Meat Quality Characteristics of Giraffe (*Giraffa camelopardalis angolensis*)

by

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DECLARATION

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SUMMARY

Although some giraffe populations are threatened, their numbers have been seen to grow exponentially under ranched management conditions. This population growth can be attributed to the absence of natural predators and therefore periodic culling is essential to control their population numbers and thus prevent them from exceeding carrying capacity. These culls result in a large quantity of meat, of which very little is known of the quality. This study aimed to quantify the effect of sex on the yields of fresh cuts from giraffe, and the meat quality thereof as well as the yields and chemical composition of the red offal. For this study sixteen giraffe (*Giraffa camelopardalis angolensis*) (eight male; eight female) were culled, the majority were relatively young (2½ – 6 years old), however, one female was found to be mature (± 9 years), her data was therefore removed from all analyses except the sensory analysis, to avoid the effect of age.

Various body measurements and commercial carcass yields were investigated to quantify the effect of sex there upon. The dead weight and carcass weight was not significantly affected by the sex, however, the males did tend to be heavier (dead weight: males = 691.1 ± 45.47 kg; females = 636.5 ± 33.76 kg; $P = 0.096$; carcass weight: males = 393.1 ± 28.52 kg; females = 359.5 ± 14.49; $P = 0.053$). The giraffe were found to have a favourable dressing percentage of ~57 % for both sexes. The foreleg measurements and horn measurements were all larger for the males than the females ($P < 0.05$), despite the relatively young age.

The moisture % of the red offal (heart, liver, kidneys and tongue) averaged ~76 %, the protein % averaged ~17 %, the total fat % averaged ~5 % and the ash % averaged ~1 % across both sexes of the giraffe. The red offal had a favourably high protein content as well as a low fat content, which when combined with the high yields thereof per animal, indicates that giraffe offal can serve as a source of low cost protein.

The meat yields were investigated, and eight muscles (*Longissimus thoracis et lumborum* muscle (LTL), *Semimembranosus* muscle (SM), *Biceps femoris* muscle (BF), *Semitendinosus* muscle (ST), *Gluteus medius* muscle (GM), *Supraspinatus* muscle (SS), *Infraspinatus* muscle (IS), and *Psoas major* muscle (PM)) were removed from each giraffe and the physical meat quality thereof was assessed. The Warner-Bratzler shear force (WBSF) was affected by a significant interaction between sex and muscle ($P < 0.001$), the interaction for the CIE L* values also tended towards significance ($P = 0.054$). The cooking loss (male = 41.6 ± 0.35 %; female = 40.7 ± 0.33 %; $P = 0.024$) was found to be higher in males. Muscle had a significant effect on all physical parameters. The ultimate pH of all muscles was in the acceptable range (5.5 – 5.9); the WBSF of all the samples was found to be <43 N which is

classified as tender. The meat colour was lighter than most game meat; the myoglobin content of the muscles was found to range from 5.1-9.3 mg/g with a significant interaction between sex and muscle (P = 0.001) with higher myoglobin levels resulting in lower L* values and hue-angles.

The chemical composition of the eight muscles was assessed in terms of moisture (77.2 ± 0.09 g/100 g), protein (20.8 ± 0.09 g/100 g), intramuscular fat (IMF) (1.4 ± 0.03 g/100 g) and ash (1.1 ± 0.01 g/100 g). There was a significant interaction between sex and muscle for the moisture (P = 0.044), protein (P = 0.045) and ash (P = 0.042) contents, while muscle (P <0.001) had an effect on the fat content. The mineral content of the bone, liver and LTL muscle was also analysed, the bone was found to have a calcium to phosphorus ratio of 2:1 despite a diet low in phosphorus. The liver and LTL were both high in iron and other essential micro- and macro-minerals.

The sensory profile of the LTL muscle of the giraffe as affected by sex was assessed on a 100-point line scale. It was found that the instrumental tenderness of the giraffe meat was considered tough (WBSF >53 N), however, this did not have a strong correlation (r = - 0.616; P = 0.011) with sensory tenderness (~52). The effect of sex was limited, but the males were found to have a higher gamey and metallic aroma, while the females had a higher liver-like flavour than males. The panellists reported to find high intensities of the metallic (~23), sour- (~14) and sweet- (~25) associated and black pepper (~9) attributes of the giraffe meat in this study. The fatty acid profile of the LTL muscles was also analysed and it was found that both sexes had a low intramuscular fat (IMF) content (1.4 - 1.7 %). The polyunsaturated fatty acid to saturated fatty acid (PUFA:SFA) ratios and the n-6:n-3 PUFA ratios as well as the Atherogenicity index were favourable for inclusion in a healthy diet.

This study also investigated the effect of post-mortem aging on the tenderness and other physical parameters of the LTL, SM and BF steaks from male and female giraffe in order to determine the ideal ageing period. The tenderness improved until day 22 (19.1 ± 0.30 N) of the 38 day ageing period, after which it plateaued. The colour improved, in terms of redness and saturation, until day 18 (L* = 44.1 ± 0.29; chroma = 22.0 ± 0.15), thereafter discolouration occurred. There was progressive purge loss throughout the ageing period. Therefore, it is recommended to vacuum-age giraffe meat for no more than 18 days.

OPSOMMING

Alhoewel sommige kameelperd populasies bedreig word, kan hulle getalle eksponensieel groei onder boerdery bestuuromstandighede. Hierdie populasie groei kan toegeskryf word aan die afwesigheid van natuurlike roofvyande en dus is periodieke uitdunning noodsaaklik om hulle bevolkingsgetalle te beheer en sodoende te voorkom dat hulle die drakrag oorskry. Hierdie oespraktyke lei tot die oplewering van groot hoeveelheid vleis met steeds onbekende kwaliteit eienskappe. Die doel van die studie was om die effek van geslag op die opbrengste van vars snitte en die vleiskwaliteit daarvan te kwantifiseer, asook om die opbrengste en chemiese samestelling van die rooi afval van kameelperd te bepaal. Vir hierdie studie is sestien kameelperde (*Giraffa camelopardalis angolensis*) (agt manlik; agt vroulik) geoes, die meerderheid van hierdie diere was relatief jonk (2½ - 6 jaar oud), maar daar was egter een vroulike volwasse dier wat as ’n uitskieter hanteer was (± 9 jaar). Hierdie individu se data was dus uit alle ontledings verwyder, behalwe die sensoriese analise om die effek van ouderdom te ontwyk.

Verskeie liggaamsmetings en kommersiële karkasopbrengste was ondersoek om die effek van geslag daarop te kwantifiseer. Daar was nie noemenswaardige verskille tussen die dooiegewig en karkasgewig van manlike en vroulike diere gevind nie, die manlike diere was egter geneig om swaarder te wees (dooie gewig: mans = 691.1 ± 45.47 kg; vroulike diere = 636.5 ± 33.76 kg; P = 0.096; karkasgewig: mans = 393.1 ± 28.52 kg; wyfies = 359.5 ± 14.49; P = 0.053). Beide manlike en vroulike kameelperde het gunstige uitslagpersentasies getoon (~57 %). Die manlike diere het langer voorbeenmetings en horingmetings as die vroulike diere (P <0.05) getoon ongeag die relatiewe jong ouderdom.

Die gemiddelde vog, proteïen, totale vet en as persentasie van die rooi afval (hart, lewer, niere en tong) was ~76 %, ~17 %, ~5 %, ~1 %, onderskeidelik vir beide geslagte van die kameelperd. Die rooi afval het 'n gunstige hoë proteïeninhoud sowel as 'n lae vetinhoud gehad wat tesame met die hoë opbrengste per dier daarop dui dat kameelperdafval kan dien as ’n bekostigbare proteïene bron.

Agt spiere (*Longissimus thoracis et lumborum* muscle (LTL), *Semimembranosus* muscle (SM), *Biceps femoris* muscle (BF), *Semitendinosus* muscle (ST), *Gluteus medius* muscle (GM), *Supraspinatus* muscle (SS), *Infraspinatus* muscle (IS), and *Psoas major* muscle (PM)) van elke dier was verwyder, waarvan die opbrengste en fisiese vleiskwaliteit bepaal is. Die Warner-Bratzler skeurkrag (WBSF) was beïnvloed deur 'n beduidende interaksie tussen geslag en spier (P <0.001), die interaksie van die CIE L* waardes was ook geneig om betekenisvol te wees (P = 0.054). Die kookverlies van manlike diere (manlik = 41.6 ± 0.35 %; vroulik = 40.7 ± 0.33 %; P = 0.024) was hoër as die van die vroulike diere. Spiere het 'n beduidende effek op alle fisiese eienskappe gehad. Die uiteindelike pH van al die spiere was in normale

grense (5.5 – 5.9); daar is gevind dat die WBSF van alle toetssnitte <43 N was, en kan as sag geklassifiseer word. Die vleiskleur van die spiere was egter ligter as die van meeste wildsspesies. Daar was ook gevind dat die mioglobieninhoud van die spiere tussen 5.1 en 9.3 mg/g gewissel het met 'n beduidende interaksie tussen geslag en spier (P = 0.001) met hoër mioglobienvlakke, wat gelei het tot laer L * waardes en kleurtoon.

Die chemiese samestelling van die agt spiere was bepaal deur die vog- (77.2 ± 0.09 g/100 g), proteïen- (20.8 ± 0.09 g/100 g), intramuskulêre vet- (IMF) (1.4 ± 0.03 g/100 g) en asinhoud (1.1 ± 0.01 g/100 g) te kwantifiseer. Daar was 'n beduidende interaksie tussen geslag en spier vir die vog- (P = 0.044), proteïen- (P = 0.045) en asinhoud (P = 0.042), die spier (P <0.001) 'n effek op die vetinhoud gehad het. Die mineraalinhoud van die been, lewer en LTL was ook ontleed, en daar is gevind dat die been 'n 2:1 verhouding van kalsium tot fosfor gehad het, ongeag 'n dieet met 'n lae fosforinhoud. Die lewer en LTL was albei hoog in yster en ander essensiële mikro- en makrominerale.

Die sensoriese profiel van die kameelperd se LTL spier, wat deur geslag beïnvloed was, was op 'n 100 punt lynskaal geassesseer. Daar is gevind dat die instrumentele sagtheid van die kameelperdvleis as taai beskou kan word (WBSF >53 N), maar dit het nie 'n sterk korrelasie (r = - 0.616; P = 0.011) met die sensoriese sagtheid gehad nie (~52). Die effek van geslag was nie prominent nie, maar daar is gevind dat die manlike diere 'n hoër wild- en metaalagtige aroma getoon het, terwyl die vroulike diere 'n hoër leweragtige smaak gehad het as die manlike diere. Volgens die paneellede was daar hoë intensiteit van metaal- (~23), suur- (~14), soet- (~25) en swartpeper (~9) kenmerke van die kameelperdvleis in hierdie studie. Die vetsuurprofiel van die LTL spier is ook ontleed en daar is gevind dat beide geslagte 'n lae inhoud van intramuskulêre vet (IMF) (1.4 – 1.7 %) gehad het. Die verhoudings van poli-onversadigde vetsure tot versadigde vetsure (PUFA: SFA) en die n-6: n-3 PUFA-verhoudings, sowel as die Atherogene (Atherogenicity) indeks was gunstig vir die insluiting in 'n gesonde dieet.

Hierdie studie het ook die effek van post-mortem veroudering op die sagtheid en ander fisiese eienskappe van die LTL, SM en BF toetssnitte van manlike en vroulike kameelperde ondersoek om die ideale verouderingstydperk te bepaal. Die sagtheid het verbeter tot dag 22 (19.1 ± 0.30 N) van die 38 dae verouderingsperiode, waarna dit afgeplat het. Die kleur het, ten opsigte van rooiheid en kleur intensiteit verbeter tot op dag 18 (L * = 44.1 ± 0.29; chroma = 22.0 ± 0.15), daarna het verkleuring plaasgevind. Daar was progressiewe vogverlies gedurende die verouderingsperiode. Daarom word dit aanbeveel dat kameelperdvleis nie langer as 18 dae onder vakuum toestande verouder moet word nie.

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ABBREVIATIONS

Abbreviation	Expansion
°C	Degrees Celsius
%	Percentage
Φ	Diameter
ANOVA	Analysis of Variance
BF	*Biceps femoris* muscle
CIE	International Commission on Illumination
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
cm	Centimetre
DFD	Dark, firm, dry
DSA	Descriptive sensory analysis
FAME	Fatty acid methyl esthers
g	Gram
GIT	Gastro-intestinal tract
GM	*Gluteus medius* muscle
IMF	Intramuscular fat
IS	*Infraspinatus* muscle
IUCN	Union for Conservation of Nature
kg	Kilogram
LTL	*Longissimus thoracis et lumborum* muscle
m	Metre
mm	Millimetre
mg	Milligram
MUFA	Monounsaturated fatty acids
N	Newton
n	Number
n6:n3	Omega-6 to omega-3 ratio
pH_u	Ultimate pH
PM	*Psoas major*
PUFA	Polyunsaturated fatty acids
PUFA:SFA	Polyunsaturated to saturated fatty acid ratio
r	Pearson's correlation coefficient
SFA	Saturated fatty acids
SM	*Semimembranosus* muscle
SS	*Supraspinatus* muscle
ST	*Semitendinosus* muscle
v/v	Volume to volume ratio
WHC	Water-holding capacity
WBSF	Warner-Bratzler shear force
µl	Microliter

NOTES

This thesis is presented in the format prescribed by the Department of Animal Sciences, Stellenbosch University. The language, style and referencing format used are in accordance to the requirements of the journal of Meat Science. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, therefore, been unavoidable.

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

There is much debate over the taxonomy of giraffe, the current consensus is that there are nine different subspecies of the *Giraffa camelopardalis* species (Brown *et al.*, 2007; Dagg, 1962; Dagg 2014; Lydekker, 1904; Muller *et al*., 2018). Giraffe have recently been declared a "threatened" species by the Union for Conservation of Nature (IUCN) Red List of Threatened Species (Muller *et al*., 2018), however, the populations of five of the subspecies of giraffe have been seen to be increasing over the last 30 years (Muller *et al*., 2018). Of these growing subspecies populations, the two southern African subspecies (*G. c. angolensis* and *G. c. giraffa*) having the healthiest populations in terms of both numbers and growth (Marais *et al*., 2016; Dagg & Foster, 1982; Deacon *et al*., 2016). The growth of the southern African populations of giraffe may largely be attributed to the private farming thereof, as it has been seen that when kept in fenced areas, free of any natural predators, their populations grow exponentially, as up to 70 % of giraffe in the wild do not make it to maturity, due to predation (Lee *et al*., 2016). As the giraffe populations on farms are fenced, they only have access to limited vegetation, therefore, with population growth, culling becomes necessary in order to prevent the population from exceeding the carrying capacity. Farmers may cull the excess giraffe themselves, or sell them to trophy hunters, which both result in a large quantity of saleable meat, as the hunters seldom take the meat. There is currently very little information available on the quality of giraffe meat, other than Hall-Martin, Von La Chevallerie and Skinner's study (1977) in which the meat quality of the *Longissimus thoracis et lumborum* muscle (LTL) was assessed by means of muscle fibre analysis.

As the human population of Africa is currently growing exponentially, and there is already widespread malnutrition, there is a great need to find ways to provide for the nutritional requirements of this fast growing population. Southern Africa is currently a net importer of food (Conceicao *et al.*, 2011) despite a poor economy that is not able to sustain this. Therefore alternative local food sources need to be assessed. As the hot and arid climate of Africa is poorly suited to conventional livestock production, meat production from the multitude of naturally occurring game species, which are well adapted to these conditions, and able to utilise the poor quality forage, may be more sustainable. Game meat has been found to have a low fat content with a healthy polyunsaturated to saturated fatty acid ratio (Listrat *et al*., 2016), thus it is also a healthy alternative to traditional read meat species. There has been found to be a large degree of variation in meat quality between different game species, which necessitates the individual assessment of the nutritive value of the different species, in order

to determine its potential as an alternative source of meat. This study may therefore serve as baseline data on the nutritive value of giraffe meat.

The primary research question of this study is: Does the sex of giraffe influence the carcass yields and the quality characteristics of giraffe meat, in terms of the physical, proximate and sensory characteristics? The aim of the study was to investigate the effect of sex on the carcass yields, proximate composition of the red offal and the sensory profile of giraffe meat, and to determine the effect of sex and muscle on the meat quality (physical and chemical) as well as the effect of post-mortem ageing, on the physical meat quality of giraffe. The objectives of this study were as follows:

1. Evaluate available literature on the giraffe and assess the current management of giraffe on private game ranches and reserves in order to evaluate the suitability of giraffe as a meat source in South Africa and Namibia (Chapter 2).
2. Investigate the effect of sex on the body measurements of giraffe as well as the carcass weights (Chapter 3).
3. Investigate the effect of sex on the yields of the "fifth quarter" of giraffe, as well as quantifying the nutritional value of the red offal in terms of the proximate chemical composition (Chapter 4).
4. Investigate the effect of sex on the yields of various muscles from the giraffe and determine the decay model of the pH curve post-mortem for the giraffe as well as determine the effect of both sex and muscle on the physical meat quality parameters of giraffe (Chapter 5).
5. Determine the effect of sex and muscle on the proximate chemical composition of giraffe meat (Chapter 6).
6. Assess the effect of sex on sensory profile and fatty acid composition of giraffe meat by means of descriptive sensory analysis (DSA) and fatty acid methyl ester (FAME) analysis (Chapter 7).
7. Investigate the effect of post-mortem ageing on the physical meat quality characteristics of vacuum-aged steaks from three muscles of both sexes of giraffe in order to determine the ideal post-mortem ageing period to optimum tenderness (Chapter 8).

This study will provide baseline data on the meat quality of giraffe, this data can be utilised in order to assess the suitability of giraffe for production of fresh meat cuts and can be used in the marketing thereof.

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CHAPTER 2

GIRAFFE (*Giraffa camelopardalis angolensis*) MANAGEMENT ON PRIVATE GAME FARMS IN SOUTH AFRICA AND NAMIBIA

2.1 INTRODUCTION

The giraffe has fascinated biologists for hundreds of years, inspiring Lamarck's theory of inheritance (1809), with its incredibly long neck. Lamarck believed that the neck of the giraffe grew so long as each generation stretched their necks in order to reach the browse at the tops of trees, and the advancements gained during their life time was passed to their offspring. The evolution of the neck of the giraffe is still not fully understood, although there are two major contradicting theories. The more obvious theory is that the giraffe grew such a long neck in order to reach browse that is out of reach of other browsers with which they may compete (Wilkinson & Ruxton, 2012). However, as giraffe seldom browse at the full reach of their neck, showing a preference for browsing at shoulder height, where they compete with other large browsers (Du Toit, 1990; Leuthold & Leuthold, 1972; Young & Isbell, 1991), this is unlikely to be the case. The opposing theory postulates that the neck of the giraffe may have developed its length as the males with longer necks had a sexual advantage, as the necks are used for fighting for the right to mate (Simmons & Scheepers, 1996). Simmons and Scheepers supported this hypothesis with a study on a population of Namibian giraffe (*Giraffa camelopardalis angolensis*) in which they found that while the size of the neck plateaued in females after puberty, it continued to increase for males throughout their lifespan. However, in a study on a population of Zimbabwean giraffe (*G. c. giraffe*), any differences between the neck measurements between the sexes, could be attribute to generic sexual dimorphisms (Mitchell, van Sittert & Skinner, 2009).

While the question of why the long neck of the giraffe evolved remains unanswered, there is plenty of fossil evidence of how. The giraffe family, Giraffidae, were and are characterised as large ruminating artiodactyls, with horn-like ossicones, covered in vascularized skin protruding from the head (Dagg, 2014). Early giraffids were not characterised by a long neck, which is a relatively recent adaption. Giraffids migrated from Eurasia into Africa about 18 million years ago, where the last two remaining giraffids still live (Churcher, 1978; Mitchell & Skinner, 2003). The okapi (*Okapia johnstoni*) is the last living relative of the modern giraffe (*Giraffa camelopardalis*). The okapi, however, does not have the characteristic long neck and spotted pattern as giraffe, but rather has a relatively short neck and legs, dark brown coat and stripes like those of a zebra on its hindquarters (Bodmer & Rabb, 1992).

Churcher (1978) postulated that when the *Giraffa camelopardalis* first evolved about 4 million years ago, they spread throughout Africa, restricted only by dense forests and the cold in the south. The populations became isolated and, over the course of time, diverged into a number of distinct subspecies (Dagg, 2014). Fenessey and colleagues' (2016) findings suggest that there may be four separate species of giraffe, findings supported by the study by Winter, Fenessey and Janke (2018). However, there is, as yet, insufficient data to prove the separate species, and as organisations such as CITES (2019) and the IUCN (2018) are still treating giraffe as a single species with several subspecies, this is the taxonomic classification used throughout this study. The number of subspecies is also a matter of debate, with the current general consensus that nine distinct subspecies make up the giraffe species (*Giraffa camelopardalis*) (*G. c. angolensis, G. c. antiquorum, G. c. camelopardalis, G. c. giraffa, G. c. peralta, G. c. reticulate, G. c. rothschildi, G. c. thornicrofti* and *G. c. tippelskirchi*) (Brown *et al.*, 2007; Dagg, 1962; Dagg 2014; Lydekker, 1904; Muller *et al*., 2018).

While giraffe were once wide spread across Africa, the population has experienced a drastic decline over the past few decades, with their numbers dropping from 140 000 giraffe in Africa in the late 1990s (East, 1999), to about 80 000 over the next decade (Fennessy, 2012), which surmounts to a 40 % population decline. This has led the species as a whole to be classified as a 'threatened' species, by the Union for Conservation of Nature (IUCN) Red List of Threatened Species' latest amendment (2018). Although Winter and colleagues (2018), suggest that classifying giraffe as four species, would have a positive impact on giraffe conservation, as the three 'species' threatened with extinction (the northern giraffe, the reticulated giraffe and the Masai giraffe) could be reclassified on the IUCN Red List, which may increase conservation efforts, and the southern giraffe could be reclassified as "Least Concern". Giraffe as a single species have also been added to the Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which is the Appendix listing animals not necessarily threatened with extinction, but requiring controlled trade in order to avoid overutilization. CITES Appendix-II specimens:

- Require an export permit or re-export certificate issued by the Management Authority of the State of export or re-export.
- In the case of a live animal or plant, it must be prepared and shipped to minimize any risk of injury, damage to health or cruel treatment.
- No import permit is needed unless required by national law.

  (CITES, 2019)

The population decline is due to a number of largely region specific factors, therefore threatening specific populations to different extents. These factors include habitat loss through deforestation,

conversion of land, the expansion of agriculture, and population growth, civil unrest, poaching and ecological changes such as mining, and climatic changes (Muller *et al*., 2018). In West Africa the prevailing threats are habitat loss due to the growing human population and human-wildlife conflict. In Eastern and Central Africa the main threats are habitat loss as a result of land conversion for agriculture in order to meet the demands of the rapidly growing human population, drought, poaching and civil unrest. In Southern Africa the main threats are habitat loss due to development for human population growth and illegal hunting (Muller *et al*., 2018).

The historical distribution of giraffe across Africa is presented in Figure 2.1, while Figure 2.2 shows the current distribution, according to the IUCN Red List of Threatened Species, which is also presented in Table 2.1.

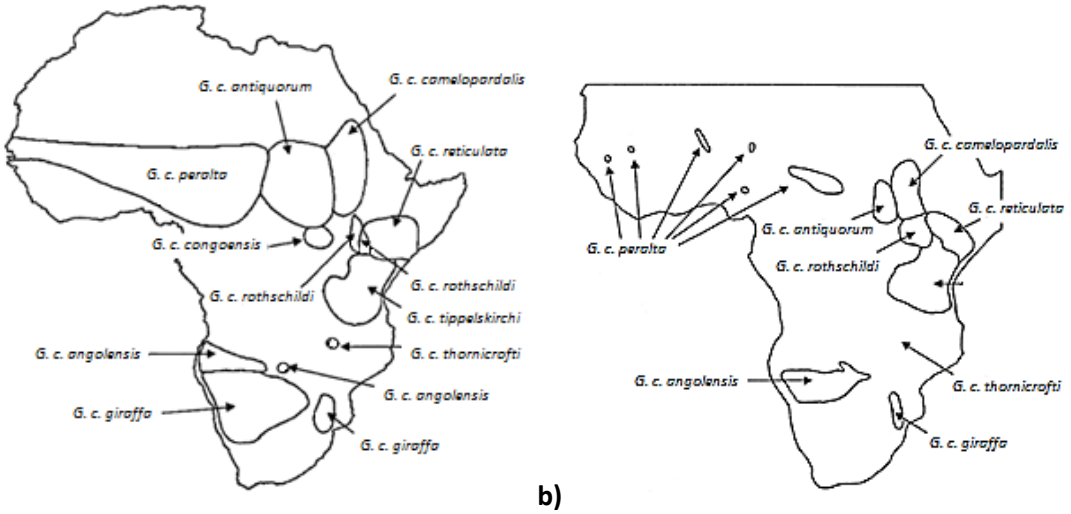

Figure 2.1 Historical distributions of giraffe subspecies. **a**, Subspecies of giraffe according to Krumbiegel (1939), based on the work of Lydekker (1904) and published by Seymour (2001). **b**, Subspecies of giraffe according to Dagg (1971), redrawn by Seymour (2001).

Figure 2.2 Current distribution of giraffe (*Giraffa camelopardalis*), adapted from the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Version 2019-2 (Muller *et al*., 2018).

Table 2.1. Giraffe (*Giraffa camelopardalis*) subspecies distribution and status in 2016 (from Muller *et al.*, 2018)

Subspecies	Common name	Region	Historic population				Current population			% change
			Status	Estimate	Year	Source	Estimate	Year	Source	
G. c. camelopardalis	Nubian	Northern and Eastern Africa (Ethiopia, South Sudan)	Decreasing	20 577	1979-1982	Wube *et al*. (2016)	650	2015	Wube *et al*. (2016)	- 97 %
G. c. tippelskirchi	Masai	Eastern Africa (Kenya, Tanzania)	Decreasing	66 449	1977-1980	Bolger *et al*. (2015)	31 611	2015	Bolger *et al*. (2015)	-52 %
G. c. thornicrofti	Thornicroft's	Eastern Africa (Zambia)	Stable	600	1983	Berry & Bercovitch (2016)	600	2015	Bercovitch *et al.* (2015)	0 %
G. c. reticulata	Reticulated	Eastern Africa (Kenya, Somalia, Ethiopia)	Decreasing	36 000-47 750	1990s	East (1999); Doherty *et al*. (2016)	8 661	2016	Doherty *et al*. (2016)	-77-82 %
G. c. rothschildi	Rothschild's	Eastern Africa (Uganda, Kenya)	Increasing	1 330	1960s	Fennessy *et al.* (2016)	1 671	2016	Fennessy *et al.* (2016)	26 %
G. c. angolensis	Angolan	Southern Africa (Namibia, Botswana)	Increasing	5 000	1970-2004	Marais *et al.* (2016)	13 031	2016	Marais *et al.* (2016)	161 %
G. c. angolensis (provisional)*	Angolan	Southern Africa (Namibia, Botswana, Zambia, Zimbabwe)	Increasing	10 000	1970s	Dagg & Foster (1982)	17 551	2016	Finnessy (Unpublished data)	76 %
G. c. giraffa	South African	Southern Africa (Zimbabwe, Mozambique, South Africa, Botswana)	Increasing	8 000	1979	Dagg & Foster (1982)	21 387	2016	Deacon *et al*. (2016)	167 %
G. c. antiquorum	Kordofan	Northern and Central Africa (Cameroon, Centeral African Republic, Chad, Democraticc Republic of Congo, South Sudan)	Decreasing	3 696	1975-1986	Fennessy & Marais (2016)	2 000	2016	Fennessy & Marais (2016)	-46 %
G. c. peralta	West African	West Africa (Niger)	Increasing	50	1990s	Fennessy *et al.* (2016)	400	2015	Fennessy *et al.* (2016)	700 %
Totals				**151 702- 163 452**			**97 562**			**-36-40 %**

*Population with uncertain taxonomic status, considered *G. c. angolensis* for the study

As seen in Table 2.1, despite the overall 40 % decline in numbers, the populations of some subspecies are increasing, with *G. c. peralta* showing the fastest growth, as a result of conservation efforts after it was the first of the subspecies declared 'Endangered' in 2008, by the IUCN (Dagg, 2014). The Niger government was, and is still, the only government to implement a National Giraffe Conservation Strategy, which has proved very successful in increasing their population of *G. c. peralta* over the last twenty years (Muller *et al*., 2018). The *G. c. rothschildi* subspecies was declared 'Endangered' in 2010, this population is also seen to be increasing as a result of the conservation measures of the Kenyan and Ugandan governments (Muller *et al*., 2018) (Table 2.1). However, the Southern African subspecies have arguably the healthiest population growth, with many giraffe translocations, repopulating former giraffe habitats. Southern Africa has a thriving wildlife industry consisting of both tourism and consumptive use in the form of legal hunting. In South Africa and Namibia the hunting of giraffe is legal and there are many private game ranches with large giraffe populations. These private game ranches frequently buy and sell giraffe to other farms, enabling gene flow between populations. Many of these private game ranches do not keep predators, or will not keep them in the same camp as the giraffe, therefore these populations grow rapidly. Giraffe typically lose between 50-70 % of their offspring to predation before they can reach maturity (Lee *et al*., 2016). As the giraffe on ranches are fenced into a limited area, and will have a rapidly growing population, with the lack of predation, they will reach carrying capacity, and cause over-browsing if the numbers are not controlled through culling or hunting.

2.2 BIOLOGY OF THE GIRAFFE

2.2.1 Growth and reproduction

The survival rate of mature giraffe is very high, due to their size and powerful legs with which they can deliver a fatal blow to an unwitting predator, it is consequently lion prides that are the only natural threat to a mature giraffe (Pienaar, 1969; Pratt & Anderson, 1979). The maximum age to which a wild giraffe has been reported to live to is 37.4 years old (Pacifici *et al*., 2013) while the general consensus is that in the wild giraffe generally live for less than 30 years (Bercovitch & Berry, 2009a; Dagg & Foster, 1982; Du Toit, 2009). According to Bercovitch and Berry (2009a), the average age at first calving is 6.4 years old, and the oldest recorded age of a giraffe giving birth in the wild was 24 years old. However, it is hard to know the exact age of giraffe in the wild, with the most accurate methods of age determination only possible after death (Hall-Martin, 1976). This makes it difficult to assess the age at which they reach maturity in the wild, as it is suspected that this age may differ to that of captive giraffe, however, according to Berry and Bercovitch (2012) male giraffe reach sexual maturity at 7 or

8 years of age. Female giraffe were reported to reach sexual maturity at an average age of 3 y 10 months ± 3 months, for captive animals, and 4 y 7 months ± 3 months for wild animals (Hall-Martin & Skinner, 1978). The age discrepancy between the captive and wild female giraffe reaching sexual maturity may be as a result of poor nutrition in the wild population, as this is known to delay puberty in mammals (Joubert, 1954; Sadleir, 1969), however, there is not enough data to confirm this.

Despite the age at which giraffe reach sexual maturity, they do not reach their mature weight until much later. The growth curve of giraffe was plotted by Hall-Martin (1975), as shown in Figure 2.3. From the commencement of puberty, the sexual dimorphisms in live weight and body measurements begin to become significant (Hall-Martin, 1975). Female giraffe reach a growth plateau at ± 11 years old, weighing between 700-1200 kg, and males reach their asymptotic mass at ± 12 years old and approximately 850-1950 kg (Hall-Martin, 1975; Bush, 2003).

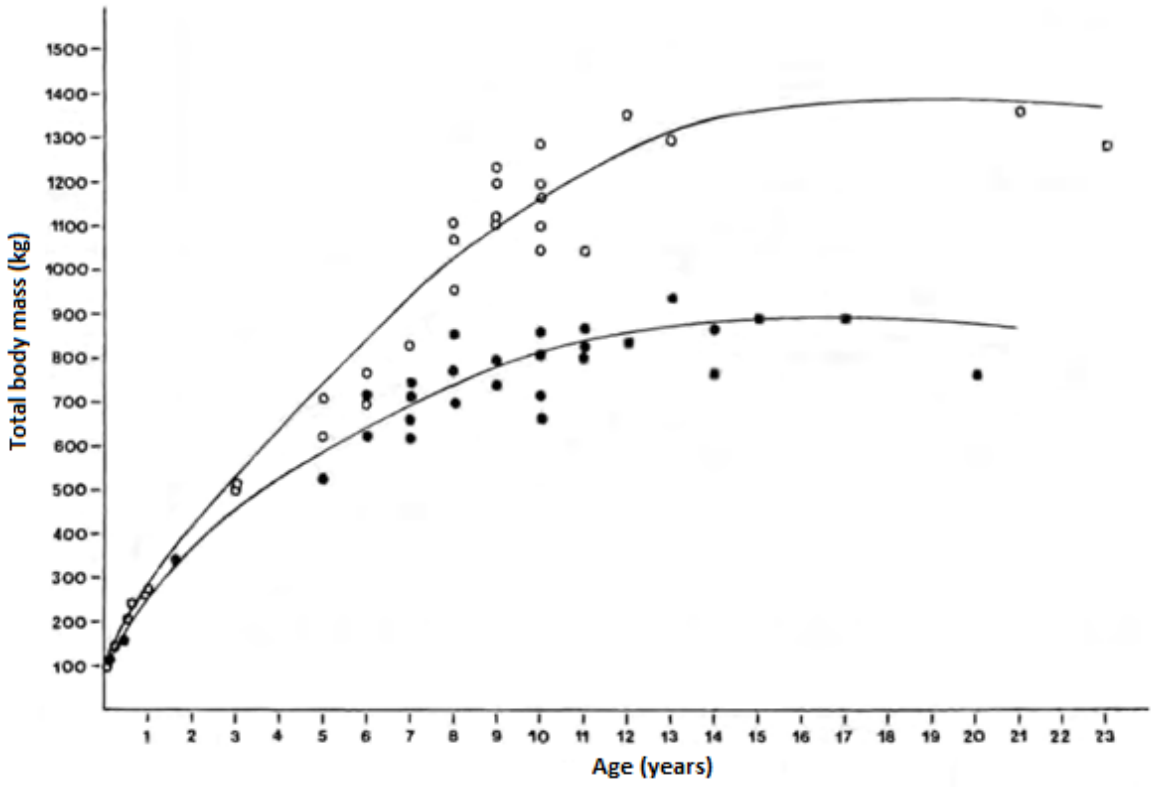

Figure 2.3 Total body mass for different ages of giraffe. Male (o), female (•). From Hall-Martin's study on Transvaal Lowveld giraffe (now Mpumalanga, South Africa) (1975).

Giraffe do not have a specific season in which they calf, but rather spread calving throughout the year, especially nearer the equator (Berry & Bercovitch, 2012; Leuthold & Leuthold, 1975; Pratt & Anderson, 1982). Whereas in South Africa breeding is more seasonal, with 60 % of conceptions dates occurring

between December and March, when vegetation was most plentiful (Hall-Martin, Skinner & van Dyk, 1975).

After the female giraffe starts her oestrus cycle at about 3 y 10 months age, she will cycle every two weeks until she becomes pregnant (Berry & Bercovitch, 2013), only allowing males to mount her while in oestrus. The gestation period of giraffe is approximately 446-457 days long (Del Castillo *et al*., 2005). The giraffe cow will begin to cycle again about three weeks post parturition, while she is still nursing her calf, and the average inter-calving period of Thornicroft's and Masai giraffe is 22.6 months (Bercovitch & Berry, 2009a; Leuthold & Leuthold, 1978). Twins are very rare and it is unlikely for both to survive in the wild.

Giraffe stand to give birth, which means that the calf drops approximately 2 m to the ground, breaking the umbilical cord, at which point the calf begins to breathe (Dagg, 2014). In the wild females will give birth away from the herd, only re-joining the herd a few days after birth. Calves will generally stand and suckle within the first hour or two after birth and are soon galloping around as fast as their mothers. The calves begin to eat leaves after a few months of suckling, weaning during their second year, well before the new calf is born (Pratt & Anderson, 1979).

2.2.2 Herd structure

A 'herd' generally refers to a large group of the same species of animals that live and feed together, however, in giraffe it has proved hard to determine which individuals form part of the same herd. It has been observed that individuals tend to come and go as they choose, which confused the first researchers to study their social structures. It has since been found that giraffe have a complex social system of a fission/fusion society, similar to that of chimpanzees or humans (Bercovitch & Berry, 2009b; Bercovitch & Berry, 2013; Dagg, 2014). As distinguishing individual giraffe from one another, especially in populations of several hundred to a thousand strong is challenging, it has been hard to track the movements of individuals, until modern technology allowed for easier recognition of individuals. In 1966, Foster studied herd structure of giraffe and defined a herd as a group of individuals moving in the same direction, less than a kilometre apart. It has since been found that this was a very conservative definition, as the 'herd' seems to be the whole population of the area, with small groups forming between different individuals on a daily basis while browsing (Foster & Dagg, 1972; Le Pendu, Ciofolo & Gosser, 2000; Leuthold, 1979). The general trends of these studies on populations of Masai giraffe from Nairobi National Park, Masai giraffe from Tsavo East National Park and West African giraffe from Niger, respectively, were as follows:

- Adult males tend not to associate with other males, females or young; they are generally loners, who will walk long distances to find females in oestrus to mate with.
- Although females were generally in groups of on average four to nine individuals, depending on the amount of available browse, the individuals with which they associated changed from day to day. Females did generally associate with their own young for periods of about 12 to 16 months, however, there was no conclusive evidence of whether calves belonged to nursery groups.
- The sub-adult males tended to be the most sociable, interacting regularly with others, mounting, sparring and necking
- Individuals of different classes, ages and sexes would associate freely with one another.

Bercovitch and Berry (2009b) were the first to predict the fission/fusion society, from their long-term study collecting data on a population of Thornicroft's giraffe in Zambia over 34 years, Bercovitch and Berry later published a second paper confirming the fission/fusion social structure (2013). A society of this kind encompasses the formation and disbanding of subgroups that form part of a much larger social network, as the individuals choose. It has also been discovered that giraffe communicate by means of infrasound (Von Muggenthaler, 2013), enabling them to communicate over large distances, which raises the question of how big their 'herds' then really are? It may be the case that all giraffe in a large area are a herd, and associate as they choose with the rest of their community.

It has been found that the sex ratios of giraffe populations depend on the area, despite the records of zoos showing that equal numbers of male and female calves are born (Dagg, 2014). Although Pratt and Anderson (1982) found Arusha National Park to have equal numbers of adult male and female giraffe (176 male and 172 female), Fennessy, Leggett and Schneider (2003) found the following ratios in their study in the Hoanib River catchment area of Namibia:

- Lower Hoanib River 1 male to 1.38 females
- Hobatere game park 1 male to 1.6 females
- Ombonde River 1 male to 0.62 females

It has also been found that both poachers (Marealle *et al.,* 2010) and lions are more likely to kill adult males than adult females, which may be due to the tendency of males to spend time alone, and inhabit thicketed areas where it is harder to see a threat (Owen-Smith, 2008).

There have been limited studies on the age ratios of giraffe populations, however, Foster (1966) monitored the population of Nairobi National Park for a six year period, and it was found to

remain relatively constant. Therefore, this data gives a vague idea of the composition of an average giraffe population that is neither increasing nor decreasing:

31 % adult females,

25 % adult males,

12 % young in their fourth or fifth year,

8 % in their third year,

10 % young in their second year,

14 % calves in their first year (5 % of which were <3 months old).

This data further illustrates the fact that the greatest mortality rate is in the youngest animals, with mortality rate progressively declining to maturity, with females living longer on average than males.

2.2.3 Feeding habits

Giraffe devote the majority of their time feeding or ruminating, as they have a large body to maintain. While giraffe predominantly browse during the day, they are known to browse into the night as well (Innis, 1958; Foster, 1966). This is often a seasonal adaption as they do not drink water frequently, satisfying their water requirements from the vegetation they browse instead, and *Vachellia* and *Senegalia* (previously collectively known as *Acacia*; their species of choice when available (Dagg, 2014)) has a higher water content in the leaves at night (Sauer, 1983; Sauer, Skinner & Neitz, 1982). It is therefore, more beneficial to browse *Vachellia* and *Senegalia* at night during the hot summer months, and rest and ruminate during the midday heat. Despite being particularly fond of *Vachellia* and *Senegalia* trees and shrubs, they forage many other species of trees, shrubs, herbs and even grasses, depending on the season (Lamprey, 1963). Female giraffe have been observed to browse for a much greater portion of the day than males, with Leuthold and Leuthold (1978) reporting males to spend 27 % of the day foraging while females spent 53 % of their day foraging, however, this study was carried out on a small group of giraffe. There have been many studies on the plant species consumed by different giraffe populations, these are largely influenced by the species available in the area. Parker, Bernard and Colvin (2003) reported only 14 species consumed by *G. c. giraffa* in the Eastern Cape Province of South Africa (extralimital population), while Leuthold and Leuthold (1972) reported that the *G. c. tippelskirchi* giraffe of Tsavo National Park, Kenya, consumed up to 66 different plant species.

Although the long neck of the giraffe enables it to reach browse that is out of reach of the other browsers they may compete with, they most commonly browse at shoulder height which is within reach of other large browsers, such as kudu and eland (Leuthold and Leuthold, 1972; Du Toit,

1990; Young and Isbell, 1991). Giraffe generally strip the leaves off branches with their tongues, and when the branches are thorny, manage to obtain the leaves from between the thorns with their dexterous tongues (Berry, 1973). They are also known to strip and eat the bark off trees (Tutchings, 2012). In nutrient-poor Hwange National Park, Zimbabwe, Seeber and colleagues (2012) observed recurring grazing events, mostly females in groups of 4-16 individuals. While grazing the giraffe would regularly lift their head to look around, as the splay-legged position is a vulnerable position. Pica behaviour is also a well-documented phenomenon in giraffe, often observed to lick or bite salty soil (geophagia) or chew on bones (osteophagia) (Western, 1971; Wyatt, 1971). As 90 % of all pica sightings in Kruger National Park, during Langman's two year study (1978), were documented during the dry season, it was suspected that it was due to calcium and phosphorus imbalances in the diet. Calcium is present in many forms in plants but phosphorus is not always, although it is available from the soil. According to Pellew (1984) the daily feed intake of giraffe is similar to that of other ruminants, with adult males and females, on average, consuming 1.6 % and 2.1 % respectively, of their live weight per day. However, the quality of their diet, in terms of crude protein content, was higher than that of grazing ungulates, especially as the protein content of browse only showed a minor drop during the dry season, while grazing had a far greater decrease. This allows giraffe to maintain a high enough nutrient intake for year-round breeding, as there is enough nutrient rich browse available for cow and calf regardless of season.

During drought, free-ranging giraffe will migrate to other areas in search of more browse options, however, when the giraffe are fenced in, this is not possible (Brenneman *et al*., 2009). Brenneman and colleagues (2009) studied the impact of this issue on the population of Rothschild's giraffe in the Lake Nakuru National Park in Kenya, finding that the population declined from 153 in 1995 to 62 in 2002. They found that although the carrying capacity had been 150 giraffe in 1995, there was a drought during the period of 1993 to 1997, resulting in limited food, and over-browsing of the available plants. This was observed for their preferred tree species, *Vachellia xanthophloea*, for which they over-browsed both the leaves and the bark. *Vachellia* and *Senegalia* are known to produce increased toxic tannin when stressed, as in over-browsing (Furstenburg & van Hoven, 1994). These tannins are incorporated into the milk of lactating cows feeding on these trees, which will have a detrimental effect on their young, which may have led to a higher calf mortality. The researchers therefore recommend that the forage available in an enclosed area be constantly monitored and the carrying capacity reassessed regularly in order to avoid the detrimental effects of exceeding this.

Giraffe have been introduced into areas further south, in southern South Africa, than they apparently ever lived before (Dagg, 2014). This is largely on private game reserves, or game ranches, wishing to draw in tourists, however, these extralimital locales are fenced, and therefore there are

some important factors to consider. There was concern over how these giraffe would react to the available vegetation, especially during the winter months when most indigenous plants lose their leaves, and there was the critical question of how many giraffe could be kept without degrading their vegetation? According to the studies of Parker and colleagues (2003) and Parker and Bernard (2005), in the Eastern Cape of South Africa, the giraffe (*G. c. giraffa*) adapted to the available browse. They were reported to preferentially consume the *Vachellia karroo* (43 %) during the summer months, supplementing this with *Rhus longispina* (17 %) and 46 other species during the winter when *Vachellia karroo* loses most of its leaves. The question of stocking density was assessed by Marais, Watson and Schmidt (2011), who calculated the giraffe to constitute 0.063-0.16 BU/ha per giraffe, which can be used as a guideline to calculate the carrying capacity of an enclosed area.

2.2.4 Thermoregulation and adaptations to heat

Giraffe are well adapted to life in hot and arid areas, having developed several means of thermoregulation, by anatomical features and by behavioural and physiological mechanisms. Simply the body shape of the giraffe is adapted for coping in the heat, their slender, elongated shape means that they have a relatively large surface area to volume ratio from which to dissipate heat, relative to other animals of similar weight (Dagg, 2014). The average body temperature of giraffe is 38.5 ± 0.5°C (Mitchell & Skinner, 2004), however, large fluctuations in this body temperature has been reported (Langman, Bamford and Maloiy, 1982; Langman & Maloiy, 1989). In Langman and Maloiy's study (1989) they found that there was as much as a 6.2°C diurnal variation in body temperature, reporting that these temperature fluctuations correlate with fluctuations in the ambient temperature. They observed that when the rectal temperature of the giraffe reached 40°C they would seek shade. Langman and Maloiy concluded that giraffe are passive obligatory heterotherms, which means that they can store up to 15-20 % of the total heat gain, enabling them to keep evaporative losses to a minimum, thus reducing water requirements. However, the degree of validity of this claim is hard to assess as Langman and Maloiy's data was only published in abstract form.

Giraffe have several behavioural methods of thermoregulation, Innis (1958) found that in the heat of the day, giraffe would slow their walking pace and tended to lie down frequently. However, in this study is was found that the giraffe would lie down in shade or sun and not orientate themselves in any particular position in regard to the angle of the sun, which is in contrast to what Kuntsch and Nel (1990) reported. They reported that giraffe would position themselves at different angles to the sun, depending on ambient temperature. At lower temperatures giraffe were observed to stand perpendicular to the sun, exposing a greater surface area for heat absorption, and at higher temperatures they were reported to seek shade or stand longitudinally to the sun. An observation

also supported by Langman and Maloiy (1989), was the behavioural differences for age and sex, with females and young seeking shade more frequently than males, which tended to align themselves with the sun instead. Giraffe are also capable of going without drinking water for long periods of time (Foster & Dagg, 1972), as their water needs can be satisfied by the water content of their food. According to Dagg and Foster's calculations (1976), giraffe are as well adept at water conservation as camels.

Studies have suggested that the ossicones may have a thermoregulatory function, as they are highly vascularised, and apparently have little function other than for fighting in males. Ganey, Ogden and Olsen (1990) suggested that the ossicones and underlying structure may be a thermal insulator to avoid fluctuations in brain temperature. Ganey and colleagues (1990) also suggested that the ossicones may function as a thermal window, from which heat is dissipated, however, it is unlikely that they would have a significant effect, due to their relatively small surface are.

Evaporation of water from the body surface is the most efficient cooling method, this can either be from the skin or the respiratory system. For the respiratory system this happens in the nasal passageways, heat is lost from the blood in the nasal mucosa, with the degree of cooling determined by the surface area for evaporation. This surface area is determined by the architecture of the nasal passageways (Mitchell & Skinner, 2004). The giraffe has been found to have an elaborate turbinate nasal architecture, which results in a large surface area for evaporative cooling (Fig. 2.4), estimated to be 7500 cm^2, which is larger than that of either the camel (6000 cm^2) or the eland (*Taurotragus oryx*) (4500 cm^2) (Spinage, 1968; Langman *et al.,* 1979; Kamau, 1992). Langman and colleagues (1979) also found that the distance from the centre of the air stream to the surfaces through which it passes, to be very small, which increases the efficiency of evaporative cooling. The water expenditure of evaporative cooling is not desirable in an animal living in areas with limited water, and as Langman and colleagues (1982) found, the water recovery rate is relatively small, Mitchell and Skinner (2004) therefore postulate that nasal cooling probably serves to cool the brain via the carotid rete mechanism, or to cool the blood returning to the body core in the jugular vein.

It has long been thought that the dark patches ("spots") on a giraffe are involved in thermoregulation. It has been observed that below each patch there are two blood vessel plexuses, one at 10-15 mm below the surface on the skin and one at 20-30 mm below the surface, the shallower plexus consists of a large artery and a network of smaller veins and arteries, which supplies the patches with blood (Ackerman, 1976). From the arrangement it seems that the superficial plexus is supplied with blood intermittently, depending on the ambient temperature. Skinner and Smithers (1990) described the patches as "thermal windows", by which blood was either sent to the surface for heat

loss when body temperature was too high, or for heat gain when the body temperature dropped, of which the first is most likely. Mitchell and Skinner (2004) also found that the sweat glands are more concentrated in the skin below the patches than the surrounding skin, further supporting the idea of the thermal window function.

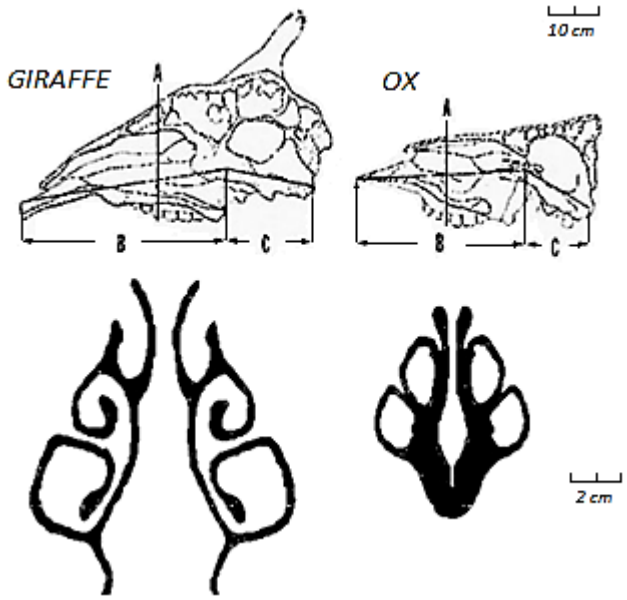

Figure 2.4 Comparison of the turbinate architecture in the giraffe and ox (*Bos taurus*). From Langman *et al.* (1979).

2.3 GIRAFFE MANAGEMENT ON PRIVATE GAME FARMS

2.3.1 Game farming in southern Africa

As a large proportion of southern Africa is arid and semi-arid, it is not always suitable for the production of domestic livestock, due to the limited vegetation and low rainfall (Otieno & Muchapondwa, 2016). Consequentially, there have been large shifts to farming of indigenous game species, which are more adept at utilising the poor quality forage, and surviving the heat and poor water supply (Bothma & Van Rooyen, 2005; Child, Musengezi, Parent & Child, 2012; Otieno & Muchapondwa, 2016). Indigenous game species also have a better resistance to parasites and diseases than domestic species, requiring lower maintenance by vaccination and medication (Oberem & Oberem, 2016). The game industry depends on four sectors: ecotourism, hunting, breeding and meat production (Oberem & Oberem, 2016; Van der Merwe, Saayman & Krugell, 2004).

Despite many critics of the rare game breeders, the survival of the tsessebe (*Damaliscus lunatus lunatus*), bontebok (*Damaliscus pygargus*), roan (*Hippotragus equinus*), sable antelope, and

even rhinoceros (*Diceros bicornis* and *Ceratotherium simum*) can largely be attributed to the private game sector, as this is responsible for giving wildlife an economic value, even if it is through hunting (Bezuidenhout, 2019; Taylor *et al*., 2016). However, there are often surplus animals that not enough hunters are willing to pay for. These are generally herbivores, and since game ranches generally do not keep predators, which would control the population, regular culling of the surplus animals is required in order to prevent over-utilisation of the natural vegetation (Hoffman *et al*., 2003; Kritzinger, Hoffman, & Ferreira, 2003). This, as well as trophy hunting, as the hunter generally does not take the meat, results in a large quantity of meat. Game meat has been found to be a healthy alternative to commercially produced red meat, as it has a low fat content with a healthy ratio of polyunsaturated fatty acids to saturated fatty acids, and a high protein content (Daszkiewicz *et al*., 2012; Hoffman, 2000; Hoffman, Kritzinger, & Ferreira, 2005; Hoffman, Kroucamp, & Manley, 2007; Hoffman, Van Schalkwyk, & Muller, 2008; Van Zyl & Ferreira, 2004; Von La Chevallerie, 1972). Therefore, if the meat, from trophy and culled animals, as well as the edible offal, is utilised, it will go a long way to alleviating the malnutrition in southern Africa, as thousands of tonnes are produced annually (McCrindle *et al.,* 2013; Taylor *et al.,* 2016).

2.3.2 The South African game industry

The original success of the game industry in South Africa was due to hunting and ecotourism, however, the breeding and live sales of high value game – whether rare or endangered game species, or colour variants – soon became the second largest contributor to the gross revenue of the game industry in South Africa (Van der Merwe *et al*., 2004). According to Taylor and colleagues in 2016, the South African game industry was growing by 6.8 % per annum, and utilizing 25 % of the country's total land. A summary of the estimated status of the South African Game industry as reported by Taylor and colleagues in 2016 is presented in Table 2.2. Breeding of rare game species and colour variants drew many new private farmers, as prices for exotic game rose exponentially from 2009 to 2014 (selling prices of sable (*Hippotragus niger*) rose 479 % and disease-free buffalo (*Syncerus caffer*) rose 540 %) according to the figures reported by Wildlife Ranching South Africa. However, with so many new game farmers, buying into the industry, the supply soon surpassed the demand, and the bottom dropped out of the market.

Since 2017, the game market of South Africa has regained some stability, with lower, but more sustainable, prices, as the value of the animals is now being driven by the hunting values, making these values more sustainable (Gouws, 2019). This means that buyers can make more meaningful predictions of the return they can expect on their investment. Contrary to what may have been expected with the current economic climate in South Africa, the numbers of registered buyers at game

auctions have been seen to increase from 2018 to 2019 (Gouws, 2019), which is sign that the game industry is recovering despite the poor National economy.

Table 2.2 Estimated status of the South African game industry in 2016 (From Taylor *et al.,* 2016)

General statistics	Total number of wildlife ranches in South Africa	8 979
	Area of all wildlife ranches in South Africa	170 419 km^2
	Total number of herbivores on all wildlife ranches	5.987 million
Intensive breeding	% area under intensive breeding	6.0 %
Live sales	Number of animals sold in South Africa	225 500
	Total revenue generated (turnover) from live sales (includes private sales and auctions)	R 4.328 billion
Trophy hunting	Number of animals hunted in South Africa	130 186
	Total revenue generated (turnover) from animals trophy hunted	R 1.956 billion
Biltong hunting	Number of animals hunted in South Africa	277 027
	Total revenue generated (turnover) from animals hunted for biltong	R 0.651 billion
Game meat production	Number of animals culled in South Africa	176 969
	Total carcass mass from trophy hunting, biltong hunting and culling	40 150 tonnes
	Total carcass mass available for sale (excludes meat from biltong hunting)	12 943 tonnes
	Total value of game meat produced (excludes meat from biltong hunting)	R 0.612 billion
Jobs and salaries	Total number of jobs created by wildlife ranching sector	65 172
Salaries	Median salary of employees	R 3 441

2.3.3 The Namibian game industry

As Namibia is more sparsely populated than South Africa, the livelihood of many people living in remote areas depends directly on the biodiversity, largely through farming, tourism and hunting (van Schalkwyk *et al*., 2012). The Namibian government passed an act that protects the biological diversity by managing the sustainable utilisation thereof, the Namibian National Constitution Act No. 34 of 1998 Article 95, which requires the *maintenance of ecosystems, essential ecological processes and*

biological diversity of Namibia and utilisation of living natural resources on a sustainable basis (Government of the Republic of Namibia, 1990).

Brown reported in 2008, that the natural resource-based production system had overtaken that of the agricultural production system in Namibia, and far exceeded it. Brown (2008) reported that, in 2005, the agricultural sector generated approximately N$ 1 878 million, while the natural resource-based production amounted to N$ 3 600 million, of which the wildlife industry made up the vast majority of this:

- Trophy hunting N$ 316 million
- Live game sales N$ 14.3 million
- Wildlife viewing N$ 2 700 million

Total: N$ 3030.3 million

However according to Barnes and Jones (2009), if one takes the indirect impact of the game industry into account, including the revenue generated by the harvesting teams, the meat processing facilities, as well as the meat retail and transport to these retail outlets, the impact on the economy is more in the vicinity of N$ 1.3 billion.

The game meat trade is a good way of generating revenue as well as prevent environmental degradation by utilising excess animals that may be exceeding the carrying capacity (Conroy, 2002). This is especially important during droughts, such as the one currently being experienced in Namibia. During droughts, farmers are less willing to buy more animals, as their primary concern is for the animals already in their care, which often entails providing large quantities of supplementary feed (Gouws, 2019), which is extremely costly. Therefore farmers often cull non-productive animals, keeping only their core breeding herd, thus generating revenue through the meat of the culled animals in order to feed the more valuable breeding herd.

2.3.4 Giraffe management in South Africa and Namibia

According to Taylor and colleagues' 2016 assessment of the South African game industry, giraffe were kept on 56 % of ranches surveyed, however, giraffe only made up 1.33 % of the total animal count. An exploratory study of some randomly selected game ranches and private nature reserves in South African and Namibia was carried out by the student (myself) in order to gain a broader picture of the giraffe industry of the two countries. A total of seven farms were included in the survey, as well as two meat processing facilities in order to investigate how giraffe meat is currently being used.

On the farms surveyed, the giraffe populations ranged from eight individuals to 1 100 giraffe, and the management of these respective populations varied accordingly. Most of the farmers were unsure of the subspecies of giraffe on the farm, however, of those that did know, all South African farms kept the *G. c. giraffa* subspecies, and the *G. c. angolensis* subspecies was kept in Namibia. The stocking density of the farms in the study ranged from 0.006 - 0.050 giraffe per hectare, averaging 0.014 per hectare.

The various game farms had different approaches to managing their populations, on farms where there was a small population at a low stocking density, they had not yet had to control the population. Some farms chose only to get rid of excess giraffe through live sales, however, these were farms with small populations that did not have large numbers to be taken off. One farmer reported that the demand for live giraffe is currently down, and they were unable to find buyers for live sales (June, 2019). The farmers that did report selling their giraffe live, did so through private capture companies. However, capture and transport of giraffe is difficult, costly and dangerous to the giraffe as well as the people involved. Fatalities in tranquilised giraffe can occur due to a number of factors: mal-positioning of the giraffe's neck while tranquilised, leading to airway obstruction; aspiration pneumonia may occur due to regurgitation while tranquilised; and extended tranquilisation may result in hyperthermia, myopathy and secondary trauma (Bush, Grobler & Raath, 2002). During transportation, giraffe may injure themselves if extreme caution is not taken to ensure their safety. Females and juveniles may fracture their ossicones if the top of the crate is not sufficiently padded, and if a giraffe falls during transportation, it may not be able to stand back up, likely injuring itself in the process (South African National Parks, 2019).

On the farm with the most giraffe, they reported that their total population had grown from 900 to 1 100 over four years despite the total culled and hunted animals amounting to between 50 and 75 giraffe per year. This farm and the other farms that culled and allowed for hunting, tended to cull unproductive animals; younger animals (sub-adult) were generally culled, only occasionally being sold to meat hunters. Old females were also culled where necessary, and old bulls were the giraffe most commonly hunted. The farmers reported to charge between R8 000 and R50 000 to hunt a giraffe. Half of the farmers skinned and dressed the carcasses in the field, while the other half transported the whole giraffe back to their on-farm abattoirs where the skinning and dressing processes took place. According to one of the farmers, a crane is used to hoist the dead giraffe onto a flat-bed truck, which transports it back to the abattoir.

The hunters generally take the giraffe skins after they have been salted and tanned, but there is seldom a market for the skins of culled animals, which are sometimes left in the veld for vultures

and other scavengers. Some farms sell their carcasses to butcheries, or process the meat themselves. Only one farmer reported to make use of any of the meat as fresh cuts, but did not specify further. The rest of the farmers reported that they process all the meat into mince or boerewors (typical South African sausage), or make biltong or droëwors (air dried meat products) from it.

The meat processing facilities that were surveyed, reported to buy between 10 and 50 giraffe carcasses per annum, many of these from trophy hunting. One of the butchers reported that the meat of the old bulls was sold to lion farms, rather than for human consumption as it had an unpleasant aroma. The processing facilities were predominantly supplied with mature males, followed by mature cows, and only seldom, younger animals. The butchers reported that the ratio of male to female carcasses was about 9:2. The average carcass weights reported were 450-500 kg for females and 500-900 kg for the male carcasses. Neither meat processor sold fresh giraffe meat, choosing rather to process it into mince and boerewors. They sell the meat predominantly to the lower income sector, at a cost averaging R 30/kg.

2.4 CONCLUSION

It can be concluded that the giraffe is well adapted to life in hot, arid Africa, with its low water requirements and excellent thermoregulative adaptations. Despite the current status as a "threatened" species, the subspecies of southern Africa are thriving, and where a concerted effort has been made to protect the population, the numbers have responded very well, as with the *G. c. peralta* and *G. c. rothschildi* subspecies. While the turnaround in these threatened populations was brought about by governmental intervention, it is largely due to the private sector that the giraffe numbers in southern Africa are high and increasing. It has also been seen that as private game ranching gives monetary value to wildlife, it has been pivotal in preventing the extinction of several species, notably the roan and sable antelope. Therefore, the increase of privately owned giraffe where their populations are threatened, may help to improve their numbers. However, as seen in South Africa and Namibia, when giraffe are kept in fenced camps without predators, their numbers grow rapidly, necessitating culling in order to prevent exceeding carrying capacity. The culling of giraffe results in a large quantity of meat, which is currently being sold at a low price as processed products. However, as there is a trend by the health conscious consumer to eat lean meat, and game meat has been found to generally be leaner than domestic red meat species, fresh giraffe meat has the potential to find a place in this niche market. The aim of this study is therefore to quantify the meat yields from giraffe and assess the quality thereof in terms of its physical, proximate and sensory characteristics. As well

as to assess the nutritional value of the red offal, in terms of its proximate composition as an alternative protein source.

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CHAPTER 3

THE INFLUENCE OF SEX ON BODY MEASUREMENTS, CARCASS WEIGHTS AND MEAT YIELDS OF GIRAFFE (*Giraffa camelopardalis angolensis*)

ABSTRACT

Various body measurements and commercial carcass yields of relatively young (2½ – 6 years old) giraffe (*Giraffa camelopardalis angolensis*) were investigated to quantify the effect of sex there upon. Eight male and eight female giraffe were culled by standard practice in Namibia, where body and horn measurements were taken, before the carcasses were dressed. There were no significant differences between the mean dead weights of the two sexes (males = 691.1 kg; females = 636.5 kg; $P = 0.096$), the only body measurements found to differ significantly were those of the forelegs, with the shoulder to hoof ($P = 0.046$) and the knee to hoof ($P = 0.025$) both significantly longer in the males. The horn measurements were all found to be significantly larger in the males than the females. The neck made up a greater percentage of the carcass weight in the males and the back made up a greater percentage of the carcass in the females. There was a strong positive correlation between the body weight and most of the body lengths, as well as between most of the individual body measurements. The giraffe used had an average age of 3.7 years old, and had therefore not yet reached their growth plateau, which may be why sex had no influence on most of the body measurements recorded.

Keywords: Body measurements, game meat, giraffe, yield.

3.1 INTRODUCTION

Giraffe are the tallest land mammal walking our planet (Dagg, 2014; Skinner & Smithers, 1990), standing at up to nearly 6m tall, yet relatively little is known about these African giants, especially in the wild. Although many South African and Namibian game farmers keep them, not many actively farm them in a structured breeding program as they may do with game species which are farmed for hunting and meat. However, it is often necessary to cull some of the population as on game farms they do not have any natural predators, and their population numbers have to be controlled in order to prevent surpassing carrying capacity. On the farm on which the giraffe for this trial were harvested their total population has increased from approximately 900 to 1100 giraffe between 2013 and 2017, despite culling between 50 and 65 predominantly young males each year, and 75 before the end of 2018. This results in a large quantity of meat for which there is little to no market, since there is very

little known about its quality as yet; Hall-Martin and colleagues (1977) and Hall-Martin (1977), carried out two basic studies on the carcass composition, body measurements and muscle fibre diameter of giraffe meat. However, these study was carried out using a scale unable to weigh the whole dead giraffe, therefor the weights were only approximate, and there have not been any follow up studies on their carcass composition or meat quality since then. Anecdotally, it seems as if giraffe meat is generally only used in processed products such as mince or boerewors (a traditional South African sausage) when sold commercially.

The tremendously long neck of the giraffe has been the muse of biologists for centuries, but every great muse has its mystery, and there is still no definitive answer to why the giraffe has such a long neck. It has always been the general assumption that the extreme height of the giraffe is to enable it to reach browse beyond the reaches of other browsers that they may compete with, as with other species where a long neck has evolved in order to access more food (Wilkinson & Ruxton, 2012). However, this theory has been cast under shadow by several studies finding that giraffe seldom browse with the full reach of their neck, but rather at their shoulder height for the majority of the time which is within reach of other (Du Toit, 1990; Leuthold & Leuthold, 1972; Young & Isbell, 1991). The other hypothesis for why giraffe developed such a long neck was that males with longer necks had a sexual advantage as they use their necks in fighting for females (Simmons & Scheepers, 1996). Their study on a Namibian giraffe population (*G. c. angolensis*) found that neck size increased for males throughout their lives, whilst it plateaued for females. However, a study on a population of Zimbabwean giraffe (*Giraffa camelopardalis giraffe*; Mitchell, van Sittert & Skinner, 2009) found evidence of limited sexual dimorphisms of neck and leg length, and head and neck mass, and those that were found could be explained as generic male female differences, as occur in most species.

A large proportion of research that does exist on giraffe was done on captive giraffe kept in zoo environments, and there is substantial evidence that giraffe behaviour, growth and general performance, from feeding and drinking patterns, to longevity and onset of puberty, is markedly different between captive giraffe and giraffe in the wild (Dagg, 2014; Veasey, Waran & Young, 1996). This, therefore, must be taken into account when considering any of the findings where only captive giraffe have been used.

This study aims to clarify some of the findings of Hall-Martin (1977) and broaden the knowledge base on these African giants as well as provide baseline information on their potential meat yields.

3.2 MATERIALS AND METHODS

3.2.1 EXPERIMENTAL LOCATION AND ANIMALS

Sixteen giraffe (eight males, eight females) were obtained from Mount Etjo Game Farm in July of 2018 in the Otjozondjupa region of Namibia; the prevailing veld type in this area is the thornbush savanna, with predominantly *Senegalia* and *Vachellia* (formally known collectively as *Acacia* spp.) trees and sweet grass species. The farm has approximately 1100 giraffe which live in an extensive camp of approximately 22000ha. They receive no supplementary feed and undergo no selective breeding and only minimal human intervention by means of watering holes and mineral licks. The animals used in this study comprised part of an annual cull carried out on the farm. All animals were aged by professional hunters and all but one were estimated to be between two and a half years and six years old, G13, however, was judged to be a mature female approximately nine years old, and was consequently removed from the analyses, in order to prevent age from skewing the data. The giraffe were culled by a head shot and then bled (Ethical approval: ACU-2018-7366, Stellenbosch University; Namibian Shoot and sell permit number: 118690) before being measured as described below. The giraffe were then weighed to give a dead weight (live weight less blood loss), before being transported to the abattoir where the carcasses were dressed as described by Ledger (1963) and cut into sections similarly to Hall-Martin (1977) for cooling in the cold-room.

3.2.2 PROCESSING AND MEASUREMENTS

The measurements were taken with a soft measuring tape with the giraffe lying flat on its side with neck and legs extended (except where otherwise stated) as follows (Figure 1):

Body length measured from the point of the sternum protruding furthest from the chest, over the shoulder and side, to the dorsal point of the hip, the pin.

Back length was measured from the top of the withers (the highest point of the spine at the third thoracic vertebra), along the curve of the back to the base of the tail.

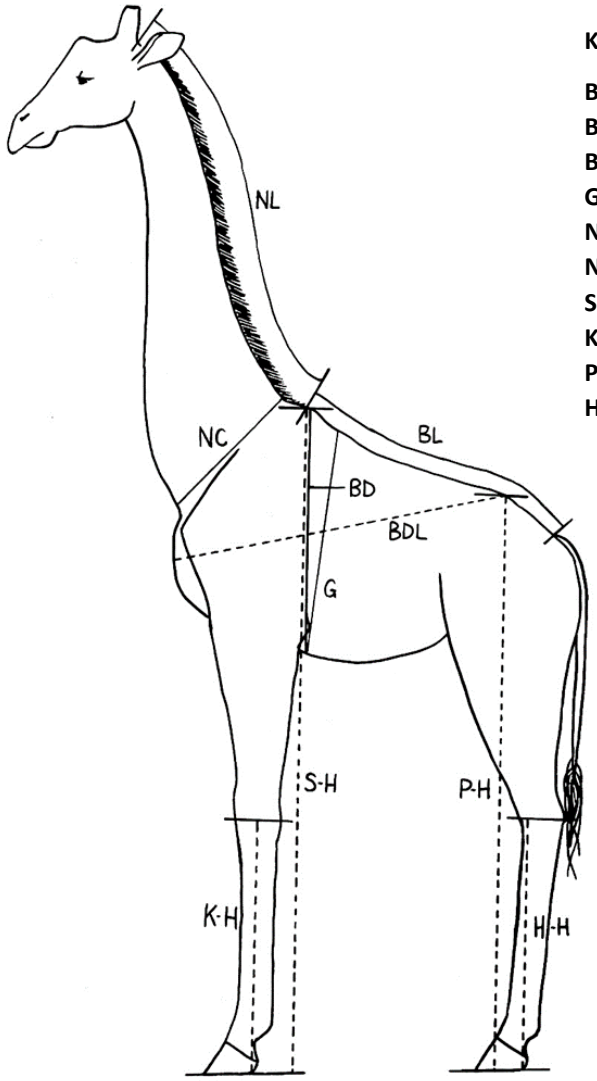
Body depth was measured from the top of the withers around the girth to the mesodistal point of the sternum directly below the withers.

The girth measurements were taken when the giraffe was hanging by the neck, and were taken around the girth line just behind the withers and just behind the forelegs and around the mesodistal point of the sternum.

Neck circumference was taken around the base of the neck at the broadest part of the neck where it meets the shoulders.

Neck length was taken from the base of the skull along the neck to the top point of the withers.

The shoulder to hoof measurement was taken in a straight line from the top of the withers to the bottom of the hoof when extended as though flat on the floor as when the giraffe is standing.



Key:

BDL	Body length
BL	Back length
BD	Body depth
G	Girth
NC	Neck circumference
NL	Neck length
S-H	Shoulder to hoof
K-H	Knee to hoof
P-H	Pin to hoof
H-H	Hock to hoof

Figure 3.1 Diagram of the locations where body measurements were taken on the giraffe (*Giraffa camelopardalis angolensis*).

Knee to hoof measurement was taken from the mid-point of the knee to the bottom of the extended hoof in a straight line.

Pin to hoof measurements were taken in a straight line from the top point of the hip, the pin, to the bottom of the extended hoof.

Hock to hoof measurements were taken from the point of the hock to the bottom of the extended hoof in a straight line.

The scrotal circumference on male animals was taken around the widest section of the scrotum.

The horn length was taken in a straight line from the mid-point at the base of the horns where the two meet to the tip of one of the horns and assumed to be the same for both.

Minimum horn circumference was taken around the narrowest point of the horn.

The maximum horn circumference was taken around the broadest part of the horn at the base where it joins the skull.

The tip to tip measurement was taken from the top most point of one horn to the same point on the other horn in a straight line.

On arrival at the abattoir the pre-rigor giraffe were hoisted by a crane with a hook placed through the hock of one hind leg, they were then skinned and eviscerated as described by Ledger (1963). The carcass was then split into eight sections, the two forelegs, two hind legs, the neck, two rib racks and the spinal column including the tail. These sections were cut as described by Hall-Martin (1977) except for the cut between the ribs and the spinal column.

The forelegs were removed by cutting from the olecranon process of the ulna along the *tensor fasciae antibrachii* muscle to the caudal angle of the scapula, thus cutting the *latissimus dorsi* muscle where it runs inferior to the caudal edge of the *triceps* muscle. The pectoral muscles were then severed close to where they join the foreleg as it was being held out from the body. The cut was then continued along the cranial edge of the *biceps branchii* muscle and the *supraspinatus* muscle around the dorsal end of the scapular cartilage, through the *trapezium* muscle, before cutting through the last of the connective tissue connecting the cartilage of the scapular to the thorax.

The hind legs were removed by making a cut along the lateral edge of the sacrum, severing muscle attachments with a mesodistal cut between the *tuber coxae* and the *tuber ischia*, removing the muscles cleanly from the bone and obturator membrane. The muscle attachments of the *tensor fasciae* muscle and the patellar ligament were then severed with a ventral cut along the caudal edge of the *tuber coxae*. The head of the femur could then be disarticulated and the remaining connective tissue severed.

The head was removed at the axis-atlas joint from the neck. The neck was then removed from the thorax by cutting between the seventh cervical vertebra and the first thoracic vertebra.

A cut was made through the middle of the abdominal muscles from just before the pelvis through the heads of the thoracic ribs and down through the sternum, splitting it ventrally. The organs were then removed from the thoracic cavity. The cut was extended towards the spine from the pelvis to where it met the edge of the *longissimus lumborum* muscle, a fine toothed chainsaw was then used to cut through all the ribs along the outer edge of the *longissimus lumborum* muscle and *longissimus thoracis* muscle.

This left the spinal column, from the first thoracic vertebra to the end of the tail, with the *longissimus lumborum* muscle, *longissimus thoracis* muscle and *psoas major* and *minor* muscles (PM) still attached (called the "back"), unlike in Hall-Martin's procedure.

The ossicones were removed from the rest of the skull with a saw, they were then frozen and a micro-computerized tomography (CT) scan was performed on those of the largest male and female, which was G13, the mature female, respectively. The ossicones were kept frozen and secured in a manner that the scan would revolve around the centre line of the ossicone itself.

Each carcass section was weighed as the warm carcass weight, before being placed into a chiller for approximately 24 h, after which they were weighed again for a cold carcass weight.

3.2.3 STATISTICAL ANALYSIS

Statistica Version 13.4 (2018) R (lmer package) was used to perform a univariate analysis of variance (ANOVA) using the General Linear Models (GLM). For the comparison of sex effects, Fisher's least significant difference was calculated at the 5 % significance level (Lyman Ott & Longnecker, 2010). The variables were accepted to be significantly different if the probability of rejection of H_0 was less than 5 % for sex. Pearson's correlation coefficients were also calculated between dead weights and the various body measurements, as well as between the body measurements.

3.3 RESULTS

As mentioned, one female was estimated to be significantly older (9 years) than the rest of the females and her data was subsequently removed from the data analyses.

The only significant difference between the body measurements of the two sexes were those of the forelegs, with both the shoulder to hoof (P = 0.046) and the knee to hoof (P = 0.025) being significantly longer in the males than the females (Table 3.1; Supplementary Table 1), as well as all of the horn measurements which were also significantly larger in the males ($P \leq 0.05$).

There was a moderate to strong positive correlation between dead weight and all body measurements, except girth, which had only a moderate positive correlation (r = 0.438; p = 0.10) (Table 3.2). Age had a moderate to strong positive correlation with all body measurements, other than the girth (r = 0.353; p = 0.20). In general, the correlations between girth measurements and other body measurements were not as strong as correlations between other measurements including body depth; the latter was expected to be high as they were taken from similar places.

Table 3.1 Body and horn measurements of ~3.7 years old male and female giraffe (*G. c. angolensis*)

Body measurements	**Male *(n=8)***			**Female *(n=7)***			***P-value***
	Mean	**S.E.**	**Range**	**Mean**	**S.E.**	**Range**	
Dead weight (kg)	691.1	45.465	562-927	636.5	33.764	508-747.5	0.096
Body length (cm)	160.1	3.346	151-177	157.7	4.190	136-171	0.391
Back length (cm)	105.3	4.872	83-123	102.6	3.054	90-114	0.534
Body depth (cm)	123.0	3.295	109-135	122.4	2.759	109-129	0.671
Girth (cm)	236.4	8.508	202-277	230.4	4.551	210-246	0.499
Neck length (cm)	134.5	4.702	119-155	134.6	4.314	115-152	0.913
Neck circumference (cm)	135.4	5.904	117-161	132.0	4.077	119-145	0.453
Shoulder to hoof (cm)	272.9	6.306	256-304	260.1	4.688	239-276	**0.046**
Knee to hoof (cm)	92.8	1.770	88-101	88.3	1.340	82-92	**0.025**
Pin to hoof (cm)	233.0	4.702	218-253	229.0	4.309	209-240	0.381
Hock to hoof (cm)	100.5	2.471	94-113	96.4	1.837	88-102	0.137
Scrotal circumference (cm)	26.5	1.041	23-31	-	-	-	-
Horns:							
Length (cm)	16.7	0.756	13.5-19	11.6	0.404	10-13	**<0.001**
Minimum circumference (cm)	15.8	0.841	13.5-20	11.9	0.322	10.5-13	**0.001**
Maximum circumference (cm)	32.2	1.069	28-36	22.4	0.948	19-26	**<0.001**
Tip to tip (cm)	17.1	0.601	15-19.5	13.4	1.152	9.5-16.5	**0.005**

There was a strong positive correlation between all body measurements (r > 0.600), except for the girth and the scrotal circumference correlations with back, leg and neck lengths. The scrotal circumference was however, strongly correlated with body length and depth, neck circumference, and interestingly horn length.

Table 3.2 Pearson's Correlation coefficients (r) between the body measurements of ~3.7 year old giraffe (*G. c. angolensis*)

	Dead weight	Age	Body length	Back length	Body depth	Girth	Neck length	Neck circumference	Shoulder to hoof	Pin to hoof	Knee to hoof	Hock to hoof	Horn length	Min horn circumference	Max horn circumference	Tip to tip
Age	0.758															
Body length	0.921	0.724														
Back length	0.768	0.508	0.799													
Body depth	0.876	0.741	0.913	0.766												
Girth	0.438	0.353	0.496	0.496	0.260											
Neck length	0.686	0.490	0.750	0.813	0.699	0.520										
Neck circumference	0.894	0.644	0.820	0.658	0.867	0.390	0.647									
Shoulder to hoof	0.899	0.583	0.852	0.829	0.773	0.567	0.793	0.837								
Pin to hoof	0.872	0.581	0.905	0.844	0.889	0.482	0.825	0.900	0.926							
Knee to hoof	0.818	0.508	0.770	0.727	0.683	0.521	0.763	0.780	0.951	0.864						
Hock to hoof	0.786	0.474	0.767	0.682	0.710	0.443	0.758	0.818	0.891	0.907	0.926					
Horn length	0.490	0.396	0.384	0.228	0.300	0.355	0.178	0.369	0.558	0.376	0.638	0.514				
Min horn circumference	0.451	0.167	0.363	0.469	0.421	0.111	0.279	0.293	0.542	0.430	0.493	0.390	0.673			
Max horn circumference	0.364	0.098	0.285	0.221	0.216	0.243	0.215	0.260	0.489	0.345	0.553	0.443	0.878	0.802		
Tip to tip	0.405	0.374	0.452	0.266	0.388	0.296	0.265	0.346	0.438	0.406	0.569	0.492	0.826	0.493	0.769	
Scrotal circumference	0.822	0.846	0.751	0.271	0.692	0.378	0.346	0.759	0.599	0.534	0.498	0.465	0.677	0.210	0.111	0.265

*Key:

0.000 – 0.399	Weak positive correlation
0.400 – 0.599	Moderate positive correlation
0.600– 0.799	Strong positive correlation
0.800-1.000	Very strong positive correlation

*(Evans, 1996)

The horn measurements were not very strongly correlated with the body measurements, but did all have a moderate to strong positive correlation with the foreleg measurements.

The males were not found to be significantly heavier than the females (*P* = 0.096) (Table 3.3), with a dead weight of 691.1 ± 45.5 kg (min = 562.3, max = 927.1) whilst females had a mean dead weight of 636.5 ± 33.8 kg (min = 508.4, max = 747.5). Despite this difference not being statistically significant, it does seem as though the males tend to be heavier, this may be as they are pubescent animals, at the inflection point of their growth curve and they are just beginning to show sexual dimorphisms. The sex effect on the dressed carcass weights tended towards a significance, which was more pronounced in the cold carcass weights (P = 0.053) than the warm carcass weights (P = 0.063) (Table 3.3).

Table 3.3 Mean (± standard error) carcass yields of ~3.7 years old male and female giraffe (*G. c. angolensis*)

Parameter	**Male *(n=8)***	**Range (min - max)**	**Female *(n=7)***	**Range (min - max)**	***P-value***
Dead weight (kg)	691.1 ± 45.47	562.3 - 927.1	636.5 ± 33.76	508.4 - 747.5	0.096
Dressed weight (kg)	400.4 ± 28.62	314.5 - 543.5	366.4 ± 15.58	295.7 - 424.3	0.063
Dressout[a] (%)	56.7 ± 0.85	51.6 - 59.2	56.8 ± 1.28	52.3 - 63.4	0.982
Cold carcass weight (kg)	393.1 ± 28.52	310.1 - 535.8	359.5 ± 14.49	290.9 - 407.3	0.053
Moisture loss in chiller[b] (%)	1.1 ± 0.21	0.7 - 2.5	1.1 ± 0.24	0.4 - 2.4	0.965
Hind legs[c] (%)	34.1 ± 0.40	32.7 - 35.6	34.6 ± 0.32	33.5 - 36.1	0.390
Forelegs[c] (%)	26.4 ± 0.22	25.7 - 27.4	25.7 ± 0.44	23.4 - 27.1	0.189
Back[c] (%)	13.8 ± 0.49	11.1 - 15.2	15.2 ± 0.36	14.0 - 16.6	**0.026**
Ribs[c] (%)	14.4 ± 0.30	13.4 - 15.7	14.8 ± 0.32	13.8 - 16.5	0.312
Neck[c] (%)	11.3 ± 0.37	9.6 - 12.7	9.6 ± 0.28	8.4 - 10.7	**0.005**
Offal[b] (%)	35.7 ± 0.50	33.3 - 37.5	37.2 ± 1.04	33.7 - 42.5	0.227

[a] Percentage of dead weight

[b] Percentage of dressed weight

[c] Percentage of cold carcass weight

The dressing percentages did not differ significantly between the two sexes though (*P* = 0.982), with dressing percentages of 56.7 % and 56.8 % of males and females respectively. The only significant differences between the sexes for carcass sections as a percentage of the whole carcass were for the neck (*P* = 0.005), with the average weight of 44.56 ± 3.6 kg (min = 31.3 kg, max = 63.4 kg)

for males and 34.46 ± 1.3 kg (min = 29.6 kg, max = 41.7 kg) for females, and the back where the females' backs made up a larger percentage of the carcass than the males' (P = 0.026). However, as pertaining to the actual weights, females' backs averaged 54.79 ± 2.4 kg (min = 45.0 kg, max = 62.6 kg) and males' averaged 54.13 ± 5.0 kg (min = 34.3 kg, max = 81.3 kg) - it is found that they do not differ much.

3.4 DISCUSSION

The method of culling was effective, as every animal was dropped by a head shot, and only one was injured, sustaining a glancing shot to the neck, but the next shot (within 30 seconds of the first) was a good head shot and it dropped immediately. This meant that no meat had to be discarded due to damage caused by the culling method.

The only significant differences between any of the body measurements (Table 3.1), between the two sexes, were those of the forelegs. The measurements from shoulder to hoof and knee to hoof were both significantly longer in the males than the females, this seems to be supported by what Mitchell and colleagues (2009) report, although they did not report age in their study. They did, however, report that for males and females, when increasing from 100 kg to 1100 kg live weight, males had a 2.01 fold increase in foreleg length, while females only had a 1.69 fold increase.

The lack of any other significant sexual dimorphisms in length, including the neck, is supported by what Hall-Martin (1977) report on giraffe of this age. Mitchell and colleagues (2009) found that, contrary to what Simmons and Scheepers (1996) reported on males having larger necks for sexual advantages, when correcting for body weight, males and females had no significant differences in neck length, which agrees with the findings of this study, that, despite the lack of sexual dimorphism in length, there was a dimorphism in weight.

Hall-Martin's study was carried out on a group of Transvaal Lowveld (now Mpumalanga, South Africa) giraffe, of ages ranging from birth to approximately 23 years old. He found that until about five years of age, male and female giraffe show little dimorphisms in height, and that they reach a plateau in growth at about 11 years old in females and about 12 years old in males. However, as his study was only performed on one sub-species of giraffe and a relatively small group of giraffe (n = 53, of which 27 were male and 26 female) considering the age spread from birth to 23 years of age, these ages cannot be taken as the rule, especially not across all sub-species of giraffe. However, if using Hall-Martin's study as a reference for the giraffe used in this trial, the *G. c. angolensis* used in the current study were predominantly pubescent giraffe around the inflection point of their sigmoidal growth

curve, as their average age was approximately 3.7 years. One female was found to be in an early pregnancy, which supports the assumption that they were not immature giraffe. This validates the findings of sexual dimorphisms, and trends towards dimorphisms, as the giraffe move from puberty towards maturity.

There was a low correlation between the girth measurements and the other body measurements which could be due to errors in these measurements as the girth measurements were the only ones taken when the giraffe was hanging from the neck. It was not possible to get the measuring tape under the body of the giraffe when it was lying on its side, and it should be noted that when they were hung in this manner, the skin would form folds around the shoulders, which would have affected the measurements, as the folds were not uniform for each animal. The contents of the chest cavity may also have shifted downwards thus changing the way the rib cage sits when compared to when the giraffe were lying on its side as when other measurements were taken.

From the CT scans (Figure 3.2) it could be seen that the male's ossicones are more densely ossified than the females'. Males use their horns to fight and must therefore be able to withstand a huge amount of force as they slam them into their opponent. From Table 3.1 it can also be seen that the horns are substantially larger in all dimensions, in males than females, with the horn base where the maximum horn circumference was measured as well as the horn length being the most significantly larger. As females do not use their horns to fight, they have very limited use for them, and thus larger, heavier horns will be a disadvantage for them, as they must carry this weight at the top of their long necks.

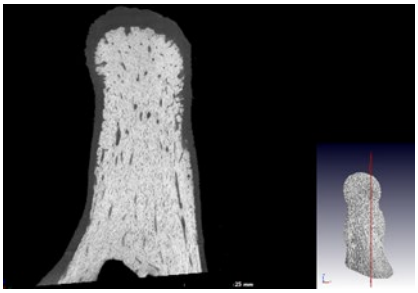
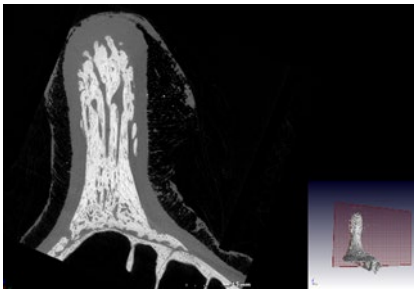
a)  **b)** 

Figure 3.2 Computerized tomography (CT) scan images of the internal structure of the ossicones of **a)** a giraffe male and **b)** a giraffe female

The dead weight reported of the giraffe in this study is not a true representation of the live mass of the animal, as it does not account for the blood loss, since they were only weighed subsequent to bleeding (Table 3.3). However, this can be estimated at ~21 kg, as it is reported as being approximately 3 - 4 % of the live mass in large mammals (Callow, 1961). The gut fill of the animal also affects the live mass value, and this depends on the eating and drinking habits of the species, as well

as the time of day that the animals were culled relative to this feeding pattern. As giraffe can go for days without drinking (Dagg, 2014), it would be very hard to standardise the time from drinking to time of death and thus control water content of the gut fill. The impact of gut fill on live weight is also affected by their feed intake as most of their water requirements are in fact satisfied from the water in the leaves that they eat, therefore the browsing pattern and resultant gut-fill should be taken into account as it has been reported that gut fill can have an influence of up to 20 % of live weight in livestock (Tayler & Wilkinson, 1972). The dressing percentages of the giraffe was 56.7 % and 56.8 % for males and females respectively, which is comparable to that of cattle which is generally accepted to be between 58 – 62 %. When comparing dressing percentage with domestic species it must be taken into consideration that domestic species are normally fasted for 12 - 24 h before slaughter, this will reduce their gut-fill substantially in the domestic species and increase their dressing percentage by up to 4 % (McKiernan, Gaden & Sundstrom, 2007).

Body weight of giraffe also varies with season, due to availability of food, however, as all giraffe in this trial were culled over a two week period in July/August of 2018 (which is late winter in Namibia), this affect should be minimal in this investigation.

The dead weight of the males and females did not differ significantly which appears to be in contradiction with the findings of Von La Chevallerie (1970), where he reported that for most African ungulates the male is significantly heavier than the female, which has been supported in a number of studies on giraffe including that of Hall-Martin (1977). However, the majority of the giraffe used in this study were young (average age of ~3.7 years old); the approximate age at which they reach puberty. According to Hall-Martin's study on Transvaal Lowveld giraffe, male and female live weights are still similar until about 4.5 years of age, and only start to show significant sexual dimorphisms thereafter. Females tend to have a lower growth rate after this point and plateau at a younger age, at about 11 years (~850 kg), and males plateau at around 12 years, at a weight generally about half a tonne heavier than the females (~1400 kg) (Hall-Martin, 1975). The difference between the dressed carcass weights of the males and females did tend towards significance, however, this may in part be due to the fact that the female reproductive system may weigh more than that of the male.

Only one of the females was found to be pregnant, which will also impact her dress-out percentage as the foetus and amniotic sac were recorded to weigh 61.15 kg which is 8.18 % of her dead weight. However, with a dress-out percentage of 52.28 % she was in alignment with the other dress-out percentages.

The only significant differences of carcass section weights between the two sexes were for the neck weight, this was expected, and for the back, which was unprecedented. The difference in neck

weights could be expected as the males use their necks for fighting and consequentially need a strong, well ossified and muscled neck to withstand the force of hitting the neck and head into rival males. This is in line with Simmons and Scheepers (1996) on the respective weights of males' and females' necks. Although the respective neck lengths and circumferences (at the base of the neck, it was not measured along the neck) of males and females did not differ significantly, the difference in weight may be explained by the respective densities of the vertebrae of the sexes. It has been found that the vertebrae, especially trending towards the top of the neck (Van Schalkwyk, Skinner & Mitchell, 2004), of giraffe are less dense than the other bones, which is more pronounced in females as their necks do not need to withstand the clubbing force of being swung into another giraffe. Therefore, their long necks are as light as possible, minimising the weight that has to be supported at such a great height. The back was found to make up a greater percentage of the carcass of the females than the males (Table 3.3). However, when looking at the actual weights of the backs it was found that there was no difference between the sexes, therefore, the difference for percentage may be a result of the necks making up a higher percentage of the carcass in the males. It may also be partially explained by females needing to carry a calf, thus needing a stronger back.

The necks made up 11.3 ± 0.37 % and 9.9 ± 0.33 % of the total carcass weight for males and females respectively (Table 3.3), and of this a large portion is bone, as their vertebrae are greatly enlarged in comparison to other ungulates of similar size, such as eland (*Taurotragus oryx*) or buffalo (*Syncerus caffer*). The little meat that is on the neck is highly sinuous as thick strong tendons and ligaments are necessary to control this ungainly neck and the large head perched on top, therefore despite making up carcass weight it would not add much value to the carcass. The hind legs made up 34.1 ± 0.40 % and 34.5 ± 0.31 % of the carcass for males and females respectively, and as this contains a large proportion of the prime cuts, this is positive, especially as the meat to bone ratio in the hindquarters is generally favourable. The forelegs made up 26.4 ± 0.22 % and 25.8 ± 0.39 % of the male and female carcass weights respectively, however, since the scapula makes up a fair portion of this weight, there is generally a less favourable meat to bone ratio here than in the hind legs. The back holding potentially the two most sought after and valuable cuts, the fillet and the loin, made up 13.8 ± 0.49 % and 14.9 ± 0.41 % of the carcass in the males and females respectively. The loin (*Longissimus thoracis et lumborum* (LTL)), made up of the *longissimus lumborum* muscle and *longissimus thoracis* muscle was found to be riddled with sinew as well, with thick tendons running throughout this cut. This is due to the fact that the tendons supporting the neck originate from all along the back, thus anchoring it for better leverage. It was also observed that the structure of the muscle as a whole was loose; it was not always clear to see the direction of the muscle fibres which seemed to run in many different directions throughout the muscle. The PM was found to be smaller than expected, but not

rife with tendons as was the loin. The PM was also more triangular and looser in shape than in other animals where it tends to be more tubular and compact. Similar structures for both the LTL and PM has been observed in the elephant's back by the authors. Another observation was that the back was shorter (~105 cm) than may have been expected (Table 3.1), when compared to the length of their neck and legs; in livestock species the back tends to be longer giving a longer length of the high value dorsal muscles. The ribs making up 14.4 ± 0.30 % and 15.0 ± 0.30 % respectively of the total carcass for males and females, as with any ribs, are predominantly made up of bone with very little meat on the sides.

The carcasses tended to have a very visible white collagenous subcutaneous layer under the skin, which was stretched very tightly over the muscles, as soon as it was punctured the underlying muscle would bulge out of the hole created. Although the giraffe generally had very little fat, the carcasses did have a fairly localised fat covering along the back, which tended to be whiter in colour, as well as a thicker yellowish fat layer around the withers. The kidney and caul fat depots were prominent and were white and hard. There was no visible intramuscular fat observed in the meat.

3.5 CONCLUSION

This study was performed on a small group of giraffe, and on predominantly pubescent giraffe around the inflection point of their sigmoidal growth curve, it could be of interest to extend this information with future studies on a wider range of ages to create a broader result and to create a more robust carcass yield and growth curve for giraffe. It may also be of interest to develop curves of the various subspecies to determine whether they differ. This study may, however, prove valuable to other farmers that also cull predominantly young giraffe, as it gives an indication of the carcass yields.

Giraffe have a favourable dressing percentage, however, it may be of interest to perform a block test on the whole carcass in order to investigate the ratios of clean meat to bone and sinew, so that a better idea of the value of the carcass could be established. On-going research should also evaluate the quality aspects of these cuts so as to give guidance on how they could be marketed. It is also interesting to note that at an average age of ~3.7 years, there is very little difference between the carcasses of the males and females.

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CHAPTER 4

THE INFLUENCE OF SEX ON THE YIELD AND CHEMICAL COMPOSITION OF THE ORGANS OF GIRAFFE (*Giraffa camelopardalis angolensis*)

ABSTRACT

Offal, often referred to as the "fifth-quarter", is often not utilised, however in Africa, this is a cheap source of protein and is regularly consumed. There is very little known about the carcass composition and chemical composition of giraffe, therefore this study aims to broaden the basic data base on giraffe. The yields of the offal as well as the nutritional value of the red offal of 15 giraffe (eight male, seven female) were evaluated by means of proximate analysis. The only significant differences of offal weights between sexes were for the head with tongue (P = 0.011), feet (P = 0.006) and kidneys (P = 0.045), with each heavier for males than females, however, as a percentage of the total dead weight, there were no significant differences between sexes. The study also looked at the proximate composition of the heart, liver, kidneys and tongue. The moisture % averaged ~76 %, protein % averaged ~17 %, total fat % averaged ~5 % and the ash % averaged ~1 % for all organs across both sexes of the giraffe. While sex only had an effect on the ash content (P = 0.038), organ had an effect on all parameters (P <0.001). Red offal had a favourably high protein content as well as a low fat content, which when combined with the high yields thereof per animal, indicates that giraffe offal can serve as a source of low cost protein.

Keywords: Game, Organs, By-products, Offal, Proximate composition

4.1 INTRODUCTION

If you ask a hunter what the first thing is to do after shooting an animal? The most common answer will be to remove, if not all the organs, at least the gastrointestinal tract (GIT) as when the whole carcass is left too long in the heat the GIT will start to bloat, making it more difficult to remove without puncturing it, which will contaminate the carcass. Gut shots also result in contamination of the carcass. While this practice means that the carcass will be lighter to transport, it also means that a large portion of the edible material from each carcass is discarded. Aduku and colleagues (1991) found that, in goats, making use of the offal can contribute up to 33 % more edible material from each animal.

While the consumption of offal is generally increasing around the world, in Africa it is especially sought after (Pearson, 1988), being nutritious and generally a cheap source of protein, although the price thereof is on the rise. In Africa there is a demand for offal including red (tongue, lungs, liver, spleen and kidneys) and brown/white (stomach and small intestine) offal, which is sold to a largely lower income market, however, with especially tourists wanting to try new and exotic dishes, especially from exotic species, game offal can find a niche market in up-market restaurants. However, a major concern for consumption of offal from game animals is the presence of zoonotic diseases and parasites (Magwedere *et al.*, 2012), which are often present only in the organs (Magwedere *et al*., 2013). This is especially an issue in game animals as they are not routinely vaccinated to the same extent as commercially farmed domestic species, due to the costs involved as well as the difficulty of administering vaccines to wild animals.

Wild animals play a role in the infection of humans with several diseases and parasites, such as The Rift Valley Fever (RVF) virus (Bunyaviridae) and *Brucella melitensis* and *Brucella abortus.* These are affected by pH changes therefore becoming inactivated relatively fast with the rigor mortis associated pH decline in the skeletal and heart muscles, but not in the other organs (Magwedere *et al.,* 2013). The organs are also generally consumed sooner as the meat is normally aged for a few days before consumption and therefore the viruses and bacteria will still be active.

Giraffe have largely been found to be fairly disease free in the wild, as they are exclusively browsers, and thus contract less soil borne and faecal borne parasites and diseases. They are not very susceptible to foot-and-mouth disease and do not seem to be responsible for its proliferation in the wild (Vosloo *et al*., 2011), which is a huge advantage in the game industry as this has been a large barrier to overcome in order to export southern African game meat, being the factor that triggered the 2011 export ban in South Africa (Taylor, Lindsey & Davies-Mostert, 2016). The first reported case of bovine tuberculosis (*Mycobacterium bovis*) has just been detected in giraffe in the Kruger National Park (Hlokwe *et al*., 2019), which is highly contagious, and affects many of the high value game species.

The giraffe is a very unique species with limited research having being conducted on its meat production potential and hardly any on the nutritional composition of its edible offal; in fact, there are not many species with a wide data base to which it can be compared in terms of offal yields and organ proximate composition. Of all African ungulates that have been studied and used for meat production the eland (*Taurotragus oryx*) is probably the species with the most similar carcass conformation, when disregarding the neck and leg lengths. As Laubser (2018) has done extensive study of the offal yields of eland, this could be used as a reference of organ weights of large African ungulates.

This study aims to determine the average yields of the “fifth quarter” of pubescent giraffe as well as quantifying the nutritional value of their red offal by proximate analysis of their chemical composition.

4.2 METHODS AND MATERIALS

4.2.1 EXPERIMENTAL LOCATION AND ANIMALS

Fifteen young giraffe (average age ± 3.7 years old) were harvested on Mount Etjo farm in the Otjozondjupa region of Namibia as part of a cull that takes place every year, in order to curb the population growth as these giraffe have no natural predators on the farm. The giraffe were culled by a head shot, and then exsanguinated in the field (Ethical approval: ACU-2018-7366, Stellenbosch University; Namibian Shoot and sell permit number: 118690). They were then transported back to the abattoir where they were skinned, eviscerated and dressed as described by Ledger (1963).

4.2.2 PROCESSING AND SAMPLING

The dressed carcasses as well as all components of the offal were weighed individually. The weights of the head with tongue, tongue, legs (as removed from the knee and hock joint), skin, gastrointestinal tract with full gut fill (GIT), heart, lungs and trachea, liver, kidneys, spleen, testes with skin, penis, udder where appropriate, and total offal, all reported in kilogram as well as percentage of the total dead weight.

After weighing, a representative sample was taken from each organ of the red offal (heart, liver, kidneys and tongue), this was then placed in a vacuum bag, vacuum-packed and placed in a freezer (- 20°C) until further analyses. A 10 cm^2 section of the heart was cut from the ventricle walls, at approximately midway between the dorsal and ventral points of the heart. The liver was placed flat on a surface and a section, approximately 10 cm^2 was taken from the centre. One kidney was taken from each giraffe. After removing the tough mucosal layer of the tongue, a section at the widest point, near the anterior end was cut for further analysis.

4.2.3 CHEMICAL ANALYSIS

The organs were removed from the freezer and allowed to defrost for approximately 24 h in a fridge at ± 4°C, before being homogenised in a bowl cutter. The organs were cut into smaller pieces before being placed in the bowl cutter, and the liquid lost from thawing was added back before homogenising. These homogenous samples were then placed into small individual bags, vacuum-sealed and refrozen at - 20°C for further analysis. All proximate analyses were performed in duplicate and the average of these two values was taken as the final measure. The error percentage between

the two values was also ascertained and any samples with an error higher than 20 % were repeated to get a more accurate measure.

4.2.3.1 Moisture and ash

The moisture content (g/100 g) of each sample was ascertained as per AOAC Official Method 934.01 (AOAC International, 2002a), by placing a 2.5 g sample of each organ in an oven at 100°C for at least 48 h to dry. These were then removed and weighed back as the moisture-free weight in order to determine the moisture content. These samples were then placed into a furnace at 500°C for 6 h to ash as in accordance with the AOAC Official Method 934.01 (AOAC International, 2002a). These samples were then weighed back to determine the ash content (g/100 g) per sample.

4.2.3.2 Lipid content

A 5.0 g sample of each homogenised organ was used to determine the lipid content, by means of a rapid solvent extraction method (Lee, Trevino & Chaiyawat, 1996). Using a mixture of chloroform/methanol as the solvent, in a ratio of 2 : 1 (v/v), which is the recommended ratio when determining a lipid percentage higher than 5 %, and after performing a test run with both this ratio and the 1 : 2 ratio (v/v), it was determined that the tongue had a fat level well over 5 %. It was therefore decided, for uniformity to make use of the 2 : 1 ratio (v/v) for all organs.

4.2.3.3 Protein content

The filtrate that remained behind after the fat extraction was collected and dried at 60°C for at least 48 h, before being ground into a fine powder. This was dried again, before being used for determining the crude protein content (g/100 g). One gram of powdered sample was weighed off into a LecoTM tinfoil sheet which was closed around the sample before analysis in a Leco Nitrogen/Protein Determinator (FP528 – Leco Corporation) as per the Dumas combustion method described in the AOAC Official Method 992.15 (AOAC International, 2002b). The Leco Determinator was calibrated using 0.1500 g of EDTA (Leco Corporation, USA) also enclosed in a tinfoil sheet. This calibration was carried out periodically during analysis to ensure continued accuracy of readings. The results from the Leco Determinator were reported in nitrogen percentage (% N) per sample, which was then converted to the crude protein content (g/100 g) by multiplying these values by a 6.25 conversion factor (assuming that animal tissue protein consists of 16 % nitrogen).

4.2.4 STATISTICAL ANALYSIS

Statistica Version 13.4 (2018) R (lmer package) was used to perform a one-way univariate analysis of variance (ANOVA) on the yield. Pearson's correlation coefficients were calculated between some of the organs and the dead weight as well as age of the giraffe.The proximate analysis took the form of a split plot design with sex (male and female) as the main plot factor and organ (heart, liver, kidneys and tongue) as the sub-plot factor. Statistica was used to perform an ANOVA using the General Linear Models (GLM) procedure on the parameters for the proximate analyses (moisture, protein, fat and ash). Deviation form normality was assessed by means of the Shapiro-Wilk test on the standardised residuals from the model (Shapiro & Wilk, 1965). Where observations diverged too far from the model value, they were removed as outliers, this was only applicable for the proximate values of the tongue of G12 (one of the female giraffe). For the comparison of sex and organ effects, Fisher's least significant difference was calculated at the 5 % significance level (Lyman Ott & Longnecker, 2010).

4.3 RESULTS

The weights of the offal components of the 15 giraffe are presented in Table 4.1; although there was no difference at the 5 % level between the sexes for the dead weights and warm carcass weights, the males did tend to be heavier. While the head with tongue (P = 0.011), feet (P = 0.006) and kidneys (P = 0.045) weights were all significantly heavier in the males, the liver (P = 0.052) and spleen (P = 0.078) also tended towards being significantly heavier in the males than the females. There were no significant differences between the percentage contributions to the total dead weight of any offal constituent between the sexes.

As none of the giraffe were fully mature, the sex organs were not yet fully developed, therefore the males had fairly small penises (605.0 ± 100.69 g) and testes (558.6 ± 74.92 g), and these weights had a highly positive correlation with age (penis: r = 0.850; testes: r = 0.822) and dead weight (penis: r = 0.953; testes: r = 0.884). Only four of the females had udders that were developed or developing, these averaged 1.2 ± 0.33 kg but ranged in size from 100.8 g to 280.1 g.

Despite the total offal of the males (246.9 ± 16.63 kg) weighing more than that of the females (235.2 ± 8.32 kg), when compared to the dead weight there was no significant difference between the sexes.

Table 4.1 Means (± standard error) of giraffe carcass yields (in kg and as a percentage of the dead weight) as influenced by sex

Carcass parameter		Sex		*P-value*
		Male (n = 8)	Female (n = 7)	
Dead weight	kg	691.1 ± 45.46	636.5 ± 33.76	0.096
Warm carcass	kg	400.4 ± 28.62	366.4 ± 15.58	0.063
	%	56.7 ± 0.85	56.8 ± 1.28	0.982
Head with tongue	kg	21.6[a] ± 1.74	19.1[b] ± 0.64	**0.011**
	%	3.1 ± 0.12	3.0 ± 0.11	0.546
Feet	kg	32.5[a] ± 1.90	27.6[b] ± 1.02	**0.006**
	%	4.7 ± 0.13	4.4 ± 0.16	0.125
Skin	kg	70.5 ± 4.27	67.9 ± 2.92	0.418
	%	10.3 ± 0.46	10.7 ± 0.31	0.432
Heart	kg	3.3 ± 0.30	3.3 ± 0.19	0.638
	%	0.5 ± 0.02	0.5 ± 0.03	0.250
Lungs & trachea	kg	5.4 ± 0.39	4.8 ± 0.12	0.151
	%	0.8 ± 0.06	0.8 ± 0.04	0.874
Liver	kg	7.3 ± 0.56	6.6 ± 0.22	0.052
	%	1.1 ± 0.03	1.1 ± 0.04	0.905
Kidneys	kg	1.5[a] ± 0.11	1.4[b] ± 0.07	**0.045**
	%	0.2 ± 0.01	0.2 ± 0.01	0.977
Spleen	kg	1.8 ± 0.10	1.6 ± 0.08	0.078
	%	0.3 ± 0.01	0.3 ± 0.02	0.842
Tongue	kg	1.07 ± 0.09	1.04 ± 0.05	0.469
	%	0.2 ± 0.00	0.2 ± 0.01	0.229
GIT (with contents)	kg	101.8 ± 9.72	102.3 ± 5.42	0.869
	%	14.7 ± 0.612	16.2 ± 0.839	0.184
Penis	g	605.0 ± 100.69		
	%	0.1 ± 0.01		
Testes with skin	g	558.6 ± 74.92		
	%	0.1 ± 0.01		
Udder (n = 4)	kg		1.2 ± 0.33	
	%		0.2 ± 0.04	
Total offal	kg	246.9 ± 16.63	235.2 ± 8.32	0.165
	%	35.7 ± 0.50	37.2 ± 1.04	0.227

GIT: Gastro intestinal tract. [a-b]Means with different superscripts within a parameter for sex differ significantly from each other ($P \leq 0.05$).

The proximate chemical composition of the red offal of the 15 giraffe is presented in Table 4.2. There was found to be a significant interaction between sex and organ for protein (P = 0.010), total lipid (P = 0.028) and ash (P = 0.018). While the moisture % was the only significantly affected by the organ, the effect of sex also tended towards significance, with a higher percentage in males.

Table 4.2 Means (± standard error) of the proximate composition (g/100 g) of four organs from giraffe (n = 15) as influenced by sex and muscle. Both main effects and interactions have been included for all parameters

Parameter (g/100 g)	Organ	Pooled for sex (n = 15)	*P-value* Organ	Sex		*P-value* Sex
				Male (n = 7)	Female (n = 8)	
Moisture	**Heart**	78.9^{a} ± 0.34	**< 0.001**	79.3^{ab} ± 0.56	78.3^{b} ± 0.26	0.063
	Liver	71.9^{b} ± 0.24		72.1^{c} ± 0.23	71.5^{c} ± 0.43	
	Kidney	80.3^{a} ± 0.31		81.0^{a} ± 0.38	79.4^{ab} ± 0.24	
	Tongue	72.9^{b} ± 0.90		73.4^{c} ± 1.09	72.4^{c} ± 1.60	
	Pooled for organ	76.0 ± 0.54		76.5 ± 0.75	75.5 ± 0.78	
Protein	**Heart**	17.7^{b} ± 0.29	**< 0.001**	17.1^{bc} ± 0.43	18.3^{b} ± 0.24	0.870
	Liver	21.7^{a} ± 0.26		21.4^{a} ± 0.38	22.1^{a} ± 0.33	
	Kidney	14.7^{c} ± 0.22		14.2^{e} ± 0.22	15.2^{de} ± 0.26	
	Tongue	14.9^{c} ± 0.88		15.9^{cd} ± 1.23	13.5^{e} ± 1.10	
	Pooled for organ	17.3 ± 0.44		17.2 ± 0.58	17.4 ± 0.68	
Total fat	**Heart**	2.5^{c} ± 0.22	**< 0.001**	2.6^{c} ± 0.35	2.4^{c} ± 0.29	0.178
	Liver	4.1^{b} ± 0.13		4.1^{c} ± 0.12	4.0^{c} ± 0.27	
	Kidney	3.7^{bc} ± 0.20		3.6^{c} ± 0.24	3.9^{c} ± 0.34	
	Tongue	9.1^{a} ± 1.08		7.5^{b} ± 0.57	11.1^{a} ± 2.23	
	Pooled for organ	4.8 ± 0.42		4.5 ± 0.38	5.1 ± 0.80	
Ash	**Heart**	1.0^{c} ± 0.03	**< 0.001**	1.0^{de} ± 0.05	1.0^{cde} ± 0.01	**0.038**
	Liver	2.0^{a} ± 0.14		2.3^{a} ± 0.15	1.7^{b} ± 0.18	
	Kidney	1.2^{b} ± 0.07		1.3^{c} ± 0.13	1.2^{cd} ± 0.03	
	Tongue	0.9^{c} ± 0.01		0.9^{e} ± 0.02	0.9^{de} ± 0.02	
	Pooled for organ	1.3 ± 0.07		1.4 ± 0.11	1.2 ± 0.08	

$^{a-e}$Means with different superscripts within a parameter for sex and organ differ significantly from each other ($P \leq 0.05$).

The kidneys had the highest moisture content (80.3 ± 0.31 %), closely followed by the heart (78.9 ± 0.34 %), while the tongue (72.9 ± 0.90 %) and liver (71.9 ± 0.24 %) had lower moisture contents. The males tended to have a higher moisture content than the females (Table 4.2). The liver had the highest protein content (21.7 ± 0.26 %), followed by the heart (17.7 ± 0.29 %). The kidneys had the

next highest protein content (14.7 ± 0.22 %) while the tongues of the females had a significantly lower protein content than the males (male: 15.9 ± 1.23 %; female: 13.5 ± 1.10 %) (Table 4.2). Sex had little influence on the fat content of all organs other than the tongue where the females (11.1 ± 2.23 %) had a significantly higher fat content than the males (7.5 ± 0.57 %), the fat content of the tongue was higher for both sexes than any of the other organs. The liver (4.1 ± 0.13 %) and kidneys (3.7 ± 0.20 %) had significantly less fat than the tongue and the heart had the least (2.5 ± 0.22 %) (Table 4.2). It must be noted that all external kidney fat was removed before processing. The liver had the highest ash content for both sexes, but the males' livers had a significantly higher ash content (2.3 ± 0.15 %) than the females (1.7 ± 0.18 %), the kidneys (1.2 ± 0.07 %), heart (1.0 ± 0.03 %) and tongue (0.9 ± 0.01 %) did not differ significantly by sex (Table 4.2).

4.4 DISCUSSION

This study aimed to develop baseline data on the yields of giraffe offal as well as the proximate chemical composition of the red offal (heart, liver, kidneys and tongue) in order to assess the nutrient content of these organs. As there is a constant demand for alternative and cheap protein sources in South Africa, this may assist in finding new potential sources. While the offal is often where parasites and diseases manifest, the organs used in this study were predominantly found to be perfectly healthy (as determined by the trained health official in the abattoir), with the exception of a few of the livers that had some minor *Echinococcosis* infestations.

While the giraffe is a very unique animal and not really comparable to any of the more commonly used game or domestic species, the eland (*Taurotragus oryx*) is probably the most comparable in terms of the carcass conformation, if one disregards the differences in neck and leg dimensions. There was no significant difference between the dead weights of the two sexes, although this and the carcass weights did tend towards significance as discussed in Chapter 3, this was the same trend noted for eland of a similar maturity (Laubser, 2018). The head with tongue (P = 0.011) weights were significantly heavier in males than in females (Table 4.1). This was expected as the males use their heads to fight one another, and therefore their skulls are a lot thicker and more densely ossified (Dagg, 1965; Spinage, 1968). Their skulls must be able to withstand the force of being used like a sledgehammer to batter other males as they fight for the right to mate. Giraffe skulls have very large frontal sinuses, which in males have an intricate bone structure which is dense enough to withstand the battering against other males, while females on the other hand, have very thin, and far less, bony supports through this frontal sinus, and for the rest, transcended only by fibrous connective tissue (Badlangana, Adams & Manger, 2011). This finer, lighter structure, is a typical sexual dimorphism,

resulting in less weight that the females need to support at the top of their long necks. While in eland the head weights were lighter than in giraffe, they made up a greater percentage of the dead weight than in giraffe (Laubser, 2018), this could be, in part, due to the heavier horns. However, eland heads do not need to be supported at the top of a 2 m long neck.

The feet of the males were significantly heavier (P = 0.006) than in the females (Table 4.1) which may be due to the fact that the males' forelegs were significantly longer than the females' as discussed in Chapter 3, therefore weighing more. When comparing the weight of the legs to that of eland (Laubser, 2018) they make up approximately twice as much of the total dead weight, which is to be expected as giraffe have thicker and more dense bone, and a narrower marrow cavity than other ungulates of similar size in their legs (Van Schalkwyk, Skinner & Mitchell, 2004), as well as giraffe having much longer legs than eland.

The skin in giraffe also made up approximately twice as much of the total dead weight in giraffe than in eland (Laubser, 2018). This is due to the thickness of giraffe skin, which measures up to of 2 cm thick in places (Sathar, Badlangana & Manger 2010), as well as the greater total surface area of giraffe compared to eland. The GIT of the eland, however, made up approximately double the percentage of the total carcass in males, and approximately 1.5 times the percentage in females, compared to giraffe. The liver, heart and kidneys all made up similar percentages of the dead weight in giraffe and eland. However, the lungs and trachea made up about double the percentage in the eland than in giraffe, despite the original assumption that a giraffe would require a larger heart and lungs in order to circulate enough oxygenated blood up their long necks to their heads. This was proved wrong by Mitchell and Skinner (2009; 2011) when they showed that giraffe have smaller lungs in comparison to body size than other large ungulates. Furthermore, giraffe do not have larger hearts relative to body size than other mammals. The spleen of eland made up approximately half the percentage of that of the giraffe spleen (Laubser, 2018).

The kidneys of the male giraffe were significantly heavier than the females (P = 0.045), while the liver (P = 0.052) and spleen (P =0.078) both also tended to be heavier in males than females (Table 4.1), however when one considers the percentage of the dead weight, there were no sexual dimorphisms for any of the organs. This may be due to the fact that the giraffe were on average 3.7 years old, and therefore mainly pubescent, and not fully mature. However, one female was found to be pregnant, which shows that at least some of them were sexually mature. Although it was found that the sexual organs had a strong positive correlation with age, it is unlikely that they were fully developed. Only four female giraffe had udders large enough to weigh and these had a large amount of variation in mass.

The tongue of G12, the pregnant female was removed from the data set as it was deemed to be an outlier, it had a moisture content of 46.8 %, a protein content of 13.4 %, a fat content of 33.3 % and an ash content of 0.5 %. The fat content of this tongue was far higher than the other tongues, and therefore the other constituents are lower to compensate. The moisture in particular was lower than for the other tongues, as this is inversely related with the fat content (Table 4.2).

The protein content tended to be similar between the sexes when the chemical composition of the organs were pooled (Table 4.2), however, when evaluating the individual organs, the males tended to have slightly lower protein percentages than the females for all organs other than the tongue, for which males had a significantly higher protein content than females. This is most likely due to the compensation for the higher fat content in the female tongues. It was observed that tongues that were very fatty tended to have less visible muscle as the fat seemed to replace some of the muscular tissue in the centre of the tongue.

The females tended to have a higher fat content than the males (Table 4.2), when the fat contents for the organs were pooled, and the tongue had a significantly higher fat content in females than males. Females do tend to have a higher carcass fat content in general than males, across most wild ungulate species (Hoffman, 2000; Ledger, Sachs & Smith 1967; Von la Chevallerie & Van Zyl, 1970), as they store more fat to provide for carrying young. There was a wide variation observed in the levels of fat in the tongues in general which could be linked to level of nutrition in general, or to maturity.

The ash content of the red offal differed significantly between the two sexes (Table 4.2), however, it was only the liver that had a significantly higher ash content in males than in females. The ash content is used as a measure of the mineral content in proximate analysis, therefore it can be concluded that males had a higher mineral content in their livers than females. The mineral content of the liver, meat (from the LTL muscle) and bone, are discussed in Chapter 6. Although the reason for the higher mineral content in the males is unknown, it may be due to their feeding patterns, as they do differ from the females' feeding patterns. Males do not spend as much time per day browsing as females, as they dedicate more time to looking out for potential threats (Pellew, 1984), although Blomqvist and Renberg (2007), found that this was not the case on farms where there were no predators. However, males do also dedicate time to walking around to look for a mate, or engaged in fighting for the right to mate. As males spend less time actively browsing, they have to consume more in a shorter space of time, than females, in order to support their larger bulk. This means that males are less selective than females in what they browse, while females will pull the leaves from the thorny branches, the males tend to take larger mouthfuls which include more of the branch, consequently

containing higher lignin and fibre, while the females' diets are more nutrient rich (Ginnett & Demment, 1997).

When the data for the sexes were pooled, the heart and kidneys had a significantly higher moisture content than the liver and tongue (Table 4.2). The heart (giraffe: 78.9 ± 0.34 %; buffalo: 78.4 ± 0.50 %) and liver (giraffe: 71.9 ± 0.24 %; buffalo: 71.9 ± 0.37 %) had a similar moisture content to that of buffalo (Verma *et al*., 2008). The moisture content of the liver was very similar to that of buffalo (Devatkal *et al*., 2004). The moisture content of the kidneys was higher than that reported for the kidneys of cattle (giraffe: 80.3 ± 0.31 %; cattle: 78.8 ± 0.77 %) (Van Heerden & Morey, 2014). The moisture of the tongue was much higher than that of cattle (giraffe: 72.9 ± 0.90 %; cattle: 64.8 ± 3.21 %) (Van Heerden & Morey, 2014).

When the sexes were pooled the heart recorded slightly higher values for protein than of buffalo (giraffe: 17.7 ± 0.29 %; buffalo: 15.5 ± 0.9 %) (Verma *et al*., 2008). The liver had a quite substantially higher protein content than that of buffalo (giraffe: 21.7 ± 0.26 %; buffalo: 18.4 ± 0.56 %) (Devatkal *et al.*, 2004). No information could be found on the chemical composition of the tongue or kidneys of buffalo, however when comparing to beef or sheep, it is found that giraffe kidneys have a protein content far closer to those of sheep than of cattle (giraffe: 14.7 ± 0.2 %; cattle: 17.0 %; sheep: 14.3 %) (Kurt & Zorba, 2007). The protein content of the tongue was lower than that of cattle tongue (giraffe: 14.9 ± 0.88 %; cattle: 16.83 ± 0.45 %) (Van Heerden & Morey, 2014) (Table 4.2).

When the percentage fat for both sexes were pooled, the tongue had far less fat content than tongues of cattle (giraffe: 9.1 ± 1.08 %; cattle: 18.1 ± 3.80 %) (Van Heerden & Morey, 2014). The heart had a greater fat content than buffalo heart (giraffe: 2.5 ± 0.22 %; buffalo: 1.1 ± 0.14 %) (Verma *et al*., 2008). The liver, however, had a lower fat content than that of buffalo (giraffe: 4.1 ± 0.13 %; buffalo: 5.6 ± 0.30 %) (Devatkal *et al*., 2004). The kidneys had a similar fat content to those of cattle (giraffe: 3.7 ± 0.20 %; cattle: 3.6 ± 0.84 %) (Van Heerden & Morey, 2014) (Table 4.2).

When the ash percentage for the two sexes were pooled, the giraffe liver had a lower ash content than buffalo liver (giraffe: 2.0 ± 0.14 %; buffalo: 5.6 ± 0.30 %) (Devatkal *et al*., 2004). The kidneys had a similar ash content to that of cattle (giraffe: 1.2 ± 0.07 %; cattle: 1.1 ± 0.1 %) (Van Heerden & Morey, 2014). The giraffe heart had a similar ash content to buffalo (giraffe: 1.0 ± 0.03 %; buffalo: 1.3 ± 0.04 %) (Verma *et al*., 2008). The ash content of the tongue was also similar to that of cattle (giraffe: 0.9 ± 0.01 %; cattle: 0.83 ± 0.1 %) (Van Heerden & Morey, 2014) (Table 4.2).

4.5 CONCLUSION

The yield of edible offal per giraffe culled is high in comparison to other large ungulates, while maintaining a favourable dressing percentage. Since offal is widely utilised in Africa by low income households, this greatly increases the usable portion of the carcass and therefore, the profit margins as well. It was found that sex only had a small impact on the weight of the organs, however, the differences in weight were all proportional to the dead weights. The red offal was found to have a favourable protein content, and generally a lower total fat content than cattle, and may therefore be a good alternative source of protein. In order to quantify sexual dimorphisms in organ weights, it may be recommended to carry out a study on mature giraffe, as the giraffe used in this study were pubescent. This study also did not encompass the chemical composition of the brown offal, and as this is also widely consumed across Africa, is an aspect worthy of further research.

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CHAPTER 5

PHYSICAL MEAT QUALITY CHARACTERISTICS OF GIRAFFE (*Giraffa camelopardalis angolensis*) AS AFFECTED BY SEX AND MUSCLE.

ABSTRACT

Despite some giraffe populations being threatened, their numbers grow exponentially when farmed, as they have no natural predators, and this necessitates periodic culling in order to control their population numbers and prevent them exceeding the carrying capacity. As these culls result in a large quantity of meat, this study aimed to quantify the effect of sex on the yields of the fresh cuts, as well as the effect of sex and muscle on the physical quality characteristics (pH, cooking and drip loss, colour and Werner-Bratzler shear force (WBSF)) of giraffe meat. There were no significant differences between yields for the sexes. The WBSF was the only physical parameter to be affected by a significant interaction between sex and muscle (P <0.001), and the interaction for the CIE L* values also tended towards significance (P = 0.054). Cooking loss (male = 41.6 ± 0.35 %; female = 40.7 ± 0.33 %; P = 0.024) and CIE L* values (male = 38.8 ± 0.23; female = 37.3 ± 0.27; P = 0.039) were both affected by sex. Muscle had a significant effect on all physical parameters. The ultimate pH of all muscles was in the acceptable range (5.5 – 5.9); the average WBSF of <43 N for all muscles indicates giraffe meat of this study is tender. The meat colour was lighter than most game meat, which may be advantageous, as consumers tend to discriminate against game meat for its dark colour. As myoglobin content is the main factor determining the colour of the meat, seven muscles from each giraffe were analysed to determine the total myoglobin content thereof, this was found to range from 5.1-9.3 mg/g with a significant interaction between sex and muscle (P = 0.001). This study shows that yield and physical characteristics of giraffe meat are favourable and the results may be useful for the marketing of giraffe meat.

Keywords: Game meat, pH, Water holding capacity, Drip loss, Cooking loss, Colour, Tenderness

5.1 INTRODUCTION

Giraffe populations in central Africa are shrinking, so much so that the International Union for Conservation of Nature (IUCN) has classified two subspecies as critically endangered and one as endangered on their Red List of Threatened Species, and declared the giraffe species as a whole as vulnerable (Muller *et al*., 2018). However, in southern Africa, the *G. c. angolensis*, which is the subspecies used in this study, has increased from an estimate of 5 000 individuals to approximately

14 748 (+295 %, Marais *et al*., 2018). The increase in these populations is largely due to private game ranches farming with these animals, where the giraffe has no natural predators. As the giraffe are fenced in, they only have access to the vegetation within these fences, therefore their populations cannot be left to grow unchecked as they will soon reach the carrying capacity of the camp. In order to avoid this, population control is necessary, whether by relocating or by culling. Relocation has its downsides as the darting and capture of giraffe is stressful and dangerous for the giraffe as well as being expensive. The market for live sale of giraffe is also not always favourable, therefore this is not always an option. Thus, many farmers opt for culling giraffe, as often as necessary, in order to maintain a constant population. This can be by shooting the giraffe themselves, or by allowing trophy hunters to hunt them. The latter is a favourable financial option (prices range between US$ 2 950 (R 43 000; Mukulu African Hunting Safaris https://huntinginafricasafaris.com/south-african-hunting-safari-prices/; accessed on 23 September 2019) and US$ 3 950 (R 58 000; Ash Adventures, African Sky Hunting, Hunting in Africa Safaris; https://www.africanskyhunting.co.za/pricelist.html; accessed on 23 September 2019) although there is negative public perception of this activity in some spheres. These trophy hunters will often only take the skin, and occasionally the bones and head, but leave the meat, as they are often foreign hunters. Therefore, even if giraffe are hunted by trophy hunters, there is a substantial amount of meat produced from every cull (Chapter 3).

There has been very little research to date in terms of the quality of giraffe meat. Hall-Martin, Von La Chevallerie and Skinner (1977) evaluated the carcass composition and very basic meat quality in terms of muscle fibre diameter of the *Longissimus thoracis et lumborum* muscle (LTL); there has been no other study since then.

The appearance of meat is very important for marketing thereof, which is determined by the combination of the physical characteristics. The colour of game meat is a big factor in consumer perception thereof, as it tends to be darker than traditional red meat species, which may affect consumer preference as consumers prefer red meat that is not too dark or light (Jeremiah, Carpenter & Smith, 1972). Myoglobin (Mb) content is the main factor determining the perceived colour of the meat. Myoglobin has three different forms, namely deoxymyoglobin (DMb), which has a purple-reddish colour, oxymyoglobin (OMb), with a bright cherry red colour, and metmyoglobin (MMb), which has a brownish tinge (Mancini & Hunt, 2005; AMSA, 2012); the latter may appear off-putting to the consumer. While the consumer preference is for the bright red of the OMb which they tend to associated with fresh meat, however, this is not the most stable form for Mb as this is how it appears after exposure to oxygen and is a transitional form in the redox reaction before becoming MMb. The most stable form is DMb, which is prior to oxygen exposure and exhibits the purple-reddish colour associated with vacuum-packed meat (Mancini & Hunt, 2005; AMSA, 2012). Game meat is generally

exported in vacuum-packaging as it often has to travel for extended periods, but may be repackaged when it reaches its destination. However, colour is also affected by the rate of pH decline and the ultimate pH (pH_u) reached, as well as the temperature decline of the meat. These factors also affect the water holding capacity of the meat and the toughness thereof, which are important to the quality of the meat. As there has been very little research on the meat quality of giraffe, and as they hold such a unique niche in semi-arid savannah areas, showing promise for diversifying the meat sources of these areas, this study aims to develop base line data of the muscle yield and physical attributes of the meat from the giraffe.

5.2 METHODS AND MATERIALS

5.2.1 EXPERIMENTAL LOCATION AND ANIMALS

Fifteen Angolan giraffe (*Giraffa camelopardalis angolensis)*, of which seven were cows and eight were bulls, with ages ranging from 2.5 years to 6 years old, were sourced from Mount Etjo Game Farm in the Otjozondjupa Region of Namibia. The prevailing veld type in this area is the thornbush savanna, with predominantly *Vachellia* and *Senegalia* (previously collectively known as *Acacia*) trees and sweet grass species. The farm has approximately 1100 giraffe which live in an extensive camp of approximately 22000 ha. They receive no supplementary feed and undergo no selective breeding and only minimal human intervention by means of watering holes and mineral licks.

5.2.2 CULLING, CARCASS PROCESSING AND SAMPLING

As the giraffe in the camp on Mount Etjo have no natural predators, it is required to cull them regularly. Despite regular culls the population on the farm has increased from 900 to 1100 over the past 6 years, in 2018 they culled approximately 70 giraffe, mainly sub-adult (<6 years old) males. The giraffe for this trial were mainly culled in the morning, however, some were culled around midday. All giraffe for this trial were culled by a head shot into the brain (Ethical approval: ACU-2018-7366, Stellenbosch University; Namibian Shoot and sell permit number: 118690), followed by exsanguination.

The giraffe were transported back to the abattoir where they were skinned, eviscerated (Ledger, 1963) and cut into eight carcass sections as described by Hall-Martin and colleagues (1977); for more information on the carcass processing refer to Chapter 3. The carcass sections were placed into industrial chillers (temperature set to 4 ± 1°C) overnight to undergo *rigor mortis*.

Approximately 24 h post-mortem, eight muscles were removed from the right side of each carcass, namely the *Longissimus thoracis et lumborum* muscle (LTL), *Semimembranosus* muscle (SM),

Biceps femoris muscle (BF), *Semitendinosus* muscle (ST), *Gluteus medius* muscle (GM), *Supraspinatus* muscle (SS), *Infraspinatus* muscle (IS), and *Psoas major* muscle (PM), for physical analysis. A further three muscles were removed from the left side of the carcasses and weighed, the LTL, SM and BF, the LTL was kept for sensory testing (Chapter 7). All of these muscles were weighed individually before sections of the muscles from the right side were sampled for physical analysis. The rest of the muscle samples were used for chemical analyses (Chapter 6) and samples from the right side LTL, SM and BF muscles were used for a post-mortem ageing study (Chapter 8).

5.2.3 PHYSICAL ANALYSIS

5.2.3.1 Acidity (pH)

The ultimate pH (pH_u) was determined and the pH curve calculated from the readings taken with an Accsen pH 70+DHS® portable pH meter (Accsen Instrumental, Barcelona, Spain) calibrated using a two-point calibration of standard buffers of pH 4 and pH 7 respectively.

For the pH curves of each animal, pH readings were taken immediately after time of death and subsequently every hour for four hours, then every two hours for the next eight hours and subsequently every four hours until processing at approximately 24 h post-mortem. The pH was taken by cutting a small hole at a posterior angle, in the loin muscle (LTL) and inserting the pH meter into it to take the reading. pH readings and corresponding body temperatures were recorded, as well as the time at which these were taken. The electrode was rinsed in distilled water and blotted dry with clean paper towel between each measurement and stored in buffer solution according to the manufacturer's instructions. The ultimate pH (pH_u) was taken in the centre of each muscle at ± 24 h post-mortem, after the removal of the eight muscles.

5.2.3.2 Temperature

The temperature of the LTL muscles was recorded at the same time as the pH for the pH curve, and the rate of decline was determined in the same manner. Temperature loggers were also placed at random into the hindquarters of several of the giraffe, these then logged the temperature every half hour. Two were placed deep in the BF muscle, near the bone, one was placed ± 5 cm into the BF, and one was placed at random into the hindquarter. These readings were recorded from when the hindquarters were placed into the chiller, until processing at ± 24 h post-mortem.

5.2.3.3 Colour

A steak, ± 2 cm thick, was cut from the centre of each muscle from the right side of the giraffe, perpendicular to the muscle fibres. These steaks were allowed to bloom for ± 30 min before five CIELab colour readings were taken at random on the muscle surface using a calibrated Colour-guide 45°/0° colorimeter (model 6801, BYK-Gardner GmbH, Geretsried, Germany; aperture diameter size: 11mm; illuminant/observer angle: D-65/10°). The reported colour values were according to lightness (CIE L*), red-green spectrum (CIE a*) and blue-yellow spectrum (CIE b*) in accordance with the CIELab colour system. These recorded values were then used to calculate the hue-angle and the chroma values which represent the colour definition and saturation/colour intensity, respectively. These values were calculated according to:

$$Hue - angle\ (°) = tan^{-1}\left(\frac{b^*}{a^*}\right)$$

$$Chroma\ (C^*) = \sqrt{(a^{*2} + b^{*2})}$$

5.2.3.4 Water-Holding Capacity

To calculate the water holding capacity of the giraffe meat, the moisture loss in terms of drip loss and cooking loss was measured (Honikel, 1998). Steaks ± 1 cm thick were cut from near the centre of each muscle, perpendicular to the muscle fibres. These were weighed for an initial weight, before being hung inside an inflated plastic bag, ensuring that the meat did not come into contact with the sides of the bag, these were hung in a chiller (4 ± 1°C) for 24 h. These samples were then removed, patted dry with an absorbent paper towel and weighed back to determine the final weight and moisture loss, expressed as a % of the initial weight.

Similar sized steaks were used for the cooking loss. After weighing, the steaks were placed into polybags, which were sealed before being placed into a water bath (80°C) for one hour. Thereafter the samples were removed, the excess liquid decanted out of the bags and placed in the chiller. The chilled samples were blotted dry and weighed. The moisture loss was calculated as a percentage of the initial weight (Honikel, 1998).

5.2.3.5 Warner-Bratzler shear force (WBSF)

The cooked cooking loss samples were used for Warner-Bratzler shear force (WBSF) determination. Six cylindrical cores (1.27 cm diameter) were cut longitudinally to the muscle fibres (Voisey, 1976). Care was taken to avoid any visible membranes and collagenous tissue in these cores (this sometimes proved difficult, as there were many membranes present; Supplementary Fig. 1). These cores were then sheared perpendicular to the muscle fibres' axis with a Warner-Bratzler blade (1.2 mm thick with

a triangular opening, 13 mm at the widest point and 15 mm high) connected to an Instron (Emerson Electrics, S44EXTJ-988, ST. Louis, United States of America) at a speed of 3.33mm/s (Honikel, 1998). The Instron gave readings in kg/1.27 cm ø, the average of these values between the six cores was used to determine the tenderness of that muscle. For ease in interpreting the meaningfulness of these values, they were converted to Newton (N) by:

$$Warner - Bratzler\ shear\ force\ (N) = \frac{(F\ x\ 9.81)}{Area}$$

$$Where\ F = \ kg/1.27cm\ \phi$$

$$and\ area = \ \pi(\frac{1.27}{2})^2$$

5.2.3.6 Myoglobin content

The myoglobin content of each sample was determined from a 5 g homogenous sample by adding a potassium phosphate buffer in a 1:10 ratio, before homogenising the sample and buffer together for ± 30 seconds. The samples were then allowed to extract for approximately 1 h at ± 4°C, before being centrifuged at 4000 rpm at 4°C for 30 min. The extract was then filtered and 200 µl thereof was pipetted into separate wells in duplicate. The wells were then scanned at 525 nm (A_{525}) with a spectrometer (Spectrostar Nano, BMG Labtech, Ortenberg, Germany) and the results were used to calculate the total myoglobin content (Tang, Faustman & Hoagland, 2004), as follows:

Total myoglobin content (mg/g) = (A_{525} / 7.6) x 17 x 11

Where 7.6 is the Millimolar extraction coefficient for myoglobin at 525 nm, 17 is the average myoglobin molecular mass, and 11 is the dilution factor.

5.2.4 STATISTICAL ANALYSIS

The muscle yields were analysed by means of a one-way univariate analysis of variance (ANOVA). The experimental method for the physical parameters was a completely random split plot design, as eight male and seven female giraffe were randomly culled. Sex was the main plot effect, with muscle as the subplot factor. The data was analysed using Statistica Version 13.4 (2018) R (lmer package), where the General Linear Models procedure was used to perform a univariate analysis of variance (ANOVA). Deviation from normality was tested for by means of a Shapiro-Wilk test, performed on the standardised residuals (Shapiro & Wilk, 1965). Fisher's least significant difference was used to compare the sex and muscle differences (Lyman Ott & Longnecker, 2010). The 5 % probability level was used ($P \leq 0.05$) as an indication of significance.

A non-linear regression model was fitted to the rate of pH decline and the rate of temperature decline for each individual as well as per sex:

$$y = l + (u - l)(1 - r)^x$$

Where *l* is the lower parameter, *u* is the upper parameter and *r* is the rate of decay. As the rate of temperature decline was found to differ between the individuals, as well as the fact that it was found that the temperature at time of death was not the same for giraffe culled in the morning compared to those culled in the afternoon, the pH readings were standardized at 5°C (the lowest temperature reached during the 24 h) using the formula of Bruce, Scott and Thompson (2001):

$$pH_{adjusted\ at\ t} = measured\ pH_t + ((T_t - T_{adjusted}) \times 0.01)$$

Where: pH_t is the measured pH at time = *t*, T_t is the muscle temperature at time = *t* and $T_{adjusted}$ is the muscle temperature (5°C) to which the data is adjusted. These $pH_{adjusted}$ values were then re-analysed as described above.

5.3 RESULTS

The effect of sex on individual muscle yields is presented in Table 5.1. There were no significant differences between the muscles of the left and right sides and therefore the average of the two sides is represented in Table 5.1. None of the muscle weights differed (P >0.05) between the male and female giraffe. The SM was the only muscle to tend towards a difference (P = 0.082) between the sexes, with males having a slightly heavier (8.9 ± 0.43 kg) weight than the females (8.0 ± 0.30 kg).

Of the physical parameters, only the WBSF was affected by a significant interaction between sex and muscle (P <0.001) (Table 5.2), however, the only muscle to differ significantly for sex was the GM (male: 27.5 ± 1.46 N; female: 33.2 ± 1.35 N) (Fig. 5.1). The effect of the interaction between sex and muscle on the CIE L* values also tended towards significance (P = 0.054). As there were no interactions between the sex and muscle for the other physical characteristics, the main effects of sex and muscle could be individually interpreted, the results of which are reported in Tables 5.3 and 5.4, respectively.

Sex only had a significant effect on the cooking loss % (P = 0.024) and the CIE L* values (P = 0.039) (Table 5.3), with the males having a higher cooking loss % (41.6 ± 0.35) than the females (40.7 ± 0.33) as well as higher L* values (38.8 ± 0.23) than the females (37.3 ± 0.27).

Table 5.1 Mean (± standard error) weights (kg) of eight muscles from giraffe as influenced by sex

Muscle (kg)	Sex				*P-value*
	Male (n = 8)		Female (n = 7)		
	Mean	#Range	Mean	Range	
Cold carcass weight (kg)	393.1 ± 28.52	310.1 – 535.8	359.5 ± 14.49	290.9 – 407.3	0.053
Longissimus thoracis et lumborum (LTL)*	7.9 ± 0.37	5.8 – 10.7	7.00 ± 0.39	5.1 – 9.3	0.134
Semimembranosus (SM)*	8.9 ± 0.43	6.6 – 11.5	8.0 ± 0.30	6.1 – 8.9	0.082
Biceps femoris (BF)*	9.4 ± 0.59	2.7 – 12.7	9.4 ± 0.40	6.7 – 12.1	0.904
Semitendinosus (ST)	2.7 ± 0.20	2.1 – 3.6	2.6 ± 0.15	2.0 – 3.3	0.271
Gluteus medius (GM)	2.9 ± 0.23	2.2 – 4.2	3.0 ± 0.18	2.3 – 3.9	0.921
Supraspinatus (SS)	1.9 ± 0.19	1.3 – 2.8	1.8 ± 0.08	1.5 – 2.1	0.465
Infraspinatus (IS)	3.3 ± 0.39	1.9 – 5.5	3.2 ± 0.09	2.9 – 3.5	0.501
Psoas major (PM)	2.2 ± 0.13	1.6 – 2.9	2.1 ± 0.12	1.6 – 2.5	0.600

*Average weight from both sides

#Minimum - Maximum

Table 5.2 Level of statistical significance (*P-values*) for the main effects of sex and muscle and their interaction for the physical parameters of giraffe meat

Parameter	Sex	Muscle	Sex*Muscle
pH_u	0.735	**<0.001**	0.589
Drip loss (%)	0.336	**<0.001**	0.975
Cooking loss (%)	**0.024**	**<0.001**	0.105
Shear force (N)	0.675	**<0.001**	**<0.001**
Colour			
L*	**0.039**	**<0.001**	0.054
a*	0.502	**<0.001**	0.696
b*	0.531	**<0.001**	0.290
Chroma	0.716	**<0.001**	0.815
Hue-angle	0.342	**<0.001**	0.144

The muscle type had a significant effect on all physical parameters (P <0.001) of the meat for both sexes (data pooled across sex) (Table 5.4). The pH_u ranged from 5.5 to 5.7 for all muscles with the highest pH_u recorded for the SS, followed by the IS, and the hindquarter muscles having lower readings than the forequarter muscles. The ST had the lowest recorded pH_u, which did not differ

Table 5.3 Means (± standard error) of physical meat quality parameters (pooled across muscles) of giraffe as influenced by sex

Parameter	Sex				*P-value*
	Male (n = 8)		Female (n = 7)		
	Mean	Range	Mean	Range	
pH_u	5.6 ± 0.02	5.2 – 5.9	5.6 ± 0.02	5.3 – 5.9	0.735
Drip loss (%)	2.5 ± 0.14	1.2 – 18.9	2.7 ± 0.17	1.2 – 7.2	0.336
Cooking loss (%)	41.6 ± 0.35	11.5 – 46.6	40.7 ± 0.33	34.5 – 45.7	**0.024**
Shear force (N)	28.8 ± 0.41	18.1 – 49.7	29.8 ± 0.45	17.9 – 46.0	0.675
Colour					
L*	38.8 ± 0.23	32.3 – 48.2	37.3 ± 0.27	30.3 – 47.8	**0.039**
a*	14.9 ± 0.13	9.1 – 18.2	15.3 ± 0.14	10.0 – 18.9	0.502
b*	11.3 ± 0.11	8.0 – 14.9	11.1 ± 0.12	7.7 – 14.6	0.531
Chroma	18.9 ± 0.11	14.7 – 22.8	19.1 ± 0.12	15.2 – 23.4	0.716
Hue-angle	37.5 ± 0.40	25.1 – 53.2	36.2 ± 0.43	25.7 – 49.4	0.342

significantly from the LTL, SM, BF, GM or PM. The results of the pH decrease curve were compared between the original pH readings and the pH values adjusted to a constant temperature, and there was no difference between the rate of decay between sexes for either (Table 5.5). Adjusting the pH did not have a large effect on the rate of decay. Both sexes dropped below the pH of 5.8 after ± 12 h (Fig. 5.2), before levelling off between pH 5.6 and 5.4.

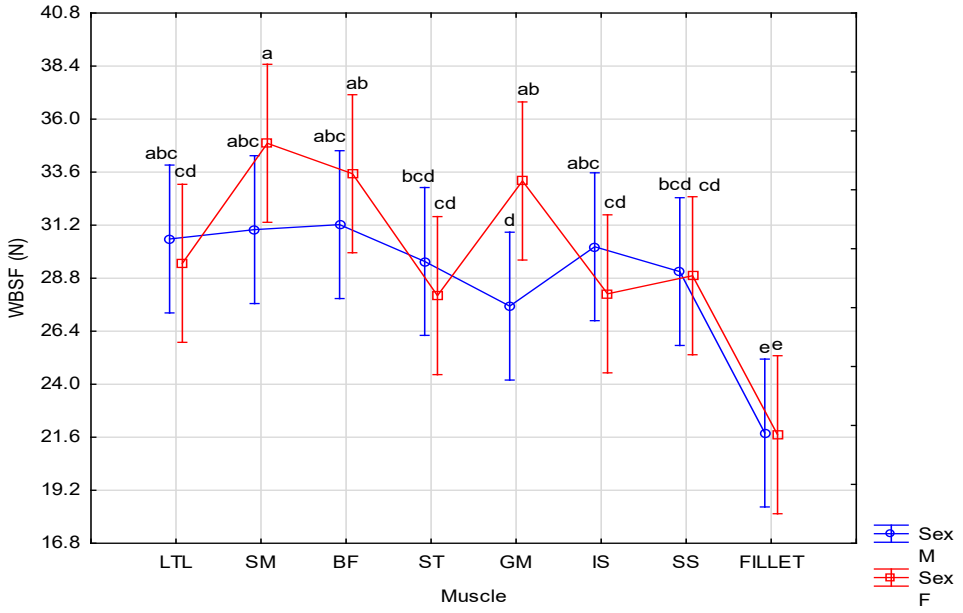

Figure 5.1 The effect of the interaction between sex and muscle on the WBSF of giraffe meat. [a-e]Means with different superscripts differ from one another ($P < 0.05$)

Table 5.4 Means (± standard error) of physical meat quality parameters of giraffe as influenced by muscle

Parameter	Muscle								*P-value*
	LTL[1]	**SM[2]**	**BF[3]**	**ST[4]**	**GM[5]**	**SS[6]**	**IS[7]**	**PM[8]**	
pH_u	5.6^{bc} ± 0.04	5.5^{c} ± 0.03	5.6^{bc} ± 0.03	5.5^{c} ± 0.03	5.5^{c} ± 0.02	5.7^{a} ± 0.04	5.6^{ab} ± 0.03	5.5^{c} ± 0.03	**<0.001**
Drip loss (%)	2.2^{cd} ± 0.20	3.5^{b} ± 0.38	2.8^{c} ± 0.25	2.1^{d} ± 0.15	2.3^{cd} ± 0.17	1.9^{d} ± 0.11	2.0^{d} ± 0.19	4.2^{a} ± 0.32	**<0.001**
Cooking loss (%)	37.5^{d} ± 0.54	43.5^{a} ± 0.39	43.3^{a} ± 0.62	42.4^{ab} ± 0.37	41.6^{b} ± 0.49	41.6^{b} ± 0.56	39.7^{c} ± 0.49	40.0^{c} ± 0.52	**<0.001**
Shear force (N)	30.1^{b} ± 0.83	32.8^{a} ± 0.87	32.3^{a} ± 0.76	28.8^{b} ± 0.72	30.2^{b} ± 1.04	29.0^{b} ± 0.74	29.2^{b} ± 0.75	21.8^{c} ± 0.48	**<0.001**
Colour									
L*	37.0^{d} ± 0.37	36.2^{d} ± 0.28	42.3^{b} ± 0.54	44.3^{a} ± 0.27	36.2^{d} ± 0.37	33.6^{e} ± 0.19	35.9^{d} ± 0.26	39.2^{c} ± 0.22	**<0.001**
a*	14.3^{cd} ± 0.30	16.2^{a} ± 0.23	13.6^{de} ± 0.33	13.1^{e} ± 0.25	15.9^{ab} ± 0.16	16.6^{ab} ± 0.20	16.1^{a} ± 0.20	15.2^{bc} ± 0.15	**<0.001**
b*	10.7^{cd} ± 0.20	11.3^{bc} ± 0.22	12.0^{ab} ± 0.19	12.4^{a} ± 0.16	10.7^{cd} ± 0.21	10.2^{d} ± 0.26	11.1^{bc} ± 0.24	11.4^{bc} ± 0.23	**<0.001**
Chroma	18.0^{c} ± 0.24	19.9^{a} ± 0.22	18.3^{bc} ± 0.28	18.1^{bc} ± 0.25	19.2^{a} ± 0.16	19.6^{a} ± 0.22	19.6^{a} ± 0.20	19.1^{ab} ± 0.14	**<0.001**
Hue-angle	37.2^{b} ± 0.84	35.0^{bc} ± 0.69	41.9^{a} ± 0.80	43.8^{a} ± 0.53	33.9^{cd} ± 0.64	31.5^{d} ± 0.70	34.5^{bc} ± 0.71	36.9^{b} ± 0.72	**<0.001**

Abbreviations: LTL[1] = *Longissimus thoracis et lumborum*, SM[2] = S*emimembranosus,* BF[3] = B*iceps femoris,* ST[4] = *Semitendinosus,* GM[5] =*Gluteus medius*, SS[6] = *Supraspinatus,* IS[7] = *Infraspinatus, PM[8] = Psoas major.*

[a-e] Means within rows with different superscripts differ significantly ($P \leq 0.05$).

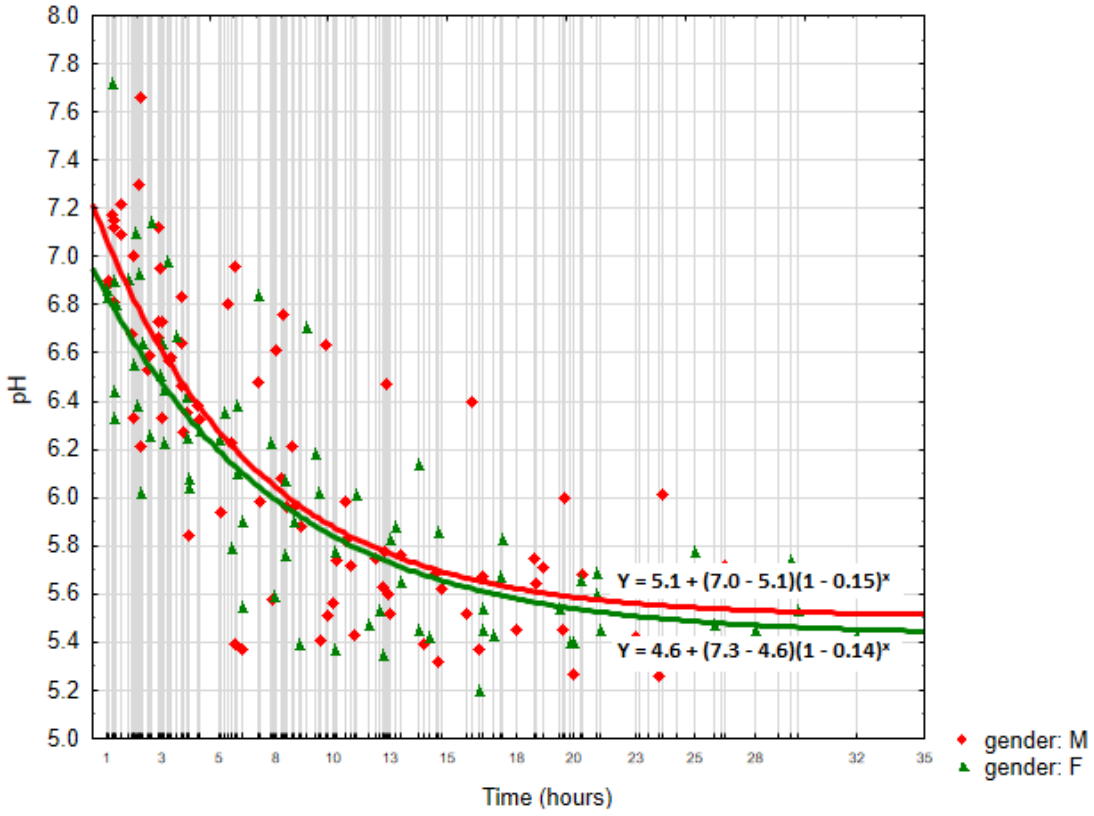

Figure 5.2 The rate of *Longissimus thoracis et lumborum* muscle pH decay of male and female giraffe over 24 h

The rate of temperature decrease of the LTLs was also recorded. It was found that the sex did not have an effect on the decrease rate (P = 0.614), and the temperature for both sexes was found to have a slow rate of decline, only dropping below 10°C after ± 17 h post-mortem. Temperature loggers were also used to log the temperature decline of the muscles in the hindquarters of a few randomly selected giraffe, and it was found that the temperature, while having a steady decline, took a lot longer to drop below 10°C than the LTLs, with only two of the loggers reporting a drop below 10°C within the recorded 24 h. (Fig 5.3).

Table 5.5 The rate of *Longissimus thoracis et lumborum* muscle decay in units/h (mean ± standard error) for pH and adjusted pH over a 24 h period

	Decay rate		
	Male	**Female**	***P-value***
pH	0.14 ± 0.03	0.15 ± 0.04	0.958
Adjusted pH*	0.12 ± 0.02	0.12 ± 0.03	0.986

*pH values adjusted to a standard temperature (5°C)

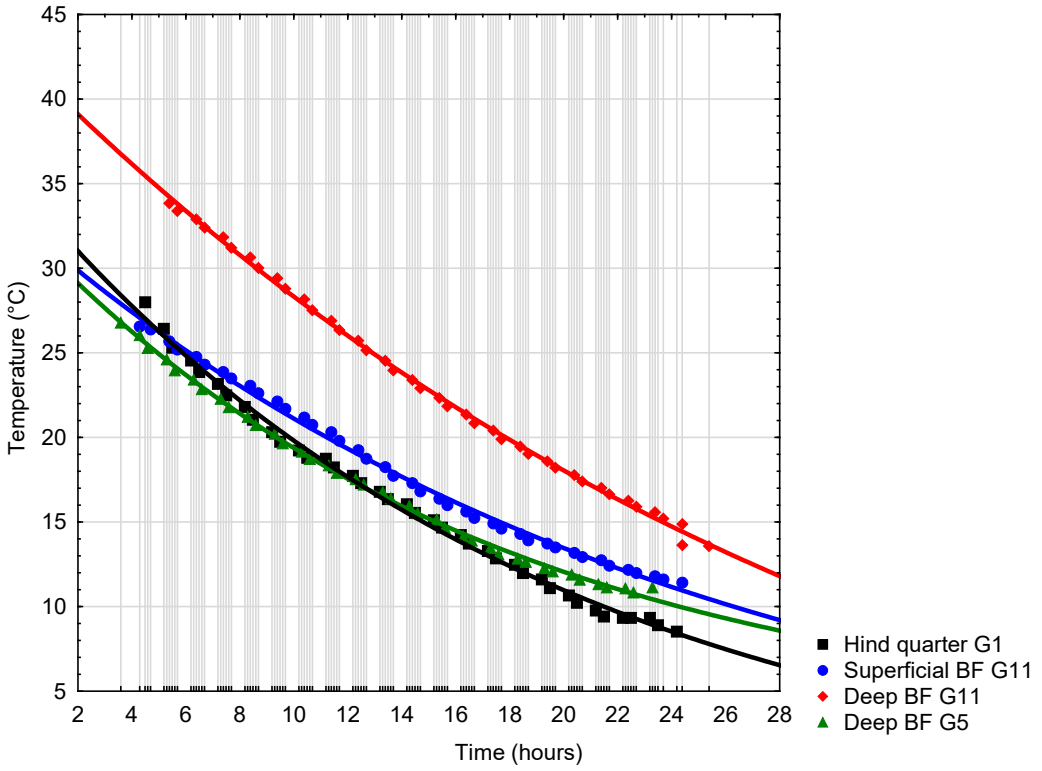

Figure 5.3 Temperature decrease over time for various locations within the hindquarters of giraffe stored in a cooler

Muscle had a significant effect on the moisture loss, with drip loss % ranging from 1.9 - 4.2 %. The PM recorded the highest drip loss, followed by the SM, the LTL, BF and GM while the ST, IS and SS had the lowest drip loss % (Table 5.4). The cooking loss % ranged from 37.5 - 43.5 % for which the LTL had the lowest losses and the SM, BF and ST had the highest, followed by the GM and SS, with the IS and PM having the second lowest losses.

The WBSF was affected by the muscle type, with the PM having the lowest shear force, the SM having the highest and similar to the LTL, BF, GM and the IS, while the ST and SS had slightly lower readings (Table 5.4; Fig. 5.1).

Muscle had a significant effect on all colour variables (Table 5.4), while the L* values were affected by the interaction between the sex and muscle; the LTL, BF and GM of the males had higher L* values than the females. The ST and BF had the lowest a* values and the highest b* value, while SM, GM, IS and SS had the highest a* values and the LTL, GM and SS had the lowest b* values. The BF and ST had the highest hue-angles and the lowest chroma values, while the GM and the SS had the lowest hue-angles and the SM, GM, IS, SS and PM had the highest chroma values (Table 5.4).

The total myoglobin (Mb) content was determined for all the muscles harvested except for the BF. The interaction between the sex and muscle had a significant effect (*P* = 0.001) on the total Mb content of the giraffe meat (Table 5.6).

Table 5.6 Level of statistical significance (*P-values*) for the main effects of sex and muscle and their interaction for the total myoglobin content of seven different muscles from giraffe

Parameter	***P-value***
Sex*Muscle	**0.001**
Sex	0.081
Muscle	**<0.001**

The SS had the highest total myoglobin for both male and female, while the GM and IS had a similar myoglobin content in the females, they had a significantly lower content in the males. The ST had the lowest total myoglobin content for both sexes. The LTL, SM and PM all had similar myoglobin contents and did not differ between the sexes (Table 5.7).

Table 5.7 Total myoglobin content of seven giraffe muscles (mean ± standard error), as influenced by sex

Muscle (mg/g)	**Sex**	
	Male	**Female**
LTL[1]	6.6^{c} ± 0.18	7.3^{bc} ± 0.31
SM[2]	6.6^{c} ± 0.16	7.1^{bc} ± 0.39
ST[3]	5.1^{d} ± 0.12	5.2^{d} ± 0.11
GM[4]	7.2^{bc} ± 0.13	9.1^{a} ± 0.64
SS[5]	9.1^{a} ± 0.28	9.3^{b} ± 0.71
IS[6]	7.7^{b} ± 0.17	9.3^{b} ± 0.22
PM[7]	6.9^{c} ± 0.10	7.0^{c} ± 0.18

Abbreviations: LTL[1] = *Longissimus thoracis et lumborum*, SM[2] = *semimembranosus,* ST[3] = *semitendinosus,* GM[4] = *gluteus medius*, SS[5] = *supraspinatus,* IS[6] = *infraspinatus,* PM[7] = *Psoas major*. [a-d]Means with different superscripts differ significantly from each other (P ≤ 0.05).

5.4 DISCUSSION

While the LTL is normally one of the most sought after and consequently most valuable cuts in beef, as it is tender and lean in nature, when it was removed from the giraffe, it had a thick membranes and connective tissue running through it. This connective tissue was found to riddle the entire length of the muscle, which would greatly decrease the value of the LTL and make it unsuitable for marketing as fresh cuts. Even though the LTL is often the heaviest muscle, this was not the case in giraffe, as they

had a short back in relation to their size, when compared to other species (Chapter 3), and both the SM and the BF were found to be heavier than the LTL. As these two muscles are found in the hindquarter, which normally contains some of the best cuts, and did not have any of the thick connective tissue present in the LTL, the hindquarters will yield a large quantity of fresh meat cuts (Table 5.1).

The LTL is often a sought after muscle for steaks, the connective tissue running through those of giraffe does not allow for this and this muscle would be more suitable for making biltong, as its long shape follows the muscle grain, allowing for longer cuts. The SM and BF are also both equally popular for biltong making (Jones *et al*., 2017). The SM has an unpredictable grain due to its location in the joint of the hindquarter while, the BF was found to have a long and clear grain running in one direction diagonally across the muscle. The BF may not yield biltong cuts quite as long as one can produce from the LTL of cattle, and could be better suited for fresh steaks although it was the more tough muscle (WBSF, Table 5.4) of those evaluated, it could still be deemed tender. The BF, SM and occasionally the LTL, have a relatively courser grain than the other skeletal muscles as a result of having thicker muscle fibres (Herring, Cassens & Briskey, 1965; Klont, Brocks & Eikelenboom, 1998), this results in tougher meat. The fibre diameter in the LTL of giraffe was analysed by Hall-Martin and colleagues (1977) and was found, for the age group 1-6 years, to have a mean fibre diameter similar to that in the LTL of beef. While the IS and SS are some of the largest forequarter muscles, in smaller ungulates these are often too thin with too much connective tissue present to produce good cuts. However, in the giraffe these muscles were large with limited connective tissue and thus suitable to be utilised either for biltong or as fresh cuts. The ST in the hindquarter has the grain running straight along its length and had no connective tissue within it. However it was bordered on the outside by a very thick elasticized membrane, which was difficult to remove without removing some of the muscle. The GM muscle, had a very loose structure, appearing to be similar in structure to the PM which also has a loose structure. The PM in the giraffe had a very different shape to other ungulates that tend to have an elongated cylindrical PM. In giraffe, it had a flat fan like shape, and a similar form was observed in elephants by the authors. This muscle is also sought after for its inherent tenderness, as a result of its limited use by an animal which also results in limited connective tissue (Herring *et al*., 1965).

The pH_u of all skeletal muscles fell within the range generally acceptable for beef of pH 5.5 – 5.8 (Immonen, Ruusunen & Puolanne, 2000). Most of the muscles were on the lower side of this range, the forequarter muscles, the SS and IS, had two of the highest pH_u, a phenomenon which has been observed in other game species (impala; Engels, 2019; eland; Needham *et al*., 2019), and is most likely due to the glycogen present, which is related to the distribution of muscle fibre types in the various muscles, which is determined by the function of the muscle.

The rate of pH decline affects the tenderness of the meat, as it affects the extent of what is termed, 'rigor resolution', which refers to the natural tenderisation processes after the meat has gone into rigor. This is also affected by the rate of chilling post-mortem (Marsh *et al*., 1987). Pale soft and exudative meat (PSE) results from a rapid pH drop, due to the glycolytic processes post-mortem, while the meat is still at a high temperature (Sosnicki *et al*., 1998; Olivo *et al.,* 2001) characterised by high moisture losses. Whereas if the pH does not drop fast or low enough, which can also be affected by a faster rate of cooling, and results in dark, firm and dry (DFD) meat, with a high water holding capacity, however, the water remains bound in the muscle structure, resulting in dry cooked meat. Cold shortening can also be an issue if the meat is cooled immediately to below 15°C while the pH is still high (Lawrie, 1998; Nuss & Wolfe, 1980-81), which causes a strong contraction, permanently shortening the sarcomeres and resulting in tough meat. As the giraffe carcass is so large, and was found to cool slowly, this is unlikely to be an issue.

Bruce and colleagues (2001) found that the rate of pH decline is not linear, as the hydrogen ion production decreases when the muscle enters rigor as affected by the rate of anaerobic glycolysis and myosin ATPase activity, which decrease with muscle cooling. The deamination of adenosine monophosphate (AMP) also slows the rate of pH decline as the ammonium results in a buffering effect (Bendall & Davey, 1957). These physiological changes lead to an exponential decay curve as found by Bruce and colleagues (2001). This study found that the rate of pH decline did not differ between the male and female giraffe (Table 5.4), with a rapid pH decline until approximately 12 h post-mortem where it began to level off above the iso-electric point of meat proteins. Adjusting the pH for a temperature effect did not influence the rate of decay and the curves for both methods followed the same shape as pH curves reported for warthogs (*Phacochoerus africanus*) (Hoffman & Sales, 2007). The decay rate could not be found in other studies, therefore the rate could not be compared between species.

The rate of temperature decline (Fig. 5.3) was slow, and the temperature did not drop to the optimum storage temperature of ± 4°C within 24 h for either the LTLs or the hindquarters. This may be due to the fact that chillers were filled to capacity, but it is also due in part to the bulk of the giraffe carcass cuts. The hind quarters in particular, are a solid bulk of muscle, which as seen by the temperatures reported for the deep BF logger in G11, takes a long time to cool to the centre (Fig. 5.3). When bulky cuts are not cooled fast enough, it can result in bone taint which causes rapid spoilage of the cut, due to microbial activity (Gill & Newton, 1978), therefore it may be necessary to further divide/seam out the hindquarters of giraffe before cooling. As the rate of pH and temperature decline together influence the water holding capacity and the colour of the meat, there may be differences

between muscles due to their location within the hindquarter and also between deep and superficial parts of the same muscle as in the SM or BF.

Hamm (1980) found that there was a strong correlation between a pH below 6.0 at 30 min post-mortem (faster pH decline) and a lower water holding capacity and paler colour, traits associated with PSE meat. The pH was not found to drop below 6.0 within the first few hours for any of the giraffe. However, there may have been a chance of heat rigor in the deeper muscles of the hindquarters, as this is caused by a pH below 6.0 while the temperature is still above 35°C (Shaw, Bruce & Murdoch, 2002), as the deep BF readings were found to still be at 35°C at 6h post-mortem, by which time the pH had likely dropped below 6.0. Heat rigor results in tougher meat due to the inactivation of proteolytic enzymes, also exhibiting the lighter colour and low water holding capacity associated in PSE pork. The BF was found to exhibit two-toning, with the superficial parts of the muscle appearing darker in colour, and the deeper parts a lot lighter indicating that heat rigor may have occurred. The giraffe maybe an ideal species to research this phenomenon further.

The water holding capacity of meat can be quantified by addition of the drip loss and cooking loss. Both these parameters are greatly influenced by the pH_u as, when the pH drops too fast, or drops below the iso-electric point of muscle protein, it results in denaturation of the proteins which reduces their water holding capacity. As glycolysis occurs naturally post-mortem until the substrates run out or the process is halted by low temperature, the pH will naturally decline to between 5.5-5.8, which implies that some moisture loss is inevitable; this is called drip loss or weep. When the meat loses too much moisture, it collects in the packaging giving an unsightly appearance, causing consumers to discriminate against it (Troy & Kerry, 2010). When the meat loses additional moisture whilst cooking this results in dry meat that consumers perceive as being less tender.

While sex did not have a significant effect on drip loss, it did on cooking loss ($P = 0.024$), with males (41.6 %) having a higher % loss than females (40.7 %), following a similar trend to impala (Engels, 2019). However, in other species where a higher cooking loss has been observed, it generally goes together with a higher pH_u (Engels, 2019; Hoffman *et al*., 2009a), which was not observed for any muscles showing a higher cooking loss in male giraffe (Table 5.3). However, despite its statistical significance, there was only a ± 1 % difference in the cooking loss between the sexes. The muscle had a significant effect on both drip loss and cooking loss, with the PM having the highest drip loss over 24 h (4.2 %). However this muscle had a low cooking loss (40.0 %). The SM had the greatest total moisture losses (%) with high drip (3.5 %) and cooking losses (43.5 %) which means that when cooked it may be dry and the consumer will perceive it as being tougher. Juiciness also aids in flavour development, as many of the flavour precursors in meat are water soluble (Mottram, 1998). The LTL had the lowest

cooking loss (37.5 %), as well as a low drip loss (2.2 %). This indicates that the LTL has good water holding capacity and should therefore be juicy when cooked. In general, drip and cooking loss values for giraffe were higher than other game species, with the drip loss for other game species averaging between 0.5 % and 4 % (Mostert & Hoffman, 2007; Hoffman *et al*., 2009a; Hoffman & Laubscher, 2009; Engels, 2019; Needham *et al*., 2019). Cooking loss for other game species range between 27 % and 41 % (Mostert & Hoffman, 2007; Hoffman *et al*., 2009a; Hoffman & Laubscher, 2009; Engels, 2019; Needham *et al*., 2019). However, in the study on the seasonal effect on meat quality of black wildebeest, the drip and cooking losses fluctuated greatly between the seasons, with spring having significantly higher net losses than winter (Hoffman, Van Schalkwyk & Muller, 2009c). Therefore season should be kept in mind when comparing studies.

Meat with a shear force value <43 N is considered tender (Destefanis *et al*., 2008), as the giraffe meat had no average values >43 N, it can be considered tender. However, there was a large amount of variation (range: 17.9 – 49.7 N), with some individual values falling into the intermediate tender classification (>43N; Destefanis *et al*., 2008). The WBSF values for the GM of the females were significantly higher than that of the males, no other muscles differed for sex. Sex did not have an effect on the tenderness of the meat, which may be due to the fact that these were pubescent animals not yet showing sexual dimorphisms (Chapter 3). Muscle had an effect with the PM having the lowest shear force (21.8 N) as expected, while the SM (32.8 N) and BF (32.3 N) had the highest. These shear force values compare favourably with other game species, such as impala, kudu, gemsbok (Hoffman, *et al*., 2009a; Hoffman & Laubscher, 2009; Hoffman & Laubscher, 2010; Engels, 2019). However, these values are far lower than for eland (Needham *et al*., 2019) and fallow deer (Cawthorn *et al*., 2018), as well as kudu (Mostert & Hoffman, 2007). Although, when comparing studies, it should be remembered that factors such as age, ante-mortem stress, rate of cooling post-mortem play a role in the tenderness of the meat. Giraffe meat can be considered as tender as other regularly consumed game species, which is contrary to what farmers who have eaten giraffe report, all claiming it to be very tough. This may be due more to the lack of juiciness as a result of the poor water holding capacity, than the shear force, this phenomenon is known as the 'halo' effect (Shorthose & Harris, 1991; Hopkins *et al*., 2006). Also, most of the farmers/hunters admit that they shoot older animals, mainly bulls, which will be tougher and dryer due to the age effect on this meat quality attribute. The possibility also exists that these hunted animals may experience ante-mortem stress whilst the animals from this investigation were not stressed during the culling operation. Tenderness is related to the rate of pH decline as well as the pH_u with maximum tenderness at pH approximately 5.5 (Purchas & Aungsupakorn, 1993). Muscle fibre diameter is also a major contributor to the toughness or tenderness where thicker muscle fibre diameters causes courser grained, tougher meat in general. This could be the reason why the SM

and BF had the highest shear force, as these muscles generally have larger fibre diameters and bundles than other skeletal muscles due to their post-natal pattern of development (Hoffman *et al*., 2009a). Tenderness also improves with post-mortem ageing of meat due to a combination of various chemical and physiological changes in the meat post-mortem, the effects of post-mortem ageing on the LTL, SM and BF of the giraffe was investigated and is discussed in Chapter 8.

Game meat is normally characterised by a dark red colour (L* values lower than 40, high a* values and low b* values) (Shange, Gouws & Hoffman, 2019), which consumers often discriminate against (Wassenaar, Kempen & Van Eeden, 2019). The dark red colour is normally associated with dark firm and dry (DFD) meat, which has undesirable characteristics when cooked. However, the giraffe meat was visibly lighter than typical game meat, with two-toning being prevalent, especially in the BF. This two-toning could be attributed to the large bulk of the hindquarters resulting in uneven cooling, which can cause the deeper muscles to exhibit PSE like traits (heat rigor). The interaction between sex and muscle for L* tended towards significance (P = 0.054) and will therefore be discussed, as it has biological significance. The males had a significantly higher L* value than the females for the LTL, BF and the GM, and as colour is largely affected by fibre type, which is determined by the function of the muscle, this difference is most likely due to these muscles serving different functions in the two sexes. Also, the myoglobin content of the muscles varies depending on the prevailing fibre type in the muscle. Glycolytic fibres generally have a lower myoglobin content and appear less red than the oxidative fibres which have a higher myoglobin content (Lawrie & Ledward, 2006). The daily activities of male and female giraffe differ, as the males also dedicate time to fighting one another and perusing potential mates. Pellew (1984) found that males tended to dedicate less time to browsing, and more time to holding vigil for predators, although Blomqvist and Renberg (2007) found that this was not the case on a game farm where there were no predators. For fighting, the males use the muscles in their necks, forequarters and backs differently to the females, therefore with the different function of their muscles the concentration of different muscle fibres will differ between sexes. Males must also support a heavier neck than females (Chapter 3) which explains the significant differences between the sexes for the LTL, as this must support the heavier neck, especially when it is being used to swing at other males when fighting. However, as the hindquarters are not often used when fighting, this cannot explain the differences in the lightness for the BF and the GM, which may be explained rather by a different weight distribution between the two sexes, with the males having a heavier neck to be supported by their forequarters (Chapter 3: Table 3.3). The higher L* values in the males could indicate a higher percentage of glycolytic fibres however, an analysis of the fibre types is necessary in order to confirm this.

The L* values of game meat are generally <40, however both the ST and BF had higher L* values (44.3 and 42.3, respectively), while consumer preference is generally for lighter meat, they may also discriminate against meat that is too light as Jeremiah and colleagues (1972) reported that consumers discriminated against pale pink meat. The ST does tend to be the lightest muscle across many game species including impala, eland, and fallow deer (Engels, 2019; Needham *et al.,* 2019; Cawthorn *et al*., 2018). As discussed earlier, the BF exhibited visible two toning, with the one half a similar colour to the ST and the other similar to the SM. This, however, was not quantified and the average colour of the muscle was ascertained by cutting the colour steaks to include part of both colour variations, to ensure it was a fair representation of the muscle as a whole. The forequarter muscles, SS and IS, were the darkest, which is also in agreement with the findings in eland (Needham *et al*., 2019). This may be due to the presence of more red muscle fibres, as the main function of the forequarter muscles is supportive, while the hindquarter muscles have a greater role in exercise, however this would have to be confirmed through investigating the muscle fibre type distribution between the muscles.

There was large variation in the a* values between muscles, with the SS having the highest a* value, thus having the most intensely red colour of all the muscles, and ST having the lowest redness (a*). The a* value of ST was still >12 which is the minimum cut-off point for consumer preference, according to Wiklund and colleagues (2001). The b* values denote the yellow colour of the meat, and the ST had the highest b* value, while the SS had the lowest. The consumer preference tends to be for lower b* values, and while these values were higher than for impala (Engels, 2019), they were in alignment with those of eland (Needham *et al*., 2019). The chroma values were much higher than those for impala (Engels, 2019), however, they were very similar to the values for both fallow deer (Cawthorn *et al*., 2018) and eland (Needham *et al*., 2019). The hue-angle for beef will generally not differ by more than 10° between the muscles, however in pigs it can differ by as much as 35° (Jones, 1995). The hue-angle was the highest in the ST and the lowest in the SS, and differed by 12.3°, ranging from just below halfway through the red-yellow light spectrum, towards the red side of the spectrum. Therefore, while the colour may not appear as appealing as beef to the consumer, it will still be acceptable, and with the general lighter colour, it may be more so than other game species.

As colour is mainly affected by the myoglobin content, this was analysed for the various muscles, except for the BF, as it was decided that due to the two-toning it exhibited, the myoglobin content would not be a good representation of the true colour of the muscle. As some of the samples used for myoglobin testing had been used for proximate analysis, and therefore previously thawed

and refrozen, it was decided that determining the respective percentages of the different Mb constituents, namely deoxymyoglobin (DMb), oxymyoglobin (OMb) and metmyoglobin (MMb) would not be a fair representation of the meat, as the different samples had not all been thawed for the same period of time. Neethling and colleagues (2019) investigated the colour stability of meat from springbok and found that there were interactions between time post-mortem and muscle, as the discolouration by denaturation of myoglobin is delayed at low temperatures (Neethling *et al*., 2017), it would have been relatively stable when frozen. However, the rate of decolouration would have been accelerated during the periods when the samples were defrosted, as there is an interaction between the time and muscle, this would not have affected the muscles uniformly. Only the total Mb was therefore determined for all muscles harvested. There was found to be a significant interaction between the sex and muscle for the total Mb content of the meat. The SS was found to have the highest myoglobin content of all the muscles (Table 5.6), for both sexes, while the GM and IS of the females, had similar myoglobin contents to the SS, in males they had a significantly lower content. This was seen to be related to the CIE L* values (Table 5.3) of these muscles, for which the SS and IS had the lowest in both sexes, and the GM had a similar L* value which was lower in the females than the males. The GM, SS and IS also had some of the lowest hue-angle values indicating redder meat, which is in agreement with the higher myoglobin content. The ST had the lowest myoglobin content for both sexes, and consequently the highest L* values and hue-angles for both sexes. The myoglobin content of the LTL, SM and PM did not differ between sexes, and were all similar across muscle, these muscles all had L* values and hue-angles lower than the ST, but higher than or similar to those of the GM, SS and IS.

5.5 CONCLUSION

Giraffe yields a substantial amount of meat, however, most of the muscles evaluated were found to contain significant amounts of connective tissue, and thick membranes. The high value hind-quarter muscles, were found to be large, and with acceptable physical characteristics. However, these hindquarter muscles had a low water holding capacity which may result in dry cooked meat, although the possibility exists that this low water holding capacity may have been caused by inadequate cooling rates. While there were no significant difference between the weights of muscles between sexes, the giraffe in this study were still relatively young, approximately pubescent age, implying that sexual dimorphisms may still develop as they reach maturity. Muscle type had a significant effect on the physical characteristics, which will result in variation in the various cuts as well, further studies should therefore include a butcher's block test. The meat to bone ratio, should also be investigated in order

to determine the actual meat yield as well as the yield of meat that can be used as fresh cuts, and what is only useable as processed meat. Other than the high moisture losses, the physical characteristics of the giraffe meat in general were positive, and within the range that is appealing to the consumer. Further research should aim to quantify the effect of age on both the yields of the two sexes, as well as the physical characteristics of the major muscles and most valuable cuts. The difference in myoglobin content is related to the muscle fibre types present in the muscle, and it is therefore recommended to do further research on the muscle fibre types of the different muscles. It is also recommended to do further study on the percentages of the different myoglobin forms, in order to better understand the colour stability of the meat.

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CHAPTER 6

THE INFLUENCE OF SEX AND MUSCLE ON THE CHEMICAL COMPOSITION OF THE MEAT OF GIRAFFE (*Giraffa camelopardalis angolensis*)

ABSTRACT

Consumers tend to buy meat based on the physical characteristics that they can see, these factors are affected by the chemical composition of the meat, for which there is very little known for the meat of giraffe. This study therefore aims to broaden the data base on the chemical composition of the meat of giraffe. Eight different muscles from 15 giraffe were analysed to determine the chemical composition in terms of moisture (77.2 ± 0.09 g/100 g), protein (20.8 ± 0.09 g/100 g), intramuscular fat (IMF) (1.4 ± 0.03 g/100 g) and ash (1.1 ± 0.01 g/100 g), which is an indication of the mineral content. There was a significant interaction between sex and muscle for the moisture (P = 0.044), protein (P = 0.045) and ash (P = 0.042) contents, while only muscle (P <0.001) had an effect on the fat content. The mineral content of the bone, liver and *Longissimus thoracis et lumborum* (LTL) muscle was also analysed, and it was found that in the bone, calcium was in the highest concentration, in the liver, iron had the highest levels and in the LTL, zinc was the highest. The chemical composition of the giraffe meat was found to compare favourably with that of other game species, as well as domestic species, although far more lean than most domestic species.

Keywords: Game meat, lipid content, moisture, ash, protein, myoglobin, mineral

6.1 INTRODUCTION

The global population is currently growing at such a rate that the population is expected to surpass nine billion within the next few decades (Tscharntke *et al*., 2012). A lot of this growth is taking place in Africa, a continent that is already struggling to feed its population, with southern Africa currently being a net importer of food, despite an economy that cannot support this (Conceicao *et al.*, 2011). Since meat has a highly concentrated protein content, which has a higher biological value than plant protein, and an excellent amino acid profile (Bender, 1992; Listrat *et al*., 2016), as well as containing other important nutrients and minerals, which also have a higher availability to humans (Ortega-Barrales & Fernández-de Córdova, 2015), meat is a very important part of the human diet.

Since southern Africa is largely an arid region, conventional meat species are often not suited to the climate, and cannot utilise the veld with its poor nutrient content, however, game species which are endemic to southern Africa are more suited to these conditions, and well adapted to the diet. Since there are so many different game species, all varying a great deal, when investigating their potential as an alternative source of meat, it is necessary to investigate the nutritive value of the meat of each potential species in order to ensure that it fulfils the nutritional requirements of the consumers. Game meat has been found to have a low fat content with a favourable polyunsaturated to saturated fatty acid ratio (Listrat *et al*., 2016), which is desirable to the consumer, due to the relationship between saturated fats in the food consumed and obesity or cardiovascular disease (Schack, Bergh, & Du Toit, 2016). The nutritional value is assessed primarily by determining the basic chemical composition in terms of moisture, protein, intramuscular fat (IMF) and ash content, which is an indication of the mineral content (Ang, Young & Wilson, 1984).

Meat contains many of the essential macro- and micro-minerals that are required for the human diet (Zarkadas *et al*., 1987). Many of which are found exclusively in animal tissue, or in a more bioavailable form than in plant tissue, such as zinc (Zn) and magnesium (Mg) (Lin *et al*., 1989). The iron (Fe) content of meat, especially red meat, also makes it an important part of the human diet, as the Fe found in meat is predominantly (50-60 %) found in the heam form, which is more readily absorbed than the non-heam form found in plant tissue (Higgs, 2000). The mineral composition of giraffe meat has not yet been investigated. The liver is also known to have a relatively high mineral content, however, the mineral composition of giraffe liver has not yet been studied. Bone consists largely of minerals and is often ground into a meal which is used as a supplement in livestock feed, as it contains easily absorbable forms of the minerals required for the bones in the livestock. Bone consists of predominantly calcium and phosphorus lattice structures, with a wide spectrum of other minerals also involved in maintaining the rigidity of the bone. Van Schalkwyk, Skinner and Mitchell (2004) investigated the density of giraffe bone in relation to that of African buffalo (*Syncerus caffer*) as another artiodactyl of similar mass. As the skeleton makes up a much greater proportion of the live weight in giraffe than in buffalo, they investigated whether this affected the density of the bones in the giraffe in any way, however the two species were found to have skeletons of similar density.

This study aims to quantify the chemical composition of giraffe meat in terms of the moisture, protein, IMF and ash contents. It also aims to quantify the mineral composition of the bone, liver and the *Longissimus thoracis et lumborum* (LTL) muscle, in order to develop a broader knowledge base on the composition and nutritional value of giraffe meat.

6.2 METHODS AND MATERIALS

6.2.1 EXPERIMENTAL LOCATION AND ANIMALS

Fifteen young giraffe (8 male, 7 female; average age ± 3.7 years old) were harvested on Mount Etjo farm in the Otjozondjupa region of Namibia as part of a cull that takes place every year, in order to curb the population growth as these giraffe have no natural predators on the farm. The giraffe were culled by a head shot, and then exsanguinated in the field (Ethical approval: ACU-2018-7366, Stellenbosch University; Shoot and sell permit number: 118690). They were then transported back to the abattoir where they were skinned, eviscerated and dressed as described by Ledger (1963). For a more detailed description of the process refer to Chapter 3.

6.2.2 PROCESSING AND SAMPLING

Eight muscles were removed from the left side of each carcass namely the *Longissimus thoracis et lumborum* muscle (LTL), *Semimembranosus* muscle (SM), *Biceps femoris* muscle (BF), *Semitendinosus* muscle (ST), *Gluteus medius* muscle (GM), *Supraspinatus* muscle (SS), *Infraspinatus* muscle (IS), and *Psoas major* muscle (PM), for chemical analysis. On processing approximately 24 h post-mortem, a representative sample of approximately 100 - 200g was cut from each muscle vacuum-packed and frozen at -20°C for analyses. Before analyses, all samples were removed from the freezer and placed into the fridge at ± 4°C to defrost for ± 24 h. These samples were then removed from the vacuum bags, the outer membranes, and any other thick membranes were removed. The samples were cut into smaller pieces before being placed into a bowl cutter, ensuring that all moisture lost during thawing was added back into the bowl cutter for this. The samples were blended up until completely homogenous, and were then placed into small vacuum bags and refrozen until further analysis.

6.2.3 CHEMICAL ANALYSIS

6.2.3.1 Moisture and ash

The moisture and ash content (g/100 g) of each muscle from each animal were determined as described in the AOAC Official Method 934.01 (AOAC International, 2002a). For further details refer to Chapter 4.

6.2.3.2 Lipid content

The lipid content of each sample was determined by the rapid solvent extraction method described by Lee, Trevino & Chaiyawat, (1996). With a mixture of chloroform/methanol as the solvent, in a 1 : 2 (v/v) ratio, which is the recommended ratio for samples with a fat percentage lower than 5 %, this was

deemed the appropriate ratio, following a test run of all the muscle from one animal, using both the 1 : 2 and the 2 : 1 ratios and finding no values higher than 5 %.

6.2.3.3 Protein content

The protein content of each sample was determined from the filtrates that remained behind after the fat extraction, using a Leco Nitrogen/Protein Determinator (FP528 – Leco Corporation) with the method described in the AOAC Official Method 992.15 (AOAC International, 2002b). For further detail refer to Chapter 4.

6.2.3.4 Mineral content

Homