7.59 ± 1.81	7.08 ± 2.14	6.46^{a} ± 1.77	8.35^{b} ± 1.78	7.33 ± 2.05	7.31 ± 1.97
Semimembranosus (SM)						
pH 24 hours *pm*	5.62 ± 0.10	5.65 ± 0.11	5.60 ± 0.10	5.67 ± 0.10	5.60^{a} ± 0.10	5.67^{b} ± 0.10
Temperature 24 hours *pm*	8.43^{a} ± 2.12	6.59^{b} ± 2.62	7.54^{a} ± 2.43	7.36^{b} ± 2.72	6.85 ± 2.28	8.17 ± 2.29

[a,b] *Means in the same row within a main effect bearing different letters differ significantly (P ≤ 0.05)*
[x,y] *Means in the same row within a main effect bearing different letters was considered as a tendency (P ≤ 0.10)*
[#]*pm = post-mortem*

The pH measured at 24 hours *post-mortem* (pH_u) were 5.6 or slightly higher and did not differ between breeds and sexes. Although relatively high pH_u for goat muscles (pH_u >5.6) compared to other red meat species such as beef have been established and this could be a normal characteristic for chevon. There are reports of chevon with similar pH_u values, such as Spanish castrates (pH 5.7; Kannan *et al.,* 2003), Boer Goats (pH 5.7; Brand *et al.,* 2018) and Boer x Angora (pH 5.6, Dhanda *et al.,* 1999). Although in older wethers (Kannan *et al.,* 2003) and Boer and Boer x indigenous (Pophiwe *et al.,* 2016), results preclude the notion that high pH_u >5.7 is an intrinsic characteristic of the species. Also, according to Kannan *et al.* (2003), pH_u values higher than pH 5.8 are not characteristic of chevon and should be avoided. Since such a high incidence of high pH_u meat often occurs amongst temperamental animals such as young bulls, heifers on heat and boars, chevon pH_u

values suggest that goats are generally more prone to stress caused by handling or that their diet provides limited glycogen reserves (Simela *et al.,* 2004). In the SM muscle BG measured 1.84˚C higher compared to that of IVG whilst at 24 hours *post-mortem*, the temperature values observed in bucks were almost 2˚C lower than in the wethers (LTL muscle).

Rigor-mortis progresses faster in lamb than in beef muscles (Marsh and Thompson, 1958). *Post-mortem* pH decline is strongly related to the glycolytic rate and is influenced by the temperature decline (Reviewed in Ferguson and Gerrard, 2014). Long-term and short-term *ante-mortem* stress can give rise to DFD- (dark, firm, and dry) and PSE- (pale, soft and exudative) meat, respectively. In many studies, and in practice, the pH of meat at 24 to 48 hours *post-mortem* has been used as a tool for detecting DFD meat. In this context, a 24-hours *post-slaughter* pH ranging between 5.7 and 6.0 has been used as a threshold for DFD meat because muscles with ultimate pH values between 5.8 and 6.2 tend to produce tough meat which cannot be differentiated visually from meat with pH values greater than 6.2, which is tender (Jeremiah *et al.,* 1991). Reduced proteolytic activity between pH 5.8 and 6.2 has been hypothesized to be the reason for this increase in toughness as this pH range is outside the pH optima for the calpain and lysosomal enzyme systems (Lomiwes *et al.,* 2013). In the current study, the frequency of DFD cases ($pH_{24hours}$ >5.8) per treatment group for the LTL and SM muscles are summarised in Table 6.3.

Table 6.3. Number of animals per treatment group for an overall impression of dark, firm, and dry phenomenon.

***Treatment* groups** [b]	**LTL** [c]		**SM** [c]	
	n	**DFD** [a]	**n**	**DFD** [a]
BBES	11	0 (0 %)	11	0 (0 %)
BBNS	10	4 (40 %) [d]	10	2 (20 %) [d]
BWES	7	1 (14 %) [d]	7	0 (0 %)
BWNS	8	0 (0 %)	8	0 (0 %)
IBES	11	0 (0 %)	11	0 (0 %)
IBNS	10	2 (20 %) [d]	10	0 (0 %)
IWES	10	1 (10 %) [d]	10	1 (10 %) [d]
IWNS	10	2 (20 %) [d]	10	2 (20 %) [d]

Number = n, dark, firm and dry = DFD

[a] *Carcass with ultimate pH ($pH_{24hours}$) >5.8 were classified as being dark, firm, and dry (DFD)*

[b] *Treatment groups (See Figure 5.1 for treatment group descriptions)*

[c] *Muscles evaluated: longissimus thoracis et lumborum (LTL) and the semimembranosus (SM)*

[d] *Number of DFD carcasses and percentages*

DFD cases were detected in ten animals for the LTL muscle and five animals for the SM muscle. In the LTL muscle the BBNS test group had the highest frequency for “DFD”, followed by IBNS and IWNS, all presenting animals from carcasses subjected to NS, however IWES and BWES also presented one animal each with “DFD” for the LTL muscle. In the SM muscle, the DFD was detected in BBNS, BWNS, IWNS and IWES. Suggesting that non-stimulated carcasses are more subjected to DFD compared to electrical stimulated carcasses.

6.3.2. Effect of breed, sex, treatment, and their interactions on instrumental meat colour

To understand the processes that affect visual and a few eating characteristics of chevon meat, it is important to study the mechanisms involved with meat colour and *pre-rigor* muscle energy profiles. The significance (P-values) for the various main effects and interactions between breeds (BG vs. IVG), sexes (bucks vs. wethers) and treatments (ES vs. NS) on meat colour attributes of the LTL and SM are presented in Table 6.4.

Table 6.4. The significance (P-values) of the main effects of breed (BG vs. IVG), sex (bucks vs. wethers), treatment (ES vs. NS) and their interactions on meat colour attributes of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles of Boer-(BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Significance (P- Values)						
	Breed	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**
***Longissimus thoracis et lumborum* (LTL)**							
*L** 1 day *pm*[#]	0.062	**0.025**	0.165	**0.050**	0.846	0.396	0.094
*L** 4 days *pm*	0.052	**0.001**	0.996	**0.013**	0.686	0.976	0.982
*a** 1 day *pm*	0.052	**0.009**	**0.002**	**0.008**	0.087	0.114	0.135
*a** 4 days *pm*	**0.047**	0.277	**0.003**	**0.007**	0.282	0.275	0.151
*b** 1 day *pm*	0.617	0.953	**0.001**	0.809	0.185	0.584	0.910
*b** 4 days *pm*	0.709	0.170	0.195	0.528	0.491	0.254	0.576
Chroma 1 day *pm*	0.467	0.093	**0.001**	0.255	**0.040**	0.227	0.261
Chroma 4 days *pm*	0.347	**0.001**	**0.008**	**0.044**	0.284	0.193	0.217
Hue-angle 1 day *pm*	**0.030**	**0.002**	0.689	**0.027**	0.346	0.232	0.066
Hue-angle 4 days *pm*	**0.016**	**0.025**	**0.029**	**0.017**	0.585	0.736	0.339
***Semimembranosus* (SM)**							
*L** 1 day *pm*	**0.008**	**0.001**	**0.019**	0.833	0.338	0.157	0.139
*L** 4 days *pm*	0.218	**<.0001**	0.619	0.479	0.097	0.338	0.796
*a** 1 day *pm*	**0.001**	**0.001**	**0.008**	**0.004**	0.130	0.079	0.244
*a** 4 days *pm*	**0.057**	**0.073**	**0.022**	0.081	0.599	0.102	0.301
*b** 1 day *pm*	0.762	0.338	**0.001**	0.554	0.152	0.358	0.832
*b** 4 days *pm*	0.165	**<.0001**	0.375	0.717	0.132	0.400	0.920
Chroma 1 day *pm*	0.158	0.103	**0.001**	0.074	0.106	0.236	0.800
Chroma 4 days *pm*	0.056	0.076	**0.002**	**0.023**	0.684	**0.033**	0.380
Hue-angle 1 day *pm*	**0.001**	**<.0001**	0.499	0.069	0.909	0.647	0.488
Hue-angle 4 days *pm*	0.543	**0.020**	0.160	0.567	0.223	0.083	0.395

Significant P-values are presented in bold; [#]pm = post-mortem

Breed x sex interactions for LTL for *L** (1- and 4-days *post-mortem*), *a** (1- and 4-days *post-mortem*), Chroma (4-days *post-mortem*), Hue-angle (1- and 4-days *post-mortem*) and a sex treatment interaction for Chroma (1 day *post-mortem*) were observed. In the SM, breed x sex interactions for *a** (1-day *post-mortem*), Chroma (4-days *post-mortem*) and a breed x sex interaction for Chroma (4-days *post-mortem*) were observed. Where applicable these interactions will be discussed.

The means and standard error of means of meat colour measurements of the LTL and SM of BG and large frame IVG, wethers and bucks are presented in Table 6.5.

Table 6.5. Least square means and standard error (SE) of means of breed, sex and treatment on meat colour of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles of Boer (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		Sex		Treatment	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
***Longissimus thoracis et lumborum* (LTL)**						
*L** 1 day *pm*[#]	34.07^{x} ± 3.22	33.04^{y} ± 1.67	34.12^{a} ± 2.80	32.80^{b} ± 2.03	33.92 ± 2.53	33.11 ± 2.54
*L** 4 days *pm*	34.70^{x} ± 3.47	33.65^{y} ± 1.30	35.86^{a} ± 2.69	33.01^{b} ± 1.96	34.19 ± 2.81	34.10 ± 2.38
*a** 1 day *pm*	10.20^{x} ± 1.36	10.71^{y} ± 1.27	10.14^{a} ± 1.46	10.86^{b} ± 1.04	10.86^{a} ± 1.36	10.06^{b} ± 1.19
*a** 4 days *pm*	10.26^{a} ± 1.37	10.60^{b} ± 1.36	10.17 ± 1.61	10.52 ± 1.05	10.75^{a} ± 1.60	9.89^{b} ±0.96
*b** 1 day *pm*	11.67 ± 1.13	11.54 ± 1.10	11.61 ± 1.34	11.59 ± 0.77	12.01^{a} ± 0.98	11.19^{b} ± 1.09
*b** 4 days *pm*	12.24 ± 0.83	12.15 ± 1.06	12.33 ± 1.04	12.02 ± 0.82	12.34 ± 1.03	12.04 ± 1.86
Chroma 1 day *pm*	15.55 ± 1.30	15.77 ± 1.61	15.43^{x} ± 1.75	15.96^{y} ± 0.99	16.23^{a} ± 1.29	15.08^{b} ± 1.43
Chroma 4 days *pm*	15.87 ± 1.12	16.14 ± 1.55	16.03^{a} ± 1.54	15.99^{b} ± 1.15	16.41^{a} ± 1.26	15.61^{b} ± 1.01
Hue-angle 1 day *pm*	48.89^{a} ± 4.42	47.29^{b} ± 2.29	49.12^{a} ± 3.95	46.75^{b} ± 2.42	47.94 ± 3.80	48.14 ± 3.26
Hue-angle 4 days *pm*	50.80^{a} ± 4.13	49.01^{b} ± 2.66	50.66^{a} ± 4.07	48.87^{b} ± 2.44	49.08^{a} ± 3.87	50.63^{b} ± 2.98
Semimembranosus (SM)						
*L** 1 day *pm*	33.68^{a} ± 3.06	32.26^{b} ± 2.10	33.92^{a} ± 2.74	31.73^{b} ± 2.05	33.57^{a} ± 2.73	32.26^{b} ± 2.47
*L** 4 days *pm*	34.02 ± 2.72	33.41 ± 2.01	34.69^{a} ± 2.47	32.50^{b} ± 1.58	33.85 ± 2.46	33.53 ± 2.29
*a** 1 day *pm*	10.20^{a} ± 1.28	11.03^{b} ± 1.15	10.19^{a} ± 1.33	11.18^{b} ± 0.96	10.93^{a} ± 1.33	10.34^{b} ± 1.15
*a** 4 days *pm*	10.78^{x} ± 1.56	11.40^{y} ± 1.39	10.83^{x} ± 1.58	11.45^{y} ± 1.33	11.46^{a} ± 1.63	10.75^{b} ± 1.26
*b** 1 day *pm*	11.67 ± 1.13	11.59 ± 1.16	11.74 ± 1.29	11.50 ± 0.92	12.08^{a} ± 1.03	11.16^{b} ± 1.06
*b** 4 days *pm*	13.96 ± 2.63	13.29 ± 2.08	14.64^{a} ± 2.41	12.36^{b} ± 1.59	13.85 ± 2.46	13.35 ± 2.25
Chroma 1 day *pm*	15.61 ± 1.26	16.00 ± 1.45	15.60 ± 1.49	16.09 ± 1.17	16.32^{a} ± 1.19	15.30^{b} ± 1.36
Chroma 4 days *pm*	10.81^{x} ± 1.28	11.32^{y} ± 1.29	10.85^{x} ± 1.35	11.36^{y} ± 1.21	11.49^{a} ± 1.37	10.67^{b} ± 1.09
Hue-angle 1 day *pm*	48.81^{a} ± 4.37	46.30^{b} ± 1.87	48.85^{a} ± 3.75	45.81^{b} ± 2.26	47.75 ± 3.79	47.19 ± 3.19
Hue-angle 4 days *pm*	52.60 ± 1.16	52.74 ± 1.04	52.93^{a} ± 1.15	52.37^{b} ± 0.95	52.85 ± 1.09	52.49 ± 1.08

^{a,b} Means in the same row per main effect bearing different letters differ significantly (P ≤ 0.05)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ (P ≤ 0.10)

[#]pm = post-mortem

In the LTL muscle, although significant breed differences (P ≤ 0.05) were observed for *L** and *a**, while smaller differences were observed for these colour attributes in the SM muscle. Ageing to 4-days *post-mortem* seems to eliminate these differences in the SM. Consistently higher Hue-angle values was found at 1- and 4-days *post-mortem* for BG LTL. In contrast, the SM BG vs. IVG Chroma (4-days *post-mortem*) and Hue-angle (1-day *post-mortem*) showed significant (P ≤ 0.05) breed differences. In summary large frame IVG had lower *L**, *b** and Hue-angle values compared to BG, thus showed a tendency to be darker and redder, whereas BG had lower values for *a** and Chroma.

It was observed that wethers in general had differences in colour ordinates compared to bucks; wethers had lower values in terms of *L**, *b**, and Hue-angle values in both muscles (LTL and SM) studied. On the contrary, buck had lower *a** and Chroma values compared to wethers. Bucks' LTL and SM muscles were both lighter (*a**) in colour than that of the wethers at 1-day *post-mortem* however at 4 days *post-mortem*, the differences were eliminated.

Some differences were observed between ES and NS in terms of instrumental colour values; NS carcasses had lower *L**, *a**, *b**, Chroma and Hue-angle values compared to ES carcasses. Whereas the redness (*a**) and brightness were higher in both the LTL and SM of ES, only the SM showed differences in lightness between ES (lighter) and NS treatments. Significant (P ≤ 0.05) breed

x sex interactions were found for LTL muscles, but not for SM where Hue-angle were higher for bucks compared to wethers. Ageing eliminated these differences. Although ES had been reported to accelerate the extent of pH decline, its efficiency in improving the colour of goat meat colour is still debatable (King *et al.,* 2004; Gadiyaram *et al.,* 2008; Cetin *et al.,* 2012). The present study supports the finding that the incorporation of ES in the slaughter procedure enhances goat meat colour and that ES would be recommended in order to improve the meat's visual quality as meat colour is an important characteristic by which the consumers judge the quality and acceptability of meat (Behkit and Faustman, 2005). Bright red is the usual preference for red meat. There are perceptions that goat meat is darker than lamb/mutton. However, research has shown that the colour of goat meat compares favourably to that of lamb and consumers may not perceive the difference (Babiker *et al.,* 1990). The energy status of muscle immediately *post-slaughter* affects meat colour and meat tenderness (Scheffler *et al.,* 2011). The instrumental colour values obtained in this study compares favourably to values previously reported for chevon of various goat breeds (Table 2.6). For example, the average *L** values (lightness) were within the range reported by Babiker *et al.,* (1990) for SM muscles of Sudanese desert goats (31.9 to 34.8). The average *a** values (redness), (9.38 to 11.92) were close to the values reported by Dhanda *et al.* (1999) for the LTL muscle of Saanen x Feral goats (12.0), however below that reported for various muscles and breeds studied (Table 2.6; King *et al.,* 2004; Simela *et al.,* 2004; Kadim *et al.,* 2006). The average *b** values (yellowness) were similar to those reported by Lee *et al.* (2008) for the LTL of cross breed goats (11.1 to 12.5). The study of Pophiwa *et al.* (2017) reported the following average *L** (35.9 to 40.2), and *a** (16.7 to 19.1) values. Animals exposed to chronic *ante-mortem* stress are known to yield high pH meat with lower *L** values (dark meat). For example, Kadim *et al.* (2006) reported a pH of 6.02 and a corresponding *L** value of 31.9 for the LTL of transport stressed Batina goats, whilst muscle with a pH value lower than 6.00 had *L** values higher than 34.0. The pH and *L** values of the present study for both muscles studied, support these findings as meat with pH values below 6.00 had *L** values ranging from 31.0 to 34.0, suggesting that the goats were exposed to *ante-mortem* stress (e.g., transportation). It is generally recognised that one of the main factors influencing meat colour is the pH_u as well as the rate of pH decline, therefore any treatment designed to promote a rapid *post-mortem* pH decline, such as ES, has the potential to cause the development of brighter and more red meat (Abril *et al.,* 2001).

6.3.3. Effect of breed, sex, treatment, and interactions in *post-mortem* muscles metabolism of goats

Following stun and exsanguination, muscle labours to maintain ATP homeostasis. However, ATP turnover is high *post-mortem* and, in an effort, to regulate ATP loss, the phosphagen system immediately activates (Scheffler *et al.,* 2014). Phosphocreatine (PCr) re-phosphorylates ADP to ATP using the enzyme creatine kinase (ADP + phosphocreatine → ATP + creatine). In addition to maintaining ATP levels, creatine kinase consumes hydrogen ions (H^+), thereby partially buffering

post-mortem pH decline. However, the phosphagen system is incapable of maintaining ATP homeostasis for an extended time. Once 70 % of PCr is consumed, ATP decreases rapidly in the muscle tissue (Bendall, 1951). This decrease in ATP, or more specifically, increase in ADP, triggers glycolysis in an effort to create more ATP to allow the muscle to stay in a relaxed state (Bate-Smith and Bendall, 1947). During this entire process, ATP is continually hydrolysed, releasing H^+ ions and inorganic phosphate (Pi). Similarly, H^+ ions accumulate in muscles during a bout of exercise, but these ions are partially consumed by the formation of lactate and its removal through blood circulation. Ultimately, these substrates (carbons) are made available to the muscle in the form of glucose through the Cori cycle (Garcia *et al.,* 1994). In *post-mortem* muscle, however, conversion to lactate remains the sole source of buffering H^+ accumulation in muscle, but with time, these ions ultimately lower muscle pH from 7.0 to 5.7 - 5.5 within 24 hours. The electrical current that passes through the carcass during ES enables a faster rate if glycolysis in the muscle to occur, reducing the concentration of ATP and other high-energy phosphates during *rigor* development (Tornberg, 1996; Gadiyaram *et al.,* 2008). The breakdown of ATP accommodates the onset and development of *rigor* (Bate-Smith and Bendall, 1947). Bate-Smith and Bendall (1947) used rabbit *psoas* muscles to show that the time-course of *rigor-mortis* was mostly influenced by at-death glycogen muscle reserves. The significance of effects (P-values) of breed, sex and treatment and their interactions on the glycolytic metabolites (glycogen, creatine-phosphate, ATP depletion, glucose, glucose-6-phosphate, and lactic acid production measured at 1-, 3-, 6- and 24-hours *post-mortem* and calculated glycolytic potential measured in the LTL and SM muscle are presented in Tables 6.6. and 6.7. At 24 hours *post-mortem*, a significant ($P \leq 0.05$) difference was observed for glycolytic potential (GP) for the breed and sex interaction in both muscles studied (Table 6.6. and Table 6.7).

In the LTL, for the glycolytic metabolites, breed x sex x treatment interactions were measured for glycogen (24 hours *post-mortem*); glucose-6-phosphate (6- and 24-hours *post-mortem*) and ATP (3- and 6-hours *post-mortem*). Significant ($P \leq 0.05$) breed x treatment (glucose-6-phosphate, 24 hours *post-mortem*); sex x treatment (glucose-6-phosphate: 3- and 6-hours *post-mortem*; ATP: 3 hours *post-mortem*) and breed x sex interactions (glucose-6-phosphate: 6 hours *post-mortem*; creatine-phosphate: 6- and 24-hours *post-mortem*) were observed in the LTL (Table 6.6). With regards to main effects, significant ($P \leq 0.05$) breed differences were observed at 1 hour *post-mortem* for glucose and glucose-6-phosphate, at 3 hours *post-mortem* for glucose, at 6 hours *post-mortem* for creatine-phosphate and at 24 hours *post-mortem* for glucose-6-phospate and creatine-phosphate. For sex, significant ($P \leq 0.05$) differences at all measured time points were observed for glycogen and glucose-6-phospate. For lactate, significant ($P \leq 0.05$) differences were only observed at 6- and 24-hours *post-mortem.* When evaluating treatment, significant ($P \leq 0.05$) differences were observed at all time points for glucose and lactate. For glucose, significant values were measure at 3- and 6-hours *post-mortem*. Lastly, for ATP and creatine-6-phoshate significant ($P \leq 0.05$)

differences were observed at 1-, 3- and 6-hours *post-mortem* with a tendency to differ at 24 hours *post-mortem*.

At 24 hours *post-mortem*, a significant ($P \leq 0.05$) difference was observed for glycolytic potential (GP) for the breed and sex interaction in both muscles studied (Table 6.6. and Table 6.7).

In the SM muscle (Table 6.7), significant ($P \leq 0.05$) interactions between breed x sex x treatment were observed for glucose-6-phosphate at 24 hours *post-mortem* and for ATP at 1-, 3- and 24-hours *post-mortem*. Significant ($P \leq 0.05$) interactions between sex x treatment were observed for glucose-6-phosphate at 3- and 6-hours *post-mortem*. In terms of breed x sex interactions, significant values were observed for ATP at 24 hours *post-mortem*, glycogen at 6 hours *post-mortem* and creatine-6-phospate at 6- and 24-hours *post-mortem.* When evaluating the main effects, significant ($P \leq 0.05$) breed differences were observed for glucose-6-phosphate (3- and 24-hours *post-mortem*); ATP (24 hours *post-mortem*) and creatine-6-phosphate (3- and 6-hours *post-mortem*). For sex, lactate (3- and 6-hours *post-mortem*), glycogen (6- and 24-hours *post-mortem*) and glucose-6-phosphate (1- and 24-hours *post-mortem*) were found to differ. Lastly, significant ($P \leq 0.05$) treatment differences for glucose and creatine-6-phosphate (all time points evaluated), lactate and ATP (1-, 3- and 6-hours *post-mortem*), glycogen and glucose-6-phosphate (3 and 6 hours *post-mortem*) were observed.

Table 6.6. The significance (P-values) of the main effects of breed (BG vs. IVG), sex (bucks vs. wethers), treatment (ES vs. NS) and their interactions on the glycolytic metabolites measured early *post-mortem* and calculated glycolytic potential of the of the *Longissimus thoracis et lumborum* (LTL), of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Significance (P- Values)						
	Breed	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**
Glycolytic potential (µmol/g muscle)							
1 hour *pm*[#]	0.071	0.074	0.102	0.051	0.487	0.861	0.562
3 hours *pm*	0.602	0.200	0.210	0.301	0.664	0.159	0.843
6 hours *pm*	0.539	0.384	0.356	0.293	0.737	0.429	0.711
24 hours *pm*	0.957	0.601	0.702	**0.011**	0.584	0.632	0.754
Glucose (µmol/g muscle)							
1 hour *pm*	**0.042**	0.639	**<.0001**	0.674	0.409	0.803	0.608
3 hours *pm*	**0.029**	0.955	**<.0001**	0.959	0.318	0.679	0.404
6 hours *pm*	0.057	0.945	**<.0001**	0.736	0.224	0.892	0.808
24 hours *pm*	0.325	0.872	**<.0001**	0.107	0.174	0.873	0.701
Lactate (µmol/g muscle)							
1 hour *pm*	0.224	0.072	**<.0001**	0.679	0.582	0.782	0.617
3 hours *pm*	0.676	0.105	**<.0001**	0.832	0.670	0.653	0.572
6 hours *pm*	0.518	**0.027**	**<.0001**	0.685	0.784	0.592	0.091
24 hours *pm*	0.827	**0.019**	**0.034**	0.174	0.384	0.127	0.562
Glycogen (µmol/g muscle)							
1 hour *pm*	**0.002**	**0.022**	0.149	0.007	0.398	0.610	0.435
3 hours *pm*	0.288	**0.015**	0.892	0.174	0.537	0.725	0.170
6 hours *pm*	0.159	**0.009**	0.061	0.226	0.545	0.565	0.063
24 hours *pm*	0.599	**0.004**	0.972	0.049	0.728	0.843	**0.022**
Glucose-6-hosphate (µmol/g muscle)							
1 hour *pm*	0.149	**0.026**	0.719	0.519	0.078	0.039	0.592
3 hours *pm*	0.812	**0.003**	**0.001**	0.275	**0.006**	0.135	0.054
6 hours *pm*	0.377	**0.006**	**<.0001**	**0.004**	**0.014**	0.739	**0.005**
24 hours *pm*	**0.006**	**0.003**	0.184	0.355	0.131	**0.035**	**0.001**
ATP (µmol/g muscle)							
1 hour *pm*	0.587	0.825	**<.0001**	0.824	0.130	0.365	0.124
3 hours *pm*	0.395	0.547	**<.0001**	0.291	**0.042**	0.839	**0.040**
6 hours *pm*	0.933	0.571	**<.0001**	0.061	0.589	0.281	**0.028**
24 hours *pm*	0.310	0.615	0.073	0.113	0.812	0.833	0.133
Creatine-phosphate (µmol/g muscle)							
1 hour *pm*	0.796	0.351	**0.012**	0.077	0.405	0.887	0.610
3 hours *pm*	0.336	0.739	**0.001**	0.043	0.516	0.936	0.828
6 hours *pm*	**0.026**	0.819	**0.009**	**0.009**	0.919	0.360	0.103
24 hours *pm*	**0.030**	0.921	0.074	**0.037**	0.351	0.658	0.531

Significant P-values are presented in bold; [#]pm = post-mortem

Table 6.7. The significance (P-values) of the effects and interactions between breed (Boer (BG) vs. large frame Indigenous Veld Goat (IVG)), sex (bucks vs. wethers), treatment (ES vs. NS) on the glycolytic metabolites measured early *post-mortem* and calculated glycolytic potential of the *of the Semimembranosus (SM),* of Boer- (BG) and large frame Indigenous Veld Goats (IVG) of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Significance (P- Values)						
	Breed	**Sex**	**Treatment**	**Breed x Sex**	**Sex x Treatment**	**Breed x Treatment**	**Breed x Sex x Treatment**
Glycolytic potential (µmol/g muscle)							
1 hour *pm*[#]	0.526	0.425	0.103	0.129	0.577	0.761	0.662
3 hours *pm*	0.224	0.811	0.290	0.174	0.674	0.259	0.943
6 hours *pm*	0.256	0.836	0.386	0.209	0.787	0.329	0.611
24 hours *pm*	0.588	0.622	0.832	**0.038**	0.984	0.832	0.754
Glucose (µmol/g muscle)							
1 hour *pm*	0.411	0.917	**<.0001**	0.573	0.934	0.858	0.283
3 hours *pm*	0.109	0.889	**<.0001**	0.277	0.843	0.631	0.850
6 hours *pm*	0.492	0.499	**<.0001**	0.556	0.701	0.620	0.959
24 hours *pm*	0.754	0.391	**<.0001**	**0.018**	0.227	0.354	0.349
Lactate (µmol/g muscle)							
1 hour *pm*	0.461	0.209	**<.0001**	0.894	0.835	0.575	0.743
3 hours *pm*	0.598	**0.040**	**<.0001**	0.925	0.769	0.838	0.227
6 hours *pm*	0.519	**0.008**	**<.0001**	0.894	0.544	0.985	0.206
24 hours *pm*	0.549	0.391	0.259	0.119	0.592	0.135	0.284
Glycogen (µmol/g muscle)							
1 hour *pm*	0.218	0.129	0.059	0.067	0.351	0.179	0.308
3 hours *pm*	0.342	0.069	**0.022**	0.067	0.388	0.149	0.183
6 hours *pm*	0.298	**0.040**	**0.028**	**0.035**	0.473	0.231	0.090
24 hours *pm*	0.287	**0.004**	0.868	0.120	0.391	0.991	0.052
Glucose-6-phosphate (µmol/g muscle)							
1 hour *pm*	0.099	**0.040**	0.059	0.682	0.192	0.159	0.243
3 hours *pm*	**0.016**	0.131	**0.005**	0.972	**0.029**	0.890	0.992
6 hours *pm*	0.348	0.087	**0.002**	0.588	**0.012**	0.757	0.369
24 hours *pm*	**0.020**	**0.006**	0.398	0.134	0.547	0.069	**0.005**
ATP (µmol/g muscle)							
1 hour *pm*	0.215	0.189	**<.0001**	0.386	0.116	0.839	**0.005**
3 hours *pm*	0.099	0.889	**<.0001**	0.176	0.372	0.656	**0.004**
6 hours *pm*	0.228	0.584	**<.0001**	0.054	0.185	0.612	0.099
24 hours *pm*	**0.045**	0.420	0.070	**0.001**	0.811	0.577	**0.044**
Creatine-phosphate (µmol/g muscle)							
1 hour *pm*	0.062	0.193	**0.008**	0.282	0.185	0.200	0.586
3 hours *pm*	**0.041**	0.666	**0.013**	0.249	0.725	0.103	0.593
6 hours *pm*	**0.035**	0.529	**0.025**	**0.021**	0.268	0.134	0.553
24 hours *pm*	0.103	0.677	**0.009**	**0.010**	0.216	0.334	0.780

Significant P-values are presented in bold; [#]pm = post-mortem

Effects of breed and sex interactions on calculated GP (µmol/g) at 1-, 3-, 6- and 24-hours *post-mortem* measured in the LTL and SM are presented in Figure 6.1 and Figure 6.2, respectively. At 24-hours *post-mortem* GP values were between 79 to 94 µmol/g, with BG wethers presenting the group with the highest GP over time (1-, 3-, 6- and 24-hours *post-mortem*) in both muscles (LTL and SM) studied. The IVG wethers presented the lowest levels over time for both muscles measured. In the LTL muscle, BG wethers and IVG bucks were similar at 24 hours *post-mortem*, the same trend was observed in the SM muscle. The GP profile of the LTL muscle dropped significantly between 1- and 3-hours *post-mortem* compared to the SM muscle. Wethers of BG and IVG were on the two

extremes of the GP curve in both muscles studied. When evaluating the GP profiles of IVG, it seems that the castration effect is not as prominent as in the BG (Figure 6.1 and Figure 6.2).

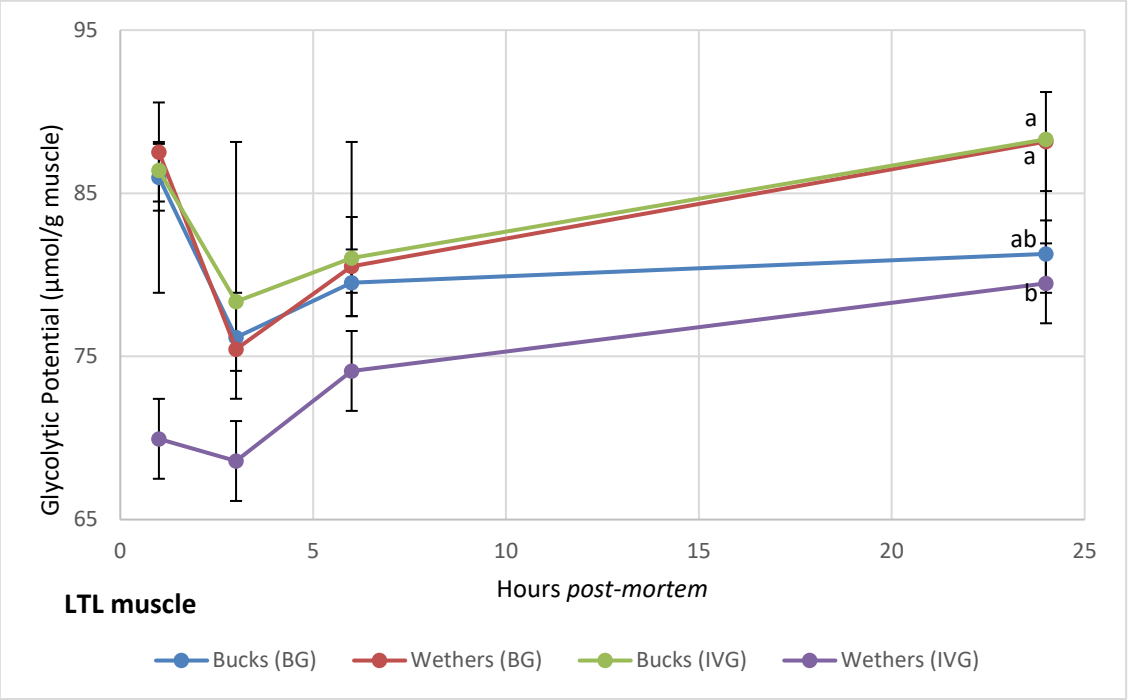

Figure 6.1. Effects of breed and sex interaction on calculated glycolytic potential (µmol/g muscle) at 1-, 3-, 6- and 24-hours *post-mortem* measured in the *Longissimus thoracis et lumborum* (LTL). Vertical bars indicating standard error of the means. [a,b] Means within the same row with different letters differ significantly ($P \leq 0.05$).

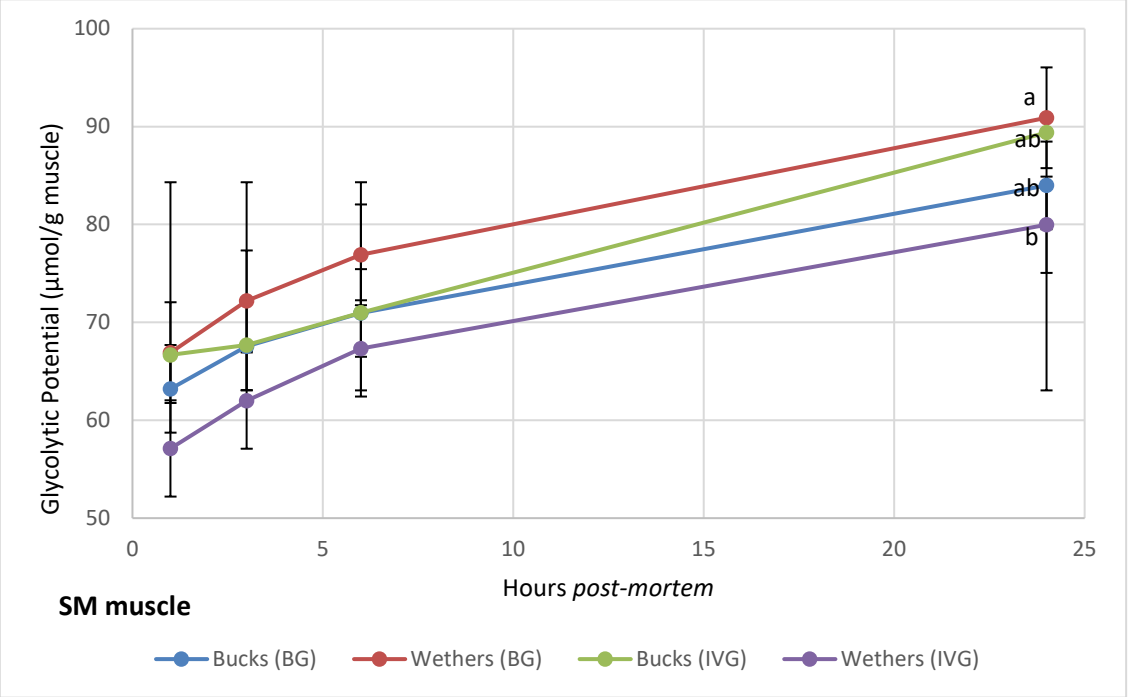

Figure 6.2. Effects of breed and sex interaction on calculated glycolytic potential (µmol/g muscle) at 1-, 3-, 6- and 24-hours *post-mortem* measured in the *Semimembranosus* (SM). Vertical bars indicating standard error of the means. [a,b] Means within the same row with different letters differ significantly ($P \leq 0.05$).

The critical threshold for GP in small ruminants has not yet been established; therefore, it cannot be concluded as to whether the goats were associated with the DFD phenomenon based on the calculated GP. Glycolytic potential (GP) is the sum of products from glycogen metabolism that are likely to produce lactic acid (Maribo *et al.,* 1999). In summary, low GP is associated with stress that occurs earlier in handling, such as during transportation, deprivation of food and lairage, whilst high lactate concentration immediately after slaughter is associated with acute *pre-slaughter* stress occurring during handling between the lairage and the stunning area (Yambayamba *et al.,* 1996). Much of the variation in meat quality due to *ante-mortem* stress appears to be associated with transportation stress. Interestingly, it was shown in Omani goats that ES of carcasses reduces the effects of transportation stress (Kadim *et al.,* 2010) by increasing the anaerobic metabolism of glucose to lactic acid, reducing cold shortening, and improving the conversion of muscle to meat. Goats have been shown to be highly susceptible to these stressors (Kannan *et al.,* 2003). In bovine muscles, there is a GP threshold of approximately 100 µmol/g muscle, below which result in high pH meat whilst values of less than 70 µmol/g muscle are associated with the DFD condition (Wulf *et al.*, 2002). Simela *et al*. (2004) concluded that sex, age, and *pre-slaughter* conditions had minimal impact on early *post-mortem* glycolytic metabolite concentrations. However, the generally high pH_u (> 5.7), high initial lactate concentration (>30 µmol/g muscle) and low GP (<114 µmol/g muscle) suggested that goats from that study suffered from both chronic and acute stress during *pre-slaughter* handling. The present study corresponds with the values by Simela *et al*. (2004) with a pH_u >5.6, a high lactate concentration 1 hour *post-mortem* of >35 µmol/g (LTL muscle) and low GP values (<94 µmol/g muscle). The colour measurements (*L**; 31.0 to 34.0) of the present study (Table 6.7), support the suggestion that the goats were exposed to *ante-mortem* stress. Further research is required to define more complex criteria in terms of minimum handling conditions for goats from the point of sale to slaughter in order to minimise stress to the animals and hence the occurrence of high pH chevon. In addition, the glycolytic metabolites were not completely exhausted at 24 hours *post-mortem*. Frylinck *et al.* (2013) reported a similar phenomenon in the *longissimus* muscle of various cattle breeds; the researchers concluded that the muscles had not attained full *rigor-mortis*.

The means and standard error of means of breed (BG vs. IVG), sex (bucks vs. wethers), treatment (ES vs. NS) on the glycolytic metabolites (glycogen, creatine-phosphate, ATP depletion, glucose, glucose-6-phosphate and lactic acid, µmol/g) at 1-, 3-, 6- and 24-hours *post-mortem* of the *Longissimus thoracis et lumborum* (LTL) and *Semimembranosus* (SM) are presented in Table 6.8.

Table 6.8. Least square means and standard error (SE) of means of breed, sex and treatment on calculated glycolytic metabolites (glycogen, creatine-phosphate, ATP depletion, glucose, glucose-6-phosphate and lactic acid, µmol/g) at 1-, 3-, 6- and 24-hours *post-mortem* of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles, of Boer (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	***Longissimus thoracis et lumborum* (LTL)**						***Semimembranosus* (SM)**					
	Breed		**Sex**		**Treatment**		**Breed**		**Sex**		**Treatment**	
	BG	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**	**BG**	**IVG**	**Bucks**	**Wethers**	**ES**	**NS**
Glucose (µmol/g muscle)												
1 hour *pm*[#]	1.64[a] ± 0.75	1.93[b] ± 0.61	1.81 ± 0.73	1.77 ± 0.64	2.14[a] ± 0.60	1.44[b] ± 0.61	1.34 ± 0.81	1.45 ± 0.56	1.40 ± 0.67	1.39 ± 0.71	1.78[a] ± 0.54	1.01[b] ± 0.59
3 hours *pm*	1.85[a] ± 0.78	2.16[b] ± 0.74	2.00 ± 0.82	2.03 ± 0.71	2.50[a] ± 0.51	1.51[b] ± 0.67	1.39 ± 0.75	1.59 ± 0.63	1.50 ± 0.71	1.50 ± 0.69	1.95[a] ± 0.52	1.04[b] ± 0.53
6 hours *pm*	2.24 ± 0.81	2.53 ± 0.76	2.38 ± 0.81	2.41 ± 0.79	2.84[a] ± 0.55	1.93[b] ± 0.73	1.77 ± 0.74	1.85 ± 0.69	1.85 ± 0.72	1.77 ± 0.70	2.31[a] ± 0.51	1.42[b] ± 0.47
24 hours *pm*	2.74 ± 0.72	2.87 ± 0.65	2.79 ± 0.72	2.82 ± 0.65	3.19[a] ± 0.50	2.42[b] ± 0.63	2.57 ± 0.67	2.53 ± 0.58	2.60 ± 0.65	2.49 ± 0.59	2.83[a] ± 0.57	2.26[b] ± 0.54
Lactate (µmol/g muscle)												
1 hour *pm*	34.66 ± 14.70	37.56 ± 15.07	34.15 ± 14.47	38.68 ± 15.18	46.68[a] ± 9.71	25.45[b] ± 11.09	25.44 ± 13.88	27.00 ± 11.98	25.01 ± 11.81	27.78 ± 14.01	35.27[a] ± 10.06	17.03[b] ± 7.87
3 hours *pm*	41.05 ± 15.90	42.12 ± 15.58	39.67 ± 15.52	43.95 ± 15.67	52.49[a] ± 9.07	30.46[b] ± 12.86	35.46 ± 14.61	34.19 ± 13.22	32.54[a] ± 12.57	37.47[b] ± 14.89	43.49[a] ± 10.37	25.85[b] ± 10.91
6 hours *pm*	49.08 ± 14.30	50.72 ± 13.60	47.32[a] ± 13.56	53.12[b] ± 13.74	57.90[a] ± 9.77	41.80[b] ± 12.72	45.10 ± 15.60	43.38 ± 13.24	40.98[a] ± 12.96	48.03[b] ± 15.10	52.02[a] ± 11.56	36.15[b] ± 12.37
24 hours *pm*	61.38 ± 11.96	61.89 ± 10.10	59.04[a] ± 10.84	64.77[b] ± 10.36	64.03[a] ± 10.64	59.21[b] ± 10.83	66.17 ± 12.49	64.52 ± 12.23	63.21 ± 11.49	72.93 ± 2.49	66.69 ± 11.68	63.85 ± 12.90
Glycogen (µmol/g muscle)												
1 hour *pm*	24.95[a] ± 9.51	18.34[b] ± 9.77	23.84[a] ± 9.44	18.54[b] ± 10.33	19.96 ± 10.46	22.94 ± 9.70	17.89 ± 9.38	15.63 ± 7.29	18.02 ± 7.65	15.08 ± 8.96	14.98 ± 7.99	18.43 ± 7.99
3 hours *pm*	14.70 ± 8.02	12.80 ± 8.26	15.76[a] ± 8.01	11.19[b] ± 7.70	12.25 ± 7.38	15.16 ± 8.72	14.87 ± 8.09	13.36 ± 6.77	15.44 ± 6.59	12.41 ± 8.07	12.26[a] ± 7.02	15.92[b] ± 7.42
6 hours *pm*	11.54 ± 6.90	9.49 ± 6.57	12.26[a] ± 6.50	8.27[b] ± 6.50	9.15 ± 6.25	11.78 ± 7.08	11.35 ± 6.43	10.02 ± 5.63	11.89[a] ± 5.34	9.14[b] ± 6.50	9.26[a] ± 5.82	12.06[b] ± 5.96
24 hours *pm*	5.81 ± 3.82	6.27 ± 4.45	7.24[a] ± 3.86	4.63[b] ± 4.08	6.08 ± 4.22	6.03 ± 4.12	5.08 ± 3.55	5.97 ± 4.11	6.65[a] ± 3.99	4.25[b] ± 3.30	5.67 ± 4.27	5.44 ± 3.44
Glucose-6-phosphate (µmol/g muscle)												
1 hour *pm*	0.43 ± 0.22	0.36 ± 0.24	0.44[a] ± 0.25	0.32[b] ± 0.20	0.40 ± 0.24	0.38 ± 0.22	0.43 ± 0.32	0.32 ± 0.28	0.44[a] ± 0.36	0.30[b] ± 0.21	0.44 ± 0.36	0.31 ± 0.22
3 hours *pm*	0.77 ± 052	0.80 ± 0.80	0.96[a] ± 0.78	0.59[b] ± 0.47	1.05[a] ± 0.83	0.53[b] ± 0.32	0.76[a] ± 0.59	0.51[b] ± 0.34	0.70 ± 0.59	0.53 ± 0.30	0.77[a] ± 0.60	0.47[b] ± 0.27
6 hours *pm*	1.65 ± 1.08	1.45 ± 1.41	1.83[a] ± 1.36	1.19[b] ± 1.05	2.10[a] ± 1.46	0.97[b] ± 0.64	1.20 ± 0.80	1.04 ± 0.85	1.26 ± 0.93	0.64 ± 4.65	1.39[a] ± 0.88	0.84[b] ± 0.67
24 hours *pm*	2.85[a] ± 1.84	1.91[b] ± 1.53	2.84[a] ± 2.01	1.76[b] ± 1.10	2.58 ± 1.66	2.11 ± 1.81	2.70[a] ± 1.67	1.88[b] ± 1.67	2.74[a] ± 1.87	1.70[b] ± 1.31	2.42 ± 1.62	2.11 ± 1.81
ATP (µmol/g muscle)												
1 hour *pm*	7.08 ± 1.61	6.92 ± 1.63	7.03 ± 1.73	6.95 ± 1.48	6.05[a] ± 1.31	7.96[b] ± 1.29	6.10 ± 1.52	6.43 ± 1.35	6.11 ± 1.47	6.48 ± 1.38	5.53[a] ± 1.37	7.04[b] ± 1.03
3 hours *pm*	5.46 ± 1.69	5.64 ± 1.58	5.53 ± 1.81	5.59 ± 1.39	4.31[a] ± 0.97	8.84[b] ± 1.05	5.39 ± 1.44	5.80 ± 1.31	5.58 ± 1.39	5.64 ± 1.38	4.81[a] ± 1.26	6.42[b] ± 0.96
6 hours *pm*	4.47 ± 1.58	4.49 ± 1.26	4.43 ± 1.51	4.55 ± 1.31	3.52[a] ± 0.92	5.48[b] ± 1.11	4.55 ± 1.55	4.86 ± 1.29	4.77 ± 1.53	4.65 ± 1.29	3.92[a] ± 1.02	5.53[b] ± 1.31
24 hours *pm*	3.22 ± 0.96	3.45 ± 1.04	3.28 ± 0.97	3.41 ± 1.05	3.14 ± 0.84	3.55 ± 1.12	3.22[a] ± 1.15	3.66[b] ± 0.92	3.36 ± 1.08	3.56 ± 1.01	3.27 ± 0.87	3.65 ± 1.18
Creatine-phospahte (µmol/g muscle)												
1 hour *pm*	3.35 ± 0.63	3.39 ± 0.75	3.30 ± 0.54	3.45 ± 0.84	3.17[a] ± 0.50	3.57[b] ± 0.80	2.90 ± 0.53	3.20 ± 0.84	2.96 ± 0.57	3.18 ± 0.87	2.85[a] ± 0.45	3.27[b] ± 0.88
3 hours *pm*	2.76 ± 0.52	2.87 ± 0.56	2.83 ± 0.50	2.80 ± 0.60	2.62[a] ± 0.38	3.02[b] ± 0.61	2.63[a] ± 0.46	2.91[b] ± 0.70	2.74 ± 0.54	2.82 ± 0.69	2.61[a] ± 0.41	2.95[b] ± 0.73
6 hours *pm*	2.40[a] ± 0.41	2.60[b] ± 0.42	2.49 ± 0.38	2.52 ± 0.48	2.39[a] ± 0.40	2.62[b] ± 0.42	2.45[a] ± 0.40	2.68[b] ± 0.57	2.53 ± 0.40	2.61 ± 0.62	2.45[a] ± 0.35	2.69[b] ± 0.61
24 hours *pm*	2.15[a] ± 0.46	2.37[b] ± 0.43	2.26 ± 0.42	2.28 ± 0.50	2.18 ± 0.38	2.36 ± 0.51	2.30 ± 0.39	2.40 ± 0.56	2.30 ± 0.36	2.35 ± 0.62	2.19[a] ± 0.40	2.45[b] ± 0.54

[a,b] *Means in the same row within a main effect bearing different letters differ significantly (P ≤ 0.05)*

[x,y] *Means in the same row within a main effect bearing different letters differ was considered as a tendency to differ (P ≤ 0.1);* [#]*pm = post-mortem*

Scheffler *et al.* (2011) explained that glycogenolysis continues *post-mortem*, with a subsequent increase in glucose levels. In the LTL muscle (Table 6.8), significantly ($P \leq 0.05$) higher glucose values (0.29 to 0.31 µmol/g muscle difference) were observed for BG vs. IVG at 1- and 3-hours *post-mortem*. No significant differences were determined for buck and wethers for both muscles studied. Significant ($P \leq 0.05$) difference was observed for glucose (µmol/g) in terms of treatment (ES vs. NS). Compared to NS, ES carcasses had significantly ($P \leq 0.05$) higher glucose levels at all time points measured: at 1 hour *post-mortem* (2.14 µmol/g and 1.78 µmol/g muscle), 3 hours *post-mortem* (2.50 µmol/g and 1.95 µmol/g muscle), 6 hours *post-mortem* (2.84 µmol/g and 2.31 µmol/g muscle) and 24 hours *post-mortem* (3.19 µmol/g and 2.83 µmol/g muscle) measured for the LTL and SM muscle, respectively. Thus, NS carcasses, regardless of sex or breed had significantly lower glucose levels compared to ES carcasses and thus support the notion that ES accelerated the rate of early *post-mortem* muscle energy metabolism as discussed.

Initial lactate values, ranged between 25 µmol/g to 47 µmol/g for the LTL and between 17 to 27 µmol/g for the SM. At 24 hours *post-mortem* the LTL muscle had lactate values >59 µmol/g and the SM muscle, >63 µmol/g muscle, regardless of breed or sex. Wethers (LTL muscle) had significantly ($P \leq 0.05$) higher values at 6- and 24-hours *post-mortem*. In the SM muscle, wethers had significantly ($P \leq 0.05$) higher values at 3- and 6-hours *post-mortem*. The lactate values of the LTL and SM muscle for NS carcasses were significant ($P \leq 0.05$) lower compared to the ES carcasses at 1-hour *post-mortem* (NS <25 µmol/g; ES >35 µmol/g) and 3-hours *post-mortem* (NS <30 µmol/g; ES >43 µmol/g). At 24-hours *post-mortem* the lactate values ranged between 59.0 and 73.0 µmol/g muscle for ES and NS carcasses and correlates with the pH values (Table 6.1 and Table 6.2).

Boer Goats (BG) had significantly ($P \leq 0.05$) higher glycogen (24.9 µmol/g muscle) compared to IVG (18.3 µmol/g muscle) 1 hour *post-mortem* in the LTL muscle. Bucks had significantly ($P \leq 0.05$) higher values compared to wethers at all time points evaluated in the LTL muscle and at 3- and 6-hours *post-mortem* in the SM muscle. Thus, glycogen decline over time was the highest in BG and buck for both muscles studied (LTL and SM). Higher values were also observed for NS carcasses at 1-, 3- and 6-hours *post-mortem*; however, 24 hours *post-mortem* ES carcasses had higher glycogen values. Non-stimulated (NS) carcasses in the SM muscle were significantly ($P \leq 0.05$) lower glycogen compared to ES carcasses at 3- and 6-hours *post-mortem*. Numerous researchers have shown the involvement of glycogen at slaughter with pH decrease. The pH of meat that contains less glycogen declines at a slower rate or remains high (above pH 6.0), (Hamm, 1974). Immonen *et al.* (2000) found that reducing glycogen loss prior to slaughter improves (lower) the final pH, thus the rate and extent of *post-mortem* glycolysis depends on muscle glycogen content at slaughter. Insufficient muscle glycogen, limits the acidification of meat, resulting in high pH and in extreme cases, DFD meat (Fabiansson and Reuterswärd, 1984). In bovine muscles (48 hours *post-mortem)*, at least 40 to 45 µmol/g muscle of glycogen is required for the normal acidification of meat

(Immonen *et al.,* 2000). However, the critical threshold value for *pre-slaughter* muscle glycogen has not been established in goats. Stress has been implicated as the main cause of *ante-mortem* glycogen depletion (Ferguson and Warner, 2008). The relatively low concentrations of muscle glycogen observed in this study could be due to a delay in initial sampling (1-hour *post-mortem*), or the goats were susceptible to *ante-mortem* stress associated with *pre-slaughter* conditions e.g., handling or transportation as discussed. This is supported by the relatively high lactate (>35 µmol/g) concentrations observed in goat muscles collected 1-hour *post-mortem*. As long as all enzymes are still active and there is no shortage of energy substrates, L-lactate levels in *post-mortem* muscles will increase (Scheffler *et al.,* 2011). The initial high levels of lactate observed in the study are similar to values previously reported by Simela *et al.,* (2004) in LTL muscle of South African indigenous goats (30.19 ± 10.57 µmol/g muscle).

At 24 hours *post-mortem* it was observed that BG and bucks had significantly ($P \leq 0.05$) higher G6P values in both muscles (LTL and SM) compared to IVG and wethers, indicating that the rate of glycolysis was much faster in these groups. Carcass subjected to NS over time had a different profile compared to ES carcasses for example, between 6 and 24 hours, *post-mortem* there was a rapid increase in G6P in both muscles. At 3- and 6-hours *post-mortem* LTL muscle of ES carcasses had significantly ($P \leq 0.05$) higher G6P levels compared to that of NS carcass LTL. In general, ES carcasses showed higher G6P values in both muscles studied compared to NS carcasses.

No significant difference was observed between breeds and sexes for adenosine-triphosphate (ATP), except IVG that had higher ATP levels at 24 hours *post-mortem* compared to BG measured in the SM muscle. In the LTM muscle, at 1 hour *post-mortem* BG and buck, had the highest ATP levels. Significant ($P \leq 0.05$) differences were observed between the treatment groups at 1-, 3- and 6-hours *post-mortem* with higher values observed for NS carcasses in both muscles studied (LTL and SM).

During the course of *post-mortem* energy metabolism, creatine-phosphate (CP) is the first metabolite to be degraded in order to maintain the muscle energy levels. Therefore, the depletion of CP indicates onset of *rigor-mortis* as describe by Savell *et al.* (2005). The resting concentrations of CP vary depending on species, but a range of 18 to 23 µmol/g was reported by Bendall (1973). Estimates that are more recent suggest that the concentration at slaughter may be much lower in beef (1 to 2 µmol/g muscle; Hertzman *et al.* 1993) and sheep (3 µmol/g muscle; Ferguson, 2003) muscle. During the first hour's *post-mortem*, the CP in BG and bucks decreased faster compared to the IVG and wethers, therefore the lower value of the initial readings. A similar pattern was observed in both muscles studied. Non-stimulated (NS) carcasses had significantly ($P \leq 0.05$) higher CP levels at 1-, 3-, 6- and 24-hours *post-mortem* as measured in the SM muscle. Similar findings were noted for the LTL muscle although no significant differences were observed at 24 hours *post-mortem*.

In summary, prior to slaughter, the energy charge created in the animal's muscles dictates the rate and extent of metabolism and, as observed differences that occurred for glycogen, lactate and ATP could be linked to this initial energy charge indicating further that acidification of meat is

closely related to the muscle energy status at slaughter (Scheffler and Gerrard, 2007). In the current study, the muscle energy status at slaughter was similar between the various test groups except for the IVG and bucks. Scheffler *et al.* (2011) explained that glycogenolysis continues *post-mortem*, with a subsequent increase in glucose levels. Glucose and glucose-6-phosphate are intermediates of glycolysis. Thus, concentration of these metabolites in a muscle are an indication of the rate at which glycolysis proceeds. The initial values for glucose and glucose-6-phosphate (Table 6.8) suggest that the goat muscles studied were more efficient in maintaining their initial levels, as indicated by higher initial ATP concentrations than previously reported by Simela *et al*. (2004). In addition, the initial ATP levels observed in this study were within the range of 5.7 to 8.7 µmol/g muscle; similar as noted by Pearson and Young (1990) for relaxed beef muscle. To replenish ATP, the breakdown of CP and degradation of carbohydrates via anaerobic pathways take place (Bendall, 1972). The initial splitting of ATP to ADP plus inorganic phosphate (Pi) and H^+ (during the first biochemical step of glycolysis), determines the rate and magnitude of carbohydrate metabolism. Without this reaction, glycolysis and acidification come to a rapid halt (Bendall, 1972). Thus, glycolysis stops when all glycogen reserves have been used or due to inactivation of the glycolytic enzymes by low pH (Scopes, 1974) and higher muscle temperature (England *et al.,* 2013). In the present study, the residual glycogen concentrations were similar between the two carcass treatments, in both LTL and SM samples. Further, glycolysis proceeds after CP have been reduced to approximately 30 % of its rest value (Scheffler and Gerrard, 2007). Thus, CP has a “sparing” effect on glycogen. In the current study, muscle CP concentration were in the range of 2.18 to 3.45 µmol/g muscle for the LTL samples and 2.19 to 2.90 µmol/g muscle for the SM samples. These values are lower compared to previous values (2.76 to 3.79 µmol/g muscle and 2.97 to 3.67 µmol/g muscle) reported for LTL and SM samples, respectively by Pophiwa *et al.* (2016) for BG and unidentified indigenous goats. Simela *et al.* (2004) reported for the LTL muscle of South African indigenous goats’ values of 3.74 ± 1.74 µmol/g muscle. To note is that the first samples of Pophiwa *et al.* (2016) were collected at 30 minutes *post-mortem* and in the study of Simela *et al.* (2004) at 15 minutes *post-mortem* compared to 1 hour *post-mortem* in the current study. This suggests that relatively lower values can be expected due to the delay in sampling of the current study compared to other studies (Simela *et al.,* 2004; Pophiwa *et al.,* 2016), as energy levels decrease rapidly after slaughter. Hertzman *et al*. (1993) suggested that the concentration of CP at slaughter for beef should be 1 to 2 µmol/gram muscle, and Ferguson (2003) estimated that in sheep it is in the region of 3 µmol/g muscle which corresponds with the measurements in the present study.

Biochemical studies of this nature are crucial in identifying enzymes, which are rate limiting during *post-mortem* glycolysis. It has been postulated that different enzymes may be rate limiting at different times during the conversion of muscle to meat (Scheffer and Gerrard, 2007). According to the review of Ferguson and Gerrard (2014), the duration and rate of the rapid glycolytic phase, as is the case for most biochemical reactions, is temperature-dependent (Marsh, 1954; Cassens and Newbold, 1967a, 1967b; Newbold and Scopes, 1967; Bendall, 1973; Hertzman *et al*., 1993; Daly,

1997; Ferguson, 2003). However, it is also important to recognise that variations in glycolytic rate can be observed, even at constant temperatures (Bendall, 1978; Daly, 1997; O'Halloran *et al.,* 1997). In the context of meat tenderness and other meat quality traits (e.g., colour, water-holding capacity), the interaction between *post-mortem* glycolysis and temperature in muscle is paramount. Electrical stimulation (ES) has been reported to accelerate muscle energy metabolism, allowing rapid chilling of goat carcasses without the risk of cold shortening (Kondos and Taylor, 1987). It is reported that ES accelerates the ATP and glycogen break down and causes a rapid pH decline (Biswas *et al.,* 2007; Kahraman and Ergun, 2009; Cetin and Topcu, 2009) as confirmed in this study. Thus, ES had an immediate effect on the energy content of both muscles studied (LTL and SM), showing a rapid depletion of CP, glycogen, and ATP content with a corresponding increase in lactate concentration. Electrical stimulation (ES) further accelerated muscle energy metabolism for at least 6 hours *post-mortem*, whereas the study of Rhee and Kim (2001) reported rapid energy metabolism during the first 3 hours of ES. No significant difference was observed in the SM muscle at 24 hours *post-mortem*. The BG and large frame IVG exhibited similar energy metabolism patterns and not only ES influenced the glycolytic rate, but the position of the muscle in the carcass (e.g., deep versus superficial muscles) as recognised by Ferguson and Gerrard (2014). Further studies should consider these varying conditions so as to minimise *ante-mortem* stress and optimise *post-slaughter* procedures.

6.4. Conclusion

Goat muscle of both Boer Goats (BG) and large frame Indigenous Veld Goats (IVG) is susceptible to *post-slaughter* external intervention such as ES to improve meat colour and tenderness. This information improved our knowledge on the biochemical processes underlying the conversion of muscle to meat in goats, however the fine-tuning of *post-slaughter* conditions should be studied further as minor interventions can make significant differences in the glycolytic system and subsequent meat colour. Experimental measurements on the energy metabolites of BG vs. IVG showed that there are minimal differences in visual quality, except that the IVG which seems to be darker. The influence of castration on diminishing the glycolytic potential might be an indication that it is not a *pre-slaughter* option for IVG. Further research should be conducted to understand the impact of *pre-* and *post-mortem* procedures as a small change in slaughter practice will have a major impact on the end product.

6.5. References

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CHAPTER 7

Sensory evaluation of, and volatiles analysed from large frame Indigenous Veld Goats and Boer Goats of Southern Africa, subjected to castration and electrical stimulation as measured in the *Longissimus thoracis et lumborum* and *Semimembranosus* muscles

Abstract

The sensory profiles and volatiles of the Longissimus thoracis et lumborum (LTL) and Semimembranosus (SM) muscles of large frame Indigenous Veld Goats (IVG; n = 41; bucks n = 21, wethers n = 20) and Boer Goats, (BG; n = 36; bucks n = 21, wethers n = 15) were assessed. Sensory attributes indicated a stronger experience of taste for sweetness for BG compared to IVG, the latter had a stronger impression of being gamey and musty. Significantly stronger goat aroma, metal and sour taste were detected for bucks, with wethers presenting a stronger sweet and ram/boar taint taste. Overall, the scores for the various sensory attributes were low (<4.00 on a 1 to 8 scale), apart from goat aroma and goat-like flavour (>4.00). A total of fifteen volatile compounds were identified and quantified in the LTL and SM muscles and included six alcohols, six aldehydes, one carboxylic acid, one aromatic and one ketone. No clear relationship could be established between the volatile compounds and sensory flavours as presented by the PCA.

Keywords: Descriptive sensory analysis, volatile aroma compounds, goat meat, Cape Lob Ear or Cape Speckled

7.1. Introduction

Sensory evaluation is a scientific discipline used to evoke, measure, analyse and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch, and hearing (Stone and Sidel, 1993). Generally, aroma and flavour are two complex attributes of meat affected by species, age, fatness and type of tissue, locality, sex, diet ,and method of cooking (Drumm and Spanier 1991; Mottram 1998; Calkins and Hodgen, 2007; Muchenje *et al*., 2009; 2010; Aaslyng and Meinert 2017). Meat aroma refers to orthonasal aroma (experienced through the external nares in the nasal cavity), whereas meat flavour refers to retronasal aroma (experienced on the consumption of meat) (Roberts and Acree, 1995; Neethling *et al.,* 2018). Flavour refers to the components of food responsible for chemosensory stimulation: volatile aroma and non-volatile taste compounds. Flavour molecules must interact with sensory receptors to be perceived. Flavour information is normally integrated with texture, visual, and other sensory cues by the brain

to create a unique sensory signature. James and Calkin (2008) reported that meat flavour is an important component of the sensory quality of meat. The type, quantity, and balance of flavour molecules are critical to the acceptability of meat flavour. The structure and composition of meat affects the way that flavour molecules are released during cooking and eating. Additionally, flavour perception is influenced by the extent to which potentially flavourful compounds are released and made available to receptors. Thus, sensory tenderness and flavour is generally correlated to the degree of overall liking of meat by consumers (Neely *et al.,* 1998; Hutchison *et al.,* 2010). The composition of the meat, particularly the fat content (acting as a solvent for flavour compounds) and structure (e.g., density of myofibrillar proteins) will also affect the release of flavour compounds. In this respect, the preparation and cooking of meat also have a significant effect on the overall flavour and eating quality (Watkins *et al.,* 2013). In its fresh uncooked state, meat has little flavour. It is only as a result of cooking that the full flavour develops. Raw meat is described as salty, metallic, and rare (bloody) with a slightly sweet aroma (Soncin *et al.,* 2007). During cooking, a complex set of thermally induced reactions occur between the non-volatile components of lean and fat tissue, which results in the generation of a large number of products. Volatile aroma compounds such as aldehydes, alcohols, ketones, carboxylic acids, ethers, esters, lactones, heterocyclic compounds and hydrocarbons are produced from low-molecular weight amino acid degradation products, lipid oxidation products and reaction products of the two, while other compounds originate through Maillard (when free amino acids condense with the carbonyl groups of reducing sugars) or Strecker (the degradation of amino acids by dicarbonyls formed in the Maillard reaction) reactions (Mottram, 1998; Shahidi 1998; Watkins *et al.,* 2013). Essentially, the sensory characteristic of meat is linked to the presence of these volatile compounds as they mainly contribute to the flavour profile (Mottram, 1998; Calkins and Hodgen, 2007). The final array of flavour compounds collectively forms the species-specific flavour for that animal (Mottram, 1998; Warris, 2000).

Various goat breeds are used as meat breeds in South Africa. However, there is no information on their acceptability, palatability, and sensory characteristics (Xazela *et al.,* 2011). Little work has been reported that describes the presence of taste compounds in the large frame eco-types of original natural “indigenous” goats that survived the intensive breeding programmes of the early twentieth century (Ramsay *et al.,* 1988). The Cape Speckled and the Cape Lob Ear are two of these and were recently formally registered as Indigenous Veld Goats (IVG) – a collective name for the eco-types conserved by the Indigenous Veld Goat Society of South Africa (https://www.indigenousveldgoats.co.za, accessed, 31 December 2020). Most meat quality research on the so called “indigenous” goats was on the unimproved BG crosses. This is the first project where meat quality and in this chapter sensory quality and volatile aroma of large frame IVG goats (Cape Speckled and Cape Lob Ear) are compared with the improved BG. Understanding the sensory profile of chevon; a controversial product depending on consumer perception (Schönfeldt *et al.,* 1993a, 1993b) and gaining insight into the volatile aroma of the meat and how it is influenced by various factors/interventions will benefit our knowledge of chevon as a fresh meat product. The aim

of the current study was to evaluate the effect of castration and electrical stimulation (ES) on the sensory characteristics and resultant volatiles of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles of Boer Goats (BG) and large frame Indigenous Veld Goats (IVG) (Cape Speckled and the Cape Lob Ear).

7.2. Material and methods

7.2.1. Animals and experimental design

Please refer to Chapter 3 (and Van Wyk *et al.,* 2020) regarding the experimental animals. The experimental design is presented in Figure 5.1 (Chapter 5).

7.2.2. Slaughter and sampling procedures

A maximum of eight goats per day representing all experimental groups were slaughtered over an 11-week period starting with the heaviest of each group (total animals slaughtered; (BG; n = 36, 21 bucks and 15 wethers; IVG; n = 41; 21 bucks and 20 wethers) - (see Chapter 3, and Van Wyk *et al.,* 2020). The carcasses were subjected to either of the following treatments: electrical stimulation (ES - 20 seconds, 400 Volts peak, 5ms pulses at 15 pulses/second), 10 minutes after stunning and exsanguination or no-electrical stimulation (NS), where after all the carcasses were placed in the chiller at 4°C within 60 minutes *post-mortem*. Samples for sensory analysis and proximate analysis were collected 4 days *post-mortem* (right LTL and SM) and stored at -20°C until analysed. Samples for volatile analysis were taken from the left LTL and SM 1 day *post-mortem* and aged for 4 days. These samples were chopped in small pieces, frozen in liquid nitrogen and frozen at -80° C until analysed.

7.2.3. Laboratory analysis

7.2.3.1. Proximate analysis

The proximate composition (moisture, protein, fat (representing chemical determined intramuscular fat - IMF) and ash) of the muscles were analysed using the procedures of the Association of Official's Analytical Chemist (AOAC, 1990) at the ARC-AP Analytical Laboratories. The moisture content (% wet weight) was determined according to method 934.01 (AOAC, 1990) by drying samples of 2.5 g of homogenized meat at 100 - 105°C for 24 hours. The ash content (% wet weight) was determined by incinerating the moisture-free samples at 500°C for a minimum of 6 hours according to AOAC (1990) method 942.05. The fat content was determined on 5 g of homogenized sample using a 1:2 chloroform/methanol solution for fat extraction as described by Lee *et al.* (1996). The protein content of the defatted sample was determined using the LECO combustion / Dumas method. The defatted samples were dried and ground to a fine powder, 0.5 g of which was weighed off into LECO™ foil cups and analysed for nitrogen content. This nitrogen content was multiplied by a factor of 6.25 in order to obtain the protein content of the sample, which was subsequently converted to a value per

gram wet meat (AOAC, 1990, method 922.15). The LECO was recalibrated after every ten test samples using an EDTA calibration sample (LECO Corporation, St Joseph, MI, USA).

7.2.3.2. GC-MS analysis (Volatile compound analysis)

All samples were frozen (less than a month) at -20°C prior to analysis. Upon thawing, 50 µL of Anisole d8 at 1 ppm was added as internal standard to the SPME vials containing the meat samples. Vials were equilibrated at 70°C for 30 minutes using a CombiPAL agitator / heater unit (CTC, Switzerland). A conditioned (conditioned by heating in a gas chromatograph injection port at 270°C for 60 minutes) fibre coated with a 50/30 µm thickness of divinylbenzene / carboxen / polydimethylsiloxane (DVB / Car / PDMS) was inserted into the headspace above the sample and held for 30 minutes (with agitation). After equilibration, the volatiles were extracted by exposing the fibre in the headspace of the SPME vial for 10 minutes where after the fibre was inserted into the injection port of the gas chromatograph (GC) Agilent 6890N (Agilent Technologies, Palo Alto, CA, USA), coupled with an Agilent mass spectrometer detector (MSD) Agilent 5975B inert XL EI/CI MSD (Agilent Technologies, Palo Alto, CA, USA). The GC-MS system was equipped with a DB-FFAP (60 m, 0.25 mm internal diameter, 0.5 µm film thickness) GC column. The SPME fibre was desorbed and held in the injection port operated in pulsed split-less mode with temperature maintained at 250°C for 10 minutes. The fibre was inserted in a fibre conditioning station for 15 minutes between samples for cleaning to prevent cross-contamination. Volatile compounds were separated using a polar (Zebron 7HG-G009-11 ZB-FFAP) capillary column (30 m, 0.25 mm e.g., 0.25 µm film thickness) from Separations Scientific (Roodepoort, 2170, South Africa). The GC oven temperature was initially held at 40°C for 10 minutes and finally increased to 240°C at 5°C/minute (held for 3 minutes). The total run time was 40 minutes. Analyses were carried out using helium as carrier gas with a flow of 1.3 mL/minute. The transfer line temperature was maintained at 280°C. The MSD were obtained using a mass selective detector working in electronic impact at 70eV, operated in full scan mode (35 - 450 m/z) with both the ion source and quadrupole temperatures were maintained at 240°C and 150°C, respectively. Compounds were tentatively identified by their mass spectra using a combination of two libraries: National Institute of Standards and Technology (NIST) 05 and Wiley (275) spectral library collection. The peak areas of each volatile organic compound detected were expressed relative to the internal standard as percentage (%) composition of the goat meat.

7.2.3.3. Cooking method

The frozen vacuumed packed muscle samples (LTL and SM) were placed in a cold room of 4°C to thaw for 24 hours before cooking. Whole cuts were prepared according to an oven-broiling method (dry heat cooking) using direct radiant heat (AMSA, 2016). Calibrated electric ovens (Mielé ovens, model H217, Miele & Cie. KG, Gütersloh, Germany) were set on “broil” 10 minutes prior to cooking at 160°C. The samples were placed on an oven pan on a rack and broiled for approximately 20

minutes until they reached an internal core temperature of 70˚C. The internal temperature was monitored by placing an iron-constant thermocouple (T-type) (Hand-model Kane-Mane thermometer, Kane International Ltd, Hertfordshire, England) in the approximate geometric centre of each sample. After cooking, all samples rested at room temperature (centrally controlled at 22 °C), for 10 minutes. Ten cubed samples (10 mm x 10 mm x 10 mm) were cut from the muscle samples (LTL and SM) and immediately wrapped individually in pre-coded (with three-digit random numbers) aluminium foil squares (9 cm x 9 cm). These samples were served warm (± 40 °C) on pre-warmed plates to the sensory panel within 20 minutes from the time the muscle samples were removed from the oven.

7.2.3.4. Description Sensory Analysis

Descriptive sensory attributes (DSA) of the samples were performed by ten female members with previous experience in the sensory evaluations of meat (Sensory Analytical Laboratory, Meat Industry Centre, ARC-AP) who assessed the goat aroma and variety of flavour components on an eight-point scale (Table 7.1). No prior acquaintance of the sensory panel with goat meat was carried out before the evaluation.

Table 7.1 Scoring of sensory panel on an eight-point scale

Reference standard	**Description of attributes presented**	**Scale**		
Aroma attribute				
Goat	Take a few short sniffs as soon as you remove the foil	1 = Extremely bland	5 = Moderate	8 = Extremely intense
Taste attributes				
Impression of juiciness	The impression of juiciness that you form as you start chewing	1 = Extremely dry	5 = Slightly juicy	8 = Extremely juicy
Muscle fibre and overall tenderness	Chew sample with a light chewing action	1= Extremely tough / stringy	5 = Slightly tough / stringy	8 = Extremely tender
Typical goat-like flavour	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Mutton-like	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Gamey	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Metallic / tin like / bloody / liver	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Sour	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense

Table 7.1. (Continued)

Sweet	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Musty	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Ram taint / boar taint	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Barnyard	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense
Shrub / grassy	Combination of taste while chewing and swallowing	1 = Extremely bland	5 = Slightly intense	8 = Extremely intense

7.2.4. Statistical analysis

The data were subjected to analysis of variance (SAS, 1999) using a three-way ANOVA to test the effect of the two goat breeds (BG and IVG), two sexes (buck and wethers), two treatments (ES and NS) and interactions as factors on descriptive sensory analysis scores (4 days *post-mortem*) and volatile compounds. Least square means were compared if a significant F statistic (5 % level of probability) was detected (Snedecor and Cochran, 1980). Slaughter day had no effect on the outcome of the results therefore the data applicable to slaughter day was pooled within the main treatments.

Prior to analyses, a Shapiro–Wilk test for normality was performed on the data (Shapiro and Wilk, 1965) and where applicable, outliers (classified as such when the standardized residual for an observation deviated with more than three SDs from the model value) were removed. Statistical significance (Fisher's t-test, least significant difference) was calculated at a 5 % level to compare means. $P \leq 0.05$ was considered statistically significant, although in some instances' data with a $P \leq 0.10$ (10 % level) was considered as a trend worthwhile discussing. Associations were illustrated using multivariate statistical analysis, specifically principal component analysis (PCA). Where applicable, the closeness of the linear relationships between the measured variables was determined using Pearson' correlation coefficient (r).

7.3. Results and Discussion

No breed x sex interactions for the chemical composition of the goat loins were observed (Table 7.2). Regarding moisture and protein, no differences were observed between the breeds which corresponds with the findings of Ripoll *et al*. (2012) (Detailed chemical composition of the loins were discussed in Chapter 3 and Van Wyk *et al.,* 2020).

Table 7.2. Least square means and standard error (SE) of means for the chemical composition of the loins of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

Proximate analyses (%)	BG		IVG		Significance (P – Values)		
	Bucks	Wethers	Bucks	Wethers	Breed	Sex	Breed × Sex
Moisture	$76.3^{x} \pm 1.8$	$75.1^{y} \pm 3.0.$	$76.8^{a} \pm 1.7$	$75.6^{b} \pm 3.4$	0.099	**<.0001**	0.350
Protein	20.0 ± 1.79	20.3 ± 2.3	$19.6^{b} \pm 1.8$	$20.1^{a} \pm 2.5$	0.200	**0.039**	0.855
Fat*	$2.2^{b} \pm 1.8$	$2.8^{a} \pm 1.7$	$1.6^{b} \pm 1.2$	$2.7^{a} \pm 1.1$	**0.032**	**0.001**	0.473
Ash	$0.9^{b} \pm 0.3$	$1.0^{a} \pm 0.2$	$1.0^{b} \pm 1.0.2$	$1.1^{a} \pm 0.2$	**0.001**	**0.001**	0.140

**Fat % = chemically determined intramuscular fat (IMF)*

^{a,b} Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

According to Berry (1992), fat levels of more than 5 % in ground beef were required to mask flavours derived from lean meat. In the present study, bucks had significantly ($P \leq 0.05$) lower % fat (1.6 % vs. 2.7 %) that could explain the significant ($P \leq 0.05$) stronger flavour sensory attributes of metallic and sour measured in the LTL muscle compared to wethers (Table 7.3).

7.3.1. Volatile compounds

A total of fifteen volatile compounds were identified and quantified in the LTL (Table 7.3) and SM muscles (Table 7.4). The identified volatile compounds included six alcohols, six aldehydes, one carboxylic acid, one aromatic, and one ketone. The aldehydes (e.g., heptanal, P = 0.005; (E)-2-nonenal, P = 0.033 and octanal, P = 0.015), carboxylic acids (e.g., acetic acid, P = 0.023) and ketones (e.g., acetoin (3-hydroxybutan-2-one), P = 0.029) indicated breed x sex x treatment interactions in the LTL muscle. Aldehydes (e.g., octanal, P = 0.046) and alcohols (e.g., 3-methyl-1-butanol, P = 0.040) also differed for the breed x sex interaction, however only aldehydes (e.g., tetradecanal, P = 0.037) differed for the sex x treatment interaction. For the main effect of breed, alcohols (e.g., 1-octene-3-ol, P = 0.005; 1-octanol, P = 0.006 and benzyl alcohol, P = 0.007), aldehydes (e.g., heptanal, P = 0.008, nonanal, P = 0.004 and octanal, P = 0.023) and ketones (e.g., acetoin (3-hydroxybutan-2-one), (P = 0.030) differed whereas for the main effect of sex, differences were observed for aldehydes (e.g., benzaldehyde, P = 0.013 and tetradecanal, P = 0.017) and aromatics (e.g., limonene, P < 0.0001).

For SM, the only difference observed regarding breed x sex x treatment interaction was for alcohols (e.g., 2-ethyl-1-hexanol, P = 0.012). Aldehydes (e.g., tetradecanal, P = 0.027) and aromatics (e.g., limonene, P =0.008) differed for the breed x treatment interaction, whereas only aldehydes (e.g., nonanal, P < 0.033 and octanal, P < 0.029) differed in terms of the breed x sex interaction. For the main effects, breed differences were observed for alcohols (e.g., 1-octene-3-ol, P = 0.008; 1-heptanol, P = 0.014; 1-octanol, P = 0.001 and benzyl alcohol, P = 0.023) and aldehydes (e.g., heptanal, P = 0.004; nonanal, P = 0.001; benzaldehyde, P = 0.003; (E)-2-nonenal, P = 0.016 and octanal, P = 0.002). Only alcohols (e.g., 1-octene-3-ol), had a significant difference regarding sex (P < 0.041) with no differences observed regarding treatment. Only the main effects (breed and

sex) will be discussed further as various different observations between the muscles were made in terms of the interactions for the detected volatile compounds and where applicable, these will be discussed.

Table 7.3. The significance (P-values) and the means and standard error of the means presenting main effects of breed (BG vs IVG) and sex (bucks vs. wethers) on the peak area ratios* of the detected volatile compound profile, % probability and retention time of the detected volatile compound profile and aroma description of the *Longissimus thoracis et lumborum* muscle (LTL), of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

Volatile compounds	Aroma description	% Probability	Retention Time (RT)	Breed		Sex		Significance (P-Values)	
				BG	IVG	Bucks	Wethers	Breed	Sex
Alcohols									
3-Methyl-1-butanol	Malt[1,2] Whiskey[2] Burnt[2]	61.0%	11.39	$5.98^{x} \pm 7.34$	$9.71^{y} \pm 10.48$	8.81 ± 10.10	7.02 ± 8.29	0.082	0.332
1-Octene-3-ol	Cucumber[1] Earth[1] Fat[1] Floral[1] Mushroom[1]	100.0%	17.13	$4.83^{a} \pm 5.97$	$1.83^{b} \pm 2.19$	4.01 ± 5.15	2.34 ± 3.77	**0.005**	0.156
1-Heptanol	Herb[2]	98.7%	17.24	0.49 ± 0.39	0.41 ± 0.40	0.49 ± 0.45	0.39 ± 0.31	0.402	0.260
2-Ethyl-1-hexanol	Green[1] Rose[1]	100.0%	17.76	1.72 ± 0.53	1.58 ± 0.51	$1.56^{x} \pm 0.50$	$1.76^{y} \pm 0.54$	0.251	0.089
1-Octanol	Bitter Almond[1] Burnt Matches[1] Fat[1] Floral[1]	100.0%	18.74	$0.92^{a} \pm 0.65$	$0.59^{b} \pm 0.28$	0.73 ± 0.58	0.75 ± 0.50	**0.006**	0.756
Benzyl alcohol	Boiled cherries[1], Moss[1], Roasted bread[1], Rose[1]	97.4%	22.31	$0.52^{a} \pm 0.68$	$1.10^{b} \pm 1.03$	0.76 ± 0.85	0.91 ± 1.02	**0.007**	0.571
Aldehydes									
Heptanal	Citrus[1] Fat[1] Green[1] Nut[1]	90.9%	6.48	$0.82^{a} \pm 0.68$	$0.47^{b} \pm 0.49$	0.65 ± 0.57	0.62 ± 0.65	**0.008**	0.976
Nonanal	Citrus[1] Fat[1,2] Green[1,2]	100.0%	15.84	$0.89^{a} \pm 0.70$	$0.54^{b} \pm 0.29$	0.72 ± 0.59	0.69 ± 0.49	**0.004**	0.953
Benzaldehyde	Bitter Almond[1] Burnt Sugar[1] Cherry[1] Malt[1] Roasted Pepper[1]	98.7%	18.22	$1.00^{x} \pm 0.41$	$0.82^{y} \pm 0.46$	$0.79^{a} \pm 0.46$	$1.03^{b} \pm 0.40$	0.070	**0.013**
(E)-2- Nonenal	Cucumber[2] Fat[2] Green[2]	92.2%	18.33	0.08 ± 0.08	0.07 ± 0.08	0.07 ± 0.06	0.08 ± 0.09	0.591	0.453
Tetradecanal	Fat[1], Orris[1]	98.7%	25.17	0.59 ± 0.38	0.73 ± 0.66	$0.79^{a} \pm 0.51$	$0.51^{b} \pm 0.55$	0.243	**0.017**
Octanal	Citrus[1] Fat[1] Green[1] Oil[1] Pungent[1] Chemical[2] Metal[2] Burnt[2]	88.3%	13.09	$0.69^{a} \pm 0.62$	$0.44^{b} \pm 0.33$	0.54 ± 0.51	0.57 ± 0.50	**0.023**	0.683
Carboxylic acids									
Acetic acid	Acid[1] Fruit[1] Pungent[1] Vinegar[1] Sour[1,2]	97.4%	17.39	10.2 ± 13.03	10.09 ± 15.67	10.11 ± 14.15	10.19 ± 14.97	0.970	0.980
Aromatics									
Limonene	Citrus[1] Mint[1] Lemon[2] Orange[2]	100.0%	5.94	0.18 ± 0.07	0.19 ± 0.08	$0.21^{a} \pm 0.07$	$0.15^{b} \pm 0.06$	0.718	**<.0001**
Ketones									
Acetoin (3-hydroxybutan-2-one)	Butter[1] Creamy[1] Green Pepper[1]	89.6%	14.09	$1.78^{a} \pm 2.14$	$0.94^{b} \pm 1.15$	1.32 ± 1.79	1.33 ± 1.66	**0.030**	0.872

**Peak area ratios calculated as a ratio of the analyte to the internal standard, anisole-d8 present at 1ppm during analysis*

[a,b] Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

Table 7.4. The significance (P-values) and the means and standard error of the means presenting main effects of breed (BG vs IVG) and sex (bucks vs. wethers) on the peak area ratios* of the detected volatile compound profile, % probability and retention time of the detected volatile compound profile and aroma description of the *Semimembranosus* muscle (SM) muscles, of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

Volatile compounds	Aroma description	% Probability	Retention Time (RT)	Breed-type		Sex-type		Significance (P-Values)	
				BG	IVG	Bucks	Wethers	Breed	Sex
Alcohols									
3-Methyl-1-butanol	Malt[1,2] Whiskey[2] Burnt[2]	57.1%	11.40	6.92 ± 7.31	6.16 ± 7.37	7.20 ± 7.47	5.69 ± 7.10	0.647	0.381
1-Octene-3-ol	Cucumber[1] Earth[1] Fat[1] Floral[1] Mushroom[1]	100.0%	17.13	11.37[a] ± 13.23	5.02[b] ± 6.51	10.32[a] ± 11.52	5.15[b] ± 8.74	**0.008**	**0.041**
1-Heptanol	Herb[2]	94.8%	17.25	0.65[a] ± 0.54	0.39[b] ± 0.31	0.50 ± 0.39	0.51 ± 0.52	**0.014**	0.829
2-Ethyl-1-hexanol	Green[1] Rose[1]	100.0%	17.77	1.70 ± 0.53	1.73 ± 0.60	1.64 ± 0.52	1.81 ± 0.61	0.827	0.181
1-Octanol	Bitter Almond[1] Burnt Matches[1] Fat[1] Floral[1]	100.0%	18.75	1.57[a] ± 1.22	0.81[b] ± 0.60	1.22 ± 1.08	1.08 ± 0.92	**0.001**	0.691
Benzyl alcohol	Boiled cherries[1], Moss[1], Roasted bread[1], Rose[1]	100.0%	22.61	0.79[a] ± 1.07	1.40[b] ± 1.17	1.11 ± 1.18	1.11 ± 1.14	**0.023**	0.849
Aldehydes									
Heptanal	Citrus[1] Fat[1] Green[1] Nut[1]	88.3%	6.48	0.91[a] ± 0.80	0.49[b] ± 0.44	0.77 ± 0.75	0.60 ± 0.54	**0.004**	0.316
Nonanal	Citrus[1] Fat[1,2] Green[1,2]	97.4%	15.85	1.68[a] ± 1.44	0.78[b] ± 0.56	1.36 ± 1.41	0.98 ± 0.65	**0.001**	0.206
Benzaldehyde	Bitter Almond[1] Burnt Sugar[1] Cherry[1] Malt[1] Roasted Pepper[1]	100.0%	18.22	1.35[a] ± 0.72	0.90[b] ± 0.53	1.11 ± 0.61	1.11 ± 0.72	**0.003**	0.865
(E)-2- Nonenal	Cucumber[2] Fat[2] Green[2]	89.6%	18.33	0.14[a] ± 0.12	0.08[b] ± 0.08	0.10 ± 0.10	0.11 ± 0.10	**0.016**	0.558
Tetradecanal	Fat[1], Orris[1]	100.0%	25.16	1.44 ± 0.97	1.19 ± 0.79	1.44 ± 0.88	1.13 ± 0.87	0.202	0.135
Octanal	Citrus[1] Fat[1] Green[1] Oil[1] Pungent[1] Chemical[2] Metal[2] Burnt[2]	81.8%	13.14	0.99[a] ± 0.92	0.49[b] ± 0.38	0.82 ± 0.84	0.59 ± 0.53	**0.002**	0.226
Carboxylic acids									
Acetic acid	Acid1 Fruit[1] Pungent[1] Vinegar[1] Sour[1,2]	100.0%	17.39	13.19 ± 19.66	11.68 ± 16.56	10.80 ± 15.32	14.21 ± 20.69	0.716	0.399
Aromatics									
Limonene	Citrus[1] Mint[1] Lemon[2] Orange[2]	96.1%	6.00	0.19 ± 0.07	0.19 ± 0.08	0.18 ± 0.06	0.20 ± 0.09	0.660	0.457
Ketones									
Acetoin (3-hydroxybutan-2-one)	Butter[1] Creamy[1] Green Pepper[1]	88.3%	14.10	1.08 ± 1.31	0.76 ± 1.17	1.02 ± 1.50	0.78 ± 0.84	0.273	0.481

**Peak area ratios calculated as a ratio of the analyte to the internal standard, anisole-d8 present at 1ppm during analysis*

[a,b] Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

[x,y] Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

Of the volatile compounds reported (Table 7.2 and Table 7.3), alcohols (e.g., 1-octene-3-ol, 2-ethyl-1-hexanol and 1-octanol), aldehyde (e.g., tetradecanal) and carboxylic acid (e.g., acetic acid) had a 100% probability in the LTL and SM muscle, where alcohols (e.g., benzyl alcohol) and aldehydes (e.g., benzaldehyde) also had a 100% probability of being identified, but only in the SM muscle. Carboxylic acids (e.g., acetic acid) had the highest peak area ratio in the LTL and SM and was therefore the most abundant relative to the internal standard (Anisole d8).

In the current study, BG had significant higher aldehydes (e.g., 1-octene-3-ol, 1-octanol, heptanal, nonanal and octanal) in both muscles (LTL and SM) studied compared to IVG. Aldehydes in general are major sources of volatile fractions obtained from domestic ruminant meat (Vasta and Priolo, 2006; Villalobos-Delgado *et al.,* 2014; Ivanovic *et al.,* 2016). Within the group, linear aldehydes that are produced during fat oxidative degradation were detected with the exception of benzaldehyde (Belitz and Grosch, 1987; Ripoll *et al.,* 2019). Aldehydes have a low aroma threshold and an intense and specific aroma, which can make important contributors to the aromatic meat profile (Madruga *et al.,* 2009). Aldehydes are believed to form as a result of lipid oxidation and protein degradation, while ketones generally correlate with the type of diet (Ivanovic *et al*., 2016). In the SM muscle, higher values for BG were also observed for aldehydes (e.g., benzaldehyde and (E)-2-nonenal), whereas, IVG had higher alcohols (e.g., benzyl alcohol) in both muscles studied (LTL and SM). Bucks (SM muscle) had significant ($P \leq 0.05$) higher values in terms of alcohols (e.g., 1-octene-3-ol, 10.32 vs. 5.15) and wethers had higher aldehydes (e.g., benzaldehyde, 1.03 vs. 0.79) compared to bucks that had higher aldehydes (e.g., tetradecanal, 0.79 vs. 0.51) and ketones (e.g., acetoin, 1.78 vs. 0.94) compared to IVG as measured in the LTL muscle. Alcohols are typically formed as products of the oxidation of lipids or their oxidation products, such as hexanal or heptanal (Kosowska *et al.,* 2017). Furthermore, alcohol formation is attributed to microorganisms' activity, such as 3-methyl-1-butanol being formed during the degradation of amino acids (Muriel *et al.,* 2004). Alcohols have herbaceous, woody and fatty notes (Lorenzo *et al.,* 2013). The determined levels of aldehydes in the current study that can be precursors for alcohol synthesis were significantly different between breeds, as well as levels of alcohols, which supports the breed's impact on volatile compounds in meat.

Ketones have also been shown to play a significant role in beef flavour with acetoin being identified as most closely linked to overall flavour desirability scores ($r = 0.57$, $P \leq 0.01$) by a consumer panel (O'Quinn *et al.,* 2016). Acetoin was further linked to positive attributes in beef such as grilled flavour ($r = 0.54$, $P \leq 0.01$) and negatively correlated to negative attributes in beef such as gamey flavour ($r = -0.47$, $P \leq 0.01$) and livery flavour ($r = -0.54$, $P \leq 0.01$) (O'Quinn *et al.,* 2016). However, other researchers have described aromas related to acetoin in meat as "non-fresh" and being associated with "cheesy" odour in spoiling meat (Dainty, 1985; Casaburi *et al.,* 2015). Although acetoin's role in flavour perception in beef has been shown to be noticeable (O'Quinn *et al.,* 2016). The high probability (89.6 %, LTL muscle and 83.3 %, SM muscle) in the current study suggest that ketones (e.g., acetoin) also contribute greatly to chevon meat flavour. However, in the current study

the sensory attributes such as gamey and metallic / tin-like / bloody and livery flavour had descriptive sensory scores <1.80, for both muscles studied (Table 7.4). A similar observation was made for springbok despite acetoin being the most abundant volatile compound detected in their study (Neethling *et al.,* 2018).

7.3.2. Sensory quality attributes

The only differences observed for the breed x sex x treatment interactions were in the LTL muscle for the sensory quality attribute, sweet flavour (P = 0.029) and in the SM muscle for ram taint / boar taint flavour (P = 0.040). Furthermore, the following significant interactions were observed between the main effects in the LTL muscle, breed x treatment (goat aroma, P < 0.011; gamey flavour, P < 0.039), sex x treatment (sweet flavour, P < 0.015). In the SM muscle, significant interactions were noted for breed x treatment (gamey flavour, P < 0.043 and sour flavour, P < 0.030). Furthermore, as only breed and sex presented significant values, these will be discussed further where applicable (Table 7.5).

In the LTL muscle, a breed difference was observed for flavour attributes, gamey, sweet and musty. In the SM muscle, only musty showed a significant breed difference. For sex, in the LTL muscle the following significant differences were observed for goat aroma and flavour attributes (e.g., metallic, sour, sweet and ram taint/boar taint), whereas in the SM muscle significant differences were observed only for goat aroma and barnyard flavour. Overall, the scores for the various sensory attributes were low (<4.00), apart from goat aroma and goat-like flavour (>4.00). It could therefore be argued that the score levels (<4.00) of detection on a scale from 1 to 8 are probably non-significant as pertaining to consumers. This hypothesis however would require further research to verify.

The breed of animals affects flavour, eating quality, and fat percentage. Normally the animals with high fat content have superior scores in terms of flavour and overall eating quality (Laborde *et al.,* 2001; Chambaz *et al.,* 2003). Wheeler *et al*. (2005) reported that meat flavour may possibly be genetic, pointing to possible selection for enhanced flavour, although this is seen to be unfeasible due to the complicated procedures and costs of phenotype assessments. Tshabalala *et al.* (2003) observed that the aroma intensity of BG meat was significantly higher than that of the indigenous goats. BG meat had a stronger goaty aroma than indigenous goats, which is confirmed in the current study as measured in the LTL muscle. The reported values for BG in terms of goat aroma (4.96) was stronger compared to IVG (4.88) (Table 7.5).

Table 7.5. The significance (P values), means and standard error of means (SE) between the breeds (BG vs. IVG) and sexes (bucks vs. wethers) on descriptive sensory quality attributes of the *Longissimus thoracis et lumborum* (LTL), and *Semimembranosus* (SM) muscles, of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats.

	Breed		Sex		Significance (P-Values)	
	BG	**IVG**	**Bucks**	**Wethers**	**Breed**	**Sex**
***Longissimus thoracis et lumborum* (LTL)**						
Aroma attribute						
Goat	4.96 ± 0.36	4.88 ± 0.30	4.99^{a} ± 0.33	4.82^{b} ± 0.30	0.278	**0.016**
Flavour attributes						
Goat-like	4.07^{x} ± 0.29	4.20^{y} ± 0.30	4.15 ± 0.27	4.12 ± 0.34	0.058	0.594
Mutton-like	3.24 ± 0.33	3.17 ± 0.27	3.17 ± 0.29	3.24 ± 0.32	0.374	0.281
Gamey	0.24^{a} ± 0.14	0.32^{b} ± 0.19	0.28 ± 0.16	0.29 ± 0.19	**0.033**	0.869
Metallic*	1.70 ± 0.25	1.74 ± 0.29	1.80^{a} ± 0.27	1.63^{b} ± 0.25	0.529	**0.008**
Sour	0.93 ± 0.29	0.98 ± 0.28	1.05^{a} ± 0.29	0.84^{b} ± 0.24	0.494	**0.001**
Sweet	0.57^{a} ± 0.17	0.48^{b} ± 0.18	0.48^{a} ± 0.15	0.57^{b} ± 0.20	**0.016**	**0.014**
Musty	0.22^{a} ± 0.12	0.28^{b} ± 0.15	0.24 ± 0.13	0.27 ± 0.16	**0.047**	0.281
Ram taint / boar taint	0.08 ± 0.13	0.12 ± 0.12	0.07^{a} ± 0.11	0.13^{b} ± 0.13	0.212	**0.037**
Barnyard	0.32^{x} ± 0.20	0.41^{y} ± 0.27	0.35 ± 0.23	0.39 ± 0.26	0.087	0.610
Shrub / grassy	0.52 ± 0.19	0.55 ± 0.15	0.54 ± 0.21	0.54 ± 0.13	0.434	0.994
***Semimembranosus* (SM)**						
Aroma attribute						
Goat	5.09 ± 0.26	5.09 ± 0.27	5.16^{a} ± 0.27	5.01^{b} ± 0.24	0.650	**0.017**
Flavour attributes						
Goat-like	4.29 ± 0.27	4.27 ± 0.27	4.33 ± 0.25	4.23 ± 0.28	0.658	0.118
Mutton-like	3.16 ± 0.36	3.06 ± 0.39	3.12 ± 0.41	3.09 ± 0.35	0.270	0.869
Gamey	0.42 ± 0.22	0.46 ± 0.19	0.46 ± 0.20	0.43 ± 0.21	0.429	0.439
Metallic*	1.72 ± 0.24	1.69 ± 0.31	1.69 ± 0.25	1.72 ± 0.32	0.647	0.651
Sour	1.08 ± 0.21	1.03 ± 0.24	1.02 ± 0.23	1.09 ± 0.21	0.373	0.161
Sweet	0.14 ± 0.08	0.15 ± 0.08	0.14 ± 0.08	0.17 ± 0.07	0.688	0.121
Musty	0.05^{a} ± 0.11	0.11^{b} ± 0.14	0.09 ± 0.13	0.08 ± 0.13	**0.047**	0.617
Ram taint / boar taint	0.05 ± 0.11	0.10 ± 0.15	0.08 ± 0.13	0.08 ± 0.14	0.130	0.748
Barnyard	0.27 ± 0.14	0.28 ± 0.15	0.32^{a} ± 0.15	0.21^{b} ± 0.11	0.829	**0.001**
Shrub / grassy	0.17 ± 0.19	0.16 ± 0.14	0.16 ± 0.14	0.18 ± 0.20	0.905	0.728

**Metallic / tin like / bloody / liver*

^{a,b} Means in the same row per main effect bearing different letters differ significantly ($P \leq 0.05$)

^{x,y} Means in the same row per main effect bearing different letters was considered a tendency to differ ($P \leq 0.1$)

A sweet flavour (similar to sweet taste) of lamb has been associated with concentrations of glucose, inosine monophosphate and adenosine monophosphate as these nucleotides are precursors for ribose, a known participant in the formation of meat aroma compounds (Oltra *et al.,* 2015). Boer Goats (BG) had statistically significantly higher values for the impression of being sweet (0.57), compared to IVG which had a higher impression of being gamey (0.32) and musty (0.28) in flavour with a tendency to have a typical goat flavour and barnyard taste. Although care should be taken in the interpretation of these results as it can be argued that these differences are so small on the sensory scale developed and used that they are of no practical value. Furthermore, goat aroma was the most important contributor to the intensity of BG and IVG meat (± 5.0 score). The similarity with goat flavour, scores >4.0 found in both muscles studied (LTL and SM) could be by the lower concentrations of aldehydes detected (Table 7.3.and Table 7.4) (Villalobos-Delgado *et al.,* 2014).

Meat from intact males may be different in flavour characteristics and different in tenderness and may be tougher than that of castrated females or males. This is especially true in older, mature animals. Female animal meat varies in fat and connective-tissue proportion, depending on the association of puberty onset and growth. The level of breakdown products of testosterone, higher levels of androstenone and skatole that form in the hind gut cause boar taint (Field, 1971). More differences were presented between the sexes in the LTL muscle for the following sensory quality attributes; impression on goat aroma ($P = 0.016$), metallic / tin like / bloody / liver flavour ($P = 0.008$), sour flavour ($P \leq 0.001$), sweet flavour ($P = 0.014$) and ram- / boar taint flavour ($P = 0.037$). A goat aroma, metallic and sour flavour were more prominent for bucks compared to wethers. Sensory quality traits such as sweet and ram and boar taint flavour attributes were more prominent for wethers. In the SM muscle, goat aroma ($P = 0.018$) while flavour attribute, barnyard ($P \leq 0.001$) differed between the two sexes. Tahir *et al.* (1994) concluded that goat-like flavour, juiciness, tenderness, and overall acceptability of goat meat improved after castration, as confirmed in the current study where bucks presented a stronger goat aroma and goat-like flavour and less tender, higher WBSF measured in both muscles studied (Chapter 5) compared to wethers. Formation of off-flavours due to lipid oxidation lowers the meat quality (Aymerich *et al.,* 2008). Flavour involves two sensations: taste and aroma. Factors affecting flavour and aroma can either have an influence pre-harvest and post-harvest. Pre-harvest factors include the animal's condition at slaughter, method of slaughter, breed, age, sex, plane of nutrition and diet, whereas post-harvest factors such as pH, temperature, protein, fats, glycogen, fatty acids, marbling, and different cooking methods (Drumm and Spanier 1991; Mottram 1998; Calkins and Hodgen, 2007; Muchenje *et al*., 2009; 2010; Aaslyng and Meinert 2017). These factors can alter the composition of the meat (e.g., fat content). Considering the natural nutritional behaviour of goats (80 % browsing and 20 % grazing) compared to the diet of the current study (e.g., natural grass diet supplemented with hay ad libitum and an average of 250 g commercial "Ram, lamb and ewe - 13" pellets (protein 130 g/kg, fat 25 - 70 g/kg, fiber 150 g/kg, moisture 120 g/kg, calcium 15 g/kg, phosphorus 3 g/kg, urea 10 g/kg; Meadow Feeds, Lanseria Corporate Estate, Malibongwe Drive, Lanseria, Gauteng, South Africa) per day per animal) warrants further research - The effect of diet on the sensory attributes of different goat breeds as a well-defined description of the characteristic sensory attributes of goat meat is still lacking.

7.3.3. Correlations between volatile and sensory composition

A principal component analysis (PCA) was used to visualise the observations and analyse the differences and relationships between the treatment groups (breed x sex). In the LTL muscle, the principal component (PC), factor axes 1 and 2 explained 36.96 % of the total variance of which F1 and F2 explained 23.41 % and 13.54 %, respectively. Whereas, in the SM muscle, the factor axes 1 and 2 explained 37.18 % of the total variance of which F1 and F2 explained 22.51 % and 14.67 %, respectively. Figure 7.1 A clearly shows that the treatment groups are not separated in terms of a breed x sex interaction, however along F1, a proportion of BG irrespective of sex and treatment

grouped in the top right quadrant and related strongly to 1-octanol, 1-octene-3-ol, nonanal, 2-ethylhexanal and acetoin.

The results of the ANOVA indicate that significant ($P \leq 0.05$) breed effects were present for these volatiles (Table 7.3 and Table 7.4). Sensory attributes such as goat aroma, and flavour attributes, sour, metal, goat-like in the top left quadrant associated with volatile aroma compounds acetic acid, tetradecanal and 3-methyl-1-butano. In the bottom left quadrant, Benzyl-alcohol related with mutton-like flavour (LTL muscle). In Figure 7.4 B, along F2, the opposite was observed for sensory attributes metal, sour and flavour with these attributes in the bottom quadrants and mutton-like in the top quadrants, suggesting that these related to the volatile aroma compound 3-methyl-1-butano. In the SM muscle, a portion of BG in the bottom left quadrant related with benzaldehyde.

The results are confirmed by the ANOVA (Table 7.4) with a significant ($P \leq 0.05$) breed effect and higher means and standard error of means in BG in comparison to IVG (Table 7.4), suggesting that BG could be sweeter compared to IVG which is more gamey and mustier in flavour. However, the overlapping of treatment groups (breed x sex) in both muscles studied, indicates that they were very similar in terms of sensory profiles and volatile aroma compounds and barely distinguishable.

In addition, in the LTL muscle, acetic acid, tetradecanal and 3-methyl-1-butanol were associated with flavour attributers, goat-like, sour, metal, and goat-like aroma, whereas benzaldehyde was associated with mutton-like flavour. In the SM muscle, benzaldehyde was associated with metal and goat flavour, whereas acetoin was more associated with mutton-like flavour and 1-octene-3-ol, 1-octanol with goat aroma. The results suggest that types of muscles affect the flavour of meat. Even though only 36.96 % (LTL muscle) and 37.18 % (SM muscle) of the variation is described, one should always bear in mind that various intrinsic and extrinsic factors could influence the sensory profile. This lack of segregation can also be seen in the ANOVA results with few of the aromatic compounds differing significantly between the different main effects and interactions of the main effects (Table 7.3 and Table 7.4).

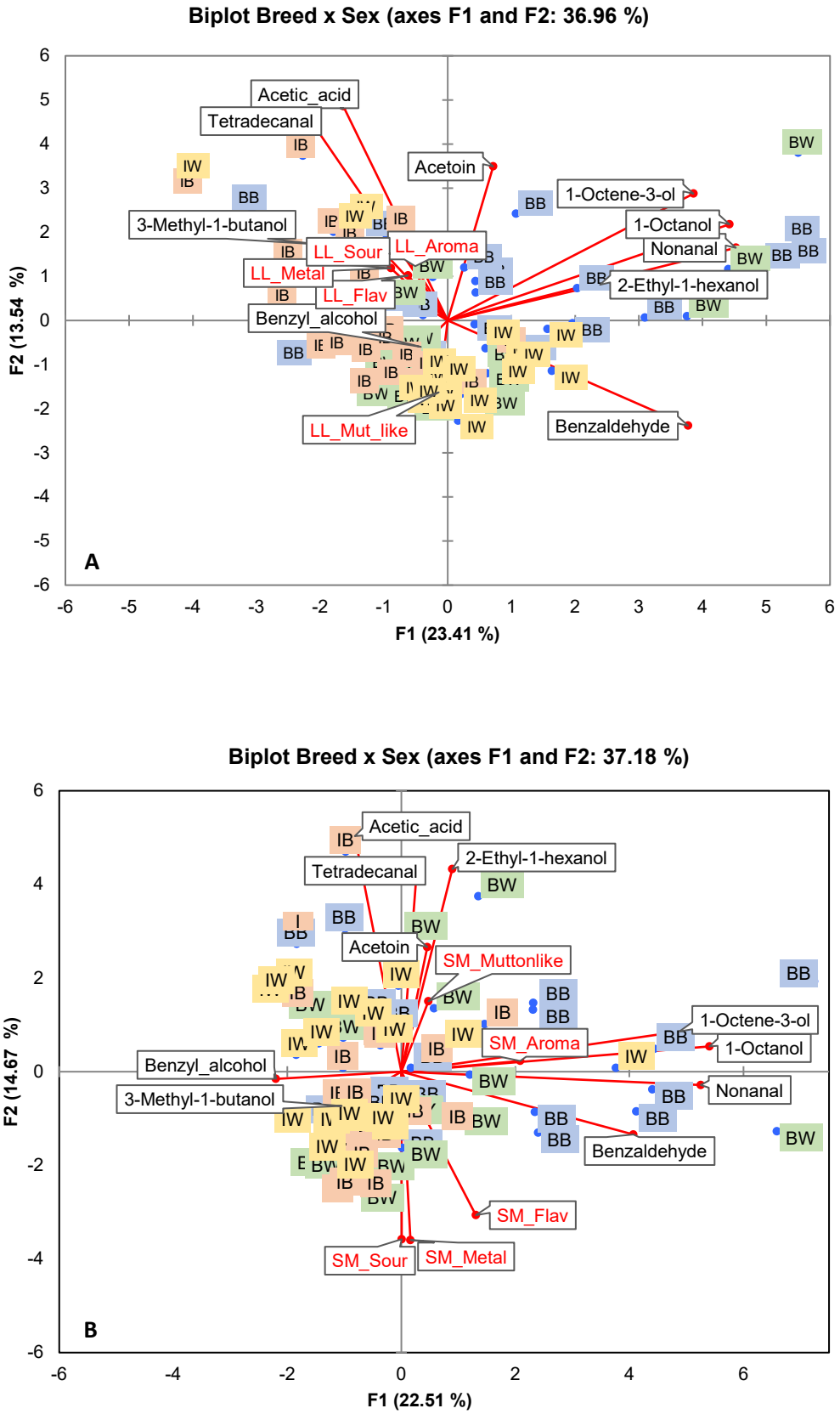

Figure 7.1. Principal component analysis (PCA) biplot (A) = *Longissimus thoracis et lumborum* (LTL), and (B) = *Semimembranosus* (SM) of the sensory attributes and volatile aroma compounds of Boer- (BG) and large frame Indigenous Veld (IVG) buck and wether goats; BB = Boer Goat bucks; BW = Boer Goat wethers; IB = large frame Indigenous Veld Goat bucks; IW = large frame Indigenous Veld Goat wethers.

7.4. Conclusion

Results of this study of the relationships between sensory attributes and volatile aroma compounds indicated that treatment groups in general were very similar and barely distinguishable. Overall, the scores for the various sensory attributes were low (<4.00), apart from goat aroma and goat-like flavour (>4.00). Nonetheless, the results obtained in this study suggests breed and sex has an impact with BG indicating stronger experience of being sweet in flavour compared to IVG, which had a stronger impression of being gamey and musty. Significant stronger goat aroma, metal and sour flavour attributes were detected for bucks, with wethers presenting a stronger sweet and ram / boar taint flavour attributes.

There is limited information/research available to compare the results of the current study, indicating the need for further studies to characterise interactions among the various factors (e.g., breed, sex, treatment, nutrition, etc.) in the volatile compounds of Southern Africa goat breeds and goats in general as to gain a clearer understanding of goat meat sensory quality or the use of specific volatile compounds for the differentiation of meat origin. However, the current study is not without limitations as only a total of 15 volatile compounds were identified of which the majority of compounds identified were alcohols and aldehydes. Further, it could be proposed that these specific alcohols and aldehydes can aid as markers and may provide useful information regarding the analysis of quality control of goat meat that enters the market. Tracing the origin of products is important for authentication of meat from different production systems. Therefore, it could be proposed to see what the effect of natural browsing / grazing would be in these compounds and sensory attributes as the goats from the current study had been fed a diet that was limited in browse plant species and the insight will provide an improved understanding of sensory attributes of chevon of these flavour-contributing chemical species and processes as to provide valuable guidance for developing meat (chevon) products with a better quality and taste.

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CHAPTER 8

General discussion and conclusion

8.1. General discussion

Goat is a worldwide spread species bred for different specialities and aptitudes, among these for meat production. Goat meat / chevon consumption varies widely depending on the region of the world considered (Chapter 2). Globally, livestock production currently accounts for some 40 % of the gross value of agricultural production (FAOSTAT, 2019). In industrial countries, this share is more than half whilst in developing countries, where livestock production accounts for one-third, its share is rising rapidly as a result of growth in population and income and changes in lifestyles and dietary habits. The total demand for animal products in developing countries is expected to more than double by 2030 (FAO, 2015). In spite of the trend towards increasing scales of production and vertical integrated production systems, the greater part of the food consumed in developing countries is still produced by semi-subsistence farmers. The projected growth in the demand for animal products therefore offers opportunities for the rural poor since they already have a significant stake in livestock production. Unfortunately, until now the large majority of the rural poor have not been able to take advantage of these opportunities. Thus far, the main beneficiaries have been processors and traders, middle-class urban consumers, and a relatively small number of large producers in high-potential areas with good access to markets (FAO, 2015).

Goat meat is an important food source in developing countries (Casey and Webb, 2010). The concept of quality is an interesting and never-ending point of debate. A commodity's "quality" is again a perception. However, the most interesting part of quality is that it has no boundaries, but it does have an extent or range, that can be set in different planes. Goat meat is almost universally acceptable, but with cultural traditions and social economic conditions influencing consumer preferences (Norman, 1991; Casey *et al.,* 2003). Most goat meat is consumed as blocks/chunks of meat where aspects such as tenderness and other quality attributes typically prised in Western consumer cuisine is of lessor importance, yet it is these attributes that will increase the value of goat meat for the producer.

In a South African context, goat meat will always compete with beef, mutton, pork, and poultry (Roets, 2002). Some important factors that make the goat a successful meat-producing animal, especially under extensive systems, is the ability to graze and utilize poor forages (e.g., they tend to browse much more than other domesticated livestock making them well adapted to harsh overgrazes areas with limited grass and with their pedal stance browsing behaviour they also can utilize scrubs and bushes in mountenous areas normally inaccessible to other livestock); short generation intervals and high reproductive rates; the feasibility of herding by children and women due to the flock instinct; and their ability to stand droughts (Roets, 2004). Although goats have potential to become important

meat-producing livestock, there is limited information on “indigenous” goat meat quality (Mahanjana and Cronje, 2000), whilst some research has been conducted on the Boar Goat (BG) (Chapter 2). Traditionally “indigenous” goats were classified under one umbrella although they consist of a variety of breeds and their performance was underestimated. To access their potential in becoming a commercial commodity it is important to identify the different eco-types and study them in more detail as pertaining to goat meat characteristics and meat quality. Factors that require more research include *ante-mortem, mortem,* and *post-mortem* interventions such as the effect of *pre-slaughter* (castration) and *post-slaughter* procedures (electrical stimulation (ES) vs. no-stimulation (NS)). To better understand the causes of the effect of these interventions, more insight on the calpain system related to ageing in the major muscles was sought. Profiling the chemical composition including the volatile chemicals and resultant sensory characteristics in different muscles in BG and large frame Indigenous Veld Goats (IVG) will provide this insight.

The study was composed of two phases, as some goat muscles are too small to perform all envisaged analyses. The first phase of the study was to describe the factors influencing the tenderness, and colour attributes of six muscles (*Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST)) of weaner male Boer Goats and large frame Indigenous Veld Goats (Chapter 4). The second phase of the study was to evaluate the effect of breed-types and castration on carcass characteristics (Chapter 3, published as Van Wyk *et al.,* 2020); to evaluate the effect of breed-types, castration and electrical stimulation (ES) on meat tenderness and the calpain system related to ageing (Chapter 5), on the *pre-rigor* muscle energy profile (Chapter 6) and meat colour (Chapter 5), and on the volatile profile and resultant sensory characteristics (Chapter 7) of the *Longissimus thoracis et lumborum* (LTL) and *Semimembranosus* (SM) muscles in weaner male BG and large frame IVG.

8.1.1. Carcass characteristics

The carcass characteristics performed in Chapter 3 laid the foundation of the study. Although the BG is the most popular goat breed globally for meat production (Owen and Norman, 1977; Casey, 1992), the results of this study showed that, under the same production conditions large frame IVG had similar potential for goat meat production (Chapter 3 and Van Wyk *et al.,* 2020). Large frame Indigenous Veld Goats are a group of specific pure-bred indigenous eco-types represented by the Indigenous Veld Goat Breeders’ Society (https://www.indigenousveldgoats.co.za, accessed, 1 January 2021) that define specific standards that a goat must adhere to before it can be classified as one of the eco-types such as the Cape Lob Ear and the Cape Speckled goats (registered as a breed at Studbook). Both of these eco-types have large frames and can compete with the BG with regards to meat yield, with added perceived advantages such as adaptability to harsh climates and disease resistance. Interesting, more differences in carcass characteristics were observed between the wethers and bucks rather than between the two breed types (Table 3.1). Goat meat is generally

considered lean meat that is an ideal protein source for health-conscious groups that try to limit their fat intake. Large frame IVG bucks seemed particularly suited for higher meat yield which is leaner with lower subcutaneous and intramuscular fat (SCF and IMF), compared to the BG bucks and, in particular, the wethers of both breed types. The latter tend to accumulate more SCF and IMF. Nonetheless, IVG wethers had the lowest chilling loss (Table 3.1) and the highest proportions of SCF in all of the commercial cuts (Table 3.2); a finding that supported the argument that higher levels of SCF reduce chilling losses (Ragni *et al.,* 2015; Rotondi *et al.,* 2018; Colonna *et al.,* 2020). High chilling losses are undesirable as they reduce the weight and the economic value of the carcasses as seen between the BG bucks and IVG wethers. The general trend in commercial goat production is to use cuts similar to that in lamb (Wilson, 1992). Within the carcasses, the leg and shoulder seem to be the most ideal high-value cuts in terms of saleable meat yield due to their exceptional lean and low-fat levels, and their lean meat to bone ratios. The possibility however exists that the quality (particularly tenderness) of these cuts might not be ideal when the market is for fresh meat.

8.1.2. The intrinsic characteristics of the six different muscles

The intrinsic characteristics of the six different muscles; *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM), *Biceps femoris* (BF), *Supraspinatus* (SS), *Infraspinatus* (IS), and *Semitendinosus* (ST) differed from each other with variations found in meat characteristics such as pH, temperature, water holding capacity, drip loss, myofibril fragment length, intramuscular fat, connective tissue characteristics, and Warner-Bratzler shear force. The amount of collagen solubility did not differ between the different muscles, wheras the total collagen measured in each muscle type did differ. The LTL muscle had the highest WBSF compared to the other muscles (Table 4.3). The IS muscle presented the lowest WBSF values at 1 day *post-mortem* as well as the SM muscle at 4 days *post-mortem*. The toughest muscles were the LTL, BF and ST with shear values in the range of 50.0 N to 60.0 N at 1 day *post-mortem* whilst some tenderisation at 4 days *post-mortem* was noted. The BF, IS, SS, and ST goat muscles only tenderised slightly over a period of 3 days *post-mortem* whilst the LTL and SM had the ability to tenderise more over the same period. The myofibril fragmentation is representative of proteolytic activity and explained the WBSF values measured in the LTL, ST, IS and SS. However, according to the MFL measured in the LTL, this muscle should have been more tender compared to most of the other muscles, indicating that other factors influenced the tenderising process at slaughter. These could include *post-mortem* procedures such as ineffective ES, chilling, or differing/inappropriate cooking methods.

Compared to extensive studies on the influence of muscle source on colour attributes in other livestock, only limited studies examined this phenomenon in chevon meat (Babiker *et al.,* 1990; Dhanda *et al.,* 1999; Pophiwa *et al.,* 2016). An interesting observation made in this study is that the LTL and SM muscle had similar soluble collagen and similar colour attributes. It could be recommended, that for future studies instead of focusing on the LTL and SM as done in Phase 2 of the present study, the focus could be on other muscles (BF, IS, SS, and ST) compared to LTL and /

or SM to determine the effect of muscle types on biochemical and meat quality traits. This approach will allow more informed decisions to support muscle-specific marketing / consumption strategies, which may be used to improve consumer acceptability of chevon. Although it should be borne in mind that these latter muscles tend to be smaller than the LTL and SM and to develop a specific intervention that will improve their quality attributes whilst not decreasing that of the larger muscles could be challenging.

8.1.3. Applying different *pre-* and *post-slaughter* procedures

Dressing percentage is both a yield and financial value-determining factor (Warmington and Kirton, 1990) and is affected by factors such as age, weight, level of nutrition, the degree of gut fill at slaughter, head and skin weight, fatness, and dressing procedures (Kadim *et al.,* 2003; Simela *et al.,* 2011; Gökdal, 2013). Castration normally slows down the growth of an animal by increasing the rate of deposition of adipose tissue (fat) to the detriment of the muscular tissue (meat) on the carcass at slaughter (Mahgoub *et al.,* 2011). This phenomenon also explained the higher percentage of kidney fat in wethers compared to that of the bucks in the current study. In addition, it is likely one of the main reasons for differences in DP between the two sexes. Sex was shown to be the main factor determining the tenderness results of all the muscles studied. Both LTL and SM muscles of buck were less tender than that of the wethers and calpastatin (higher values for bucks) could explain these sex-related differences for WBSF values. In Chapter 4, wethers' muscles were less red, displayed lower Chroma and higher Hue angle than bucks for BF, IS, LTL, SM, and SS muscles at 1 day *post-mortem* with corresponding higher pH_u in comparison to bucks. Mostly, the meat colour became similar between bucks and wethers after 4 days *post-mortem* ageing except for the IS, SM, and SS that maintained their colour differences. It is known that energy status immediately after slaughter has an influence on meat colour and tenderness (Monin and Sellier, 1985; Scheffler *et al.,* 2011). In addition, it could be suggested that IVG wethers are more prone to *ante-mortem* stress as most muscles had higher pH_u and appeared darker, suggesting that wethers may have had less muscle energy at slaughter compared to bucks (Chapter 4) and this could largely be associated with stress and adrenaline releases (Gardener *et al.,* 1999). This aspect should warrant further research. In Chapter 6, the influence of castration on diminishing the glycolytic potential might be an indication that it is not a *pre-slaughter* option for IVG wethers. The animals in the present study had all been castrated by the age of three months when they entered the trial, although the specific age of castration is not known. This phenomenon should be studied further as the length of the carcass will have an influence on the weight of high value cuts available for sale (Chapter 3, and Van Wyk *et al.,* 2020), and it is known that age of castration influences bone growth (Shahin *et al.,* 1992).

Electrical stimulation (ES) might not be effective if the application technique is not done properly and also used in conjunction with various management practices such as chilling regimes. In both LTL and SM muscles, the pH decline was accelerated by ES resulting in the pH differing significantly between ES and NS at all-time points evaluated. Both LTL and SM muscles from the

ES carcasses avoided the cold shortening window and had reached their pH_u before the carcasses' temperatures had decreased to 10°C. The fact that the higher pH_u were measured in NS muscles might indicate that *rigor-mortis* was not yet concluded at the time of measurement. Furthermore, the present results suggested that the ES treatment caused an acceleration of glycolysis and subsequent early *rigor-mortis* development. Despite extensive research on ES, the fundamental mechanisms and the appropriate commercial applications however remain obscured as applied to chevon.

8.1.4. Chevon quality

The term "meat quality" includes many attributes; texture and colour are important attributes to consumers, with texture the most important. Tenderness and mechanical properties of meat are influenced by the connective tissue, myofibrils, and their interactions (Sacks *et al.,* 1988; Listrat *et al.,* 2016). Evaluating the tenderness and calpain system during a refrigerated ageing period in the LTL and SM muscles of electrical stimulated and non-stimulated carcasses of BG and large frame IVG from wethers and bucks confirmed that the breed types did not differ in tenderness, but castration does have an advantageous effect on tenderness (Chapter 5). Wethers might result in a juicier meat product compared to bucks (Chapter 7), although concerning tenderness and meat colour differences were not significant under these specific slaughtering conditions. The choice of using only 20 seconds of ES proved to be too short and is deduced to be the cause of the tougher meat in this study (Chapter 5). The meat was however considered to be acceptable after 4 days *post-mortem* ageing. Therefore, further research is required to define the intensity and duration of ES, which would produce optimum goat meat quality. The process of ageing generally improved the colour in goat meat.

Warner-Braztler shear force values of ES carcasses were also more favourable compared to NS carcasses (Chapter 5). Differences between the breeds were minimal for collagen characteristics (Chapter 4) and proteolytic activity (Chapter 5) leading to similar tenderness and meat colour (Chapter 5). At 4 days *post-mortem* in the SM muscle, the MFL differed between breeds (trend only), sex and treatments, indicating that evaluated goat muscles reacted differently to the specific *pre-* and *post-slaughter* treatments evaluated.

Short sarcomere length could be an indication of excessive muscle contraction caused by high muscle energy levels at very low muscle temperatures (cold shortening) resulting in tougher meat. This phenomenon is frequently a cause of goat meat toughness during commercial *post-slaughter* chilling conditions (Webb *et al.,* 2005; Kannan *et al.,* 2014). In the present study, sarcomeres were on average ~1.85 µm (Table 5.4) and had shortened by 15 to 18 %; this differs from that reported for goats in South Africa that shortened between 5 and 10 % (Pophiwa *et al.,* 2017) or 20 to 40 % (Simela, 2005). It is postulated for beef that sarcomere length (SL) longer than 1.7 µm does not influence tenderness, however results of the current study indicate this is most likely different for goat meat.

Post-slaughter ES could be the reason why no single attribute measured could be identified as being the cause of the meat quality (tenderness and meat colour) differences between the different muscles (Chapter 4). The exogenous and endogenous factors affecting tenderness, colour and colour stability are not exclusive, but are rather interrelated. Further research is required to increase awareness of the role the calpain and other proteolytic systems play in different goat muscles and the factors affecting meat tenderness as the current study suggests that the proteolytic activation occurred at a later stage than in other species.

8.1.5. Volatile aroma and sensory panel

A total of fifteen volatile compounds were identified and quantified in the LTL and SM muscles (Chapter 7). The identified volatile compounds included six alcohols, six aldehydes, one carboxylic acid, one aromatic and one ketone. Overall, no clear relationship could be established between the volatile compounds and sensory flavours. The scores for the various sensory attributes were low (<4.00), apart from goat aroma and goat like flavour (>4.00). In addition, the results from the present study suggested that breed and sex had an impact with BG indicating stronger evidence of being sweet compared to IVG, which had a stronger impression of being gamey and musty. Significant stronger goat aroma, metal and sour flavour attributes were detected for bucks, with wethers presenting a stronger sweet and ram / boar taint flavour. Overlapping of the treatment groups (breed x sex) presented by the PCA (Figure 7.1) indicated that they were very similar and barely distinguishable.

8.2. Additional thoughts and recommendations

What is in a name? It sounds absurd, but many people seem to have success selling goat if they call it anything other than ‘goat’. Some consumers struggle with the concept of eating ‘goat’ or ‘kid’. Perhaps they are too charming? But so are lambs. Perhaps they think its stinky, tough meat, but we have a resurgence in eating mutton, so why not goat? Whatever the reasons, producers are finding creative ways to get around the problem, such as naming goat meat ‘chevon’ or ‘cabrito’ or running tasting sessions, since once someone has tried it and enjoyed it they are more likely to make a repurchase. Overall, it seems as if the sensory panel found the LTL and SM muscles tough (Chapter 5), although the shear force measurements was not exactly in line with their findings. As mentioned before, the slaughter conditions could have been chosen better, for instance the ES should have been 30 seconds and not 20 seconds, as better WBSF scores were observed in the study of Pophiwa *et al.* (2016) where the ES was applied for a longer period. I do recommend though that if a future sensory panel study is done, mutton should be included to remove the possibility of biasness. Although I have no reason to doubt the professionalism of the panel, I do think that there could be a possibility of a negativity towards goat meat.

Research on several fields, considering goat breeds from South Africa, are not yet so extensive as compared to other livestock species. Therefore, further research on these breeds are encouraged as the scientific generated information could help breeders and society on their education and raising global awareness of the species. The term “indigenous” goats is very broad, and should be defined more scientifically. Are we working with BG crosses or do we try to work with better defined breeds such as larger frame Cape Speckled or the Cape Lob Ear? Or a mixture of these two, Indigenous Veld Goats (IVG) - a collective name for the eco-types conserved by the Indigenous Veld Goat Society of South Africa? The question will probably not be which breed is the best, but rather which conditions will be the best for goats to grow optimally and with less stress and starting with a good quality animal in the first place. The present study showed that it is very important to use the correct *pre-* and *post-slaughter* conditions to process goats. Wrong procedures could give way to negative perceptions on this commodity. Information acquired from these and future research should be disseminated to the farmers, producers and specific abattoirs that apply to special slaughter facilities and management for chevon production.

A possible research area to expand could be to define more complex criteria in terms of minimum handling conditions for goats from the point of sale to slaughter in order to minimise stress to the animals and hence the occurrence of high pH chevon. Further, studies should consider transportation and lairage conditions that would minimise *ante-mortem* stress (e.g., keeping animals overnight at the abattoir, with feed available until slaughter as in the present study the goats were taken to the abattoir the morning of slaughter, with the supply of water and to wait without feed until slaughter. In addition to reduce stress, goats should be slaughtered one by one without seeing each other. Any goats that do not meet the set criteria should not be accepted for chevon production, granting the meat could be given another name. In addition, an integrated farm-to-fork approach is required to ensure chevon of acceptable quality in the meat market.

This study again emphasised that goat meat is healthy with lower subcutaneous fat. It would be interesting to evaluate with a consumer panel, if it has sufficient IMF to make the meat palatable. Further, it could be proposed to see what the effect of natural browsing / grazing (the diet) influences volatile compounds and sensory attributes, as the goats from the current study had been fed a diet that was limited in browse plant species and the insight will provide an improved understanding of sensory attributes of chevon of these flavour-contributing chemical species and processes as to provide valuable guidance for developing meat (chevon) products with a better quality and taste.

An aspect that came to the front within this study is that young animals are not as readily available as one would have liked – it was very difficult to source sufficient animals. It was shown that especially the specialised eco-types are very limited. In fact, discussion within the red meat production industry as well as within the retail industry, would seem to indicate that a constant source of quality chevon is a major limitation for the growth of the industry. The cause of this limitation is not known, and it is recommended that studies evaluating the production efficiency as well as the profitability of different goat production systems be conducted to see whether chevon production

systems are economically sustainable. It is a given that such studies will also include the form of the end product and whether the focus should be on production of fresh meat where meat quality aspects are of importance, or whether the focus should be producing meat that is typically consumed as chunks / block of meat. In the latter, sensory quality (e.g., tenderness and chilled shelf-life) is not always of high importance.

The future of goat meat is an important nutrient source to a large part of the world population is indisputable. Continued research is not only required in production efficiency (reproduction, growth, nutrition, performance testing) but also in adaptability to a changing climate. In addition, insight on meat quality characteristics and muscle profile data will allow more informed decisions to support muscle-specific processing and marketing strategies, which may be used to improve consumer acceptability of chevon. Goat meat is a nutrient dense food, but the complimentary role of goat meat in local diets, taking lifestyles and customs into consideration (traditional slaughter vs. normal meat consumption), should be quantified. Dietary recommendations could then be drafted. Development of the formal commercial market for goat meat would offer more diversity of species for red meat producers and especially benefit smallholder farmers who typically produce most of the goats in the world.

8.3. References

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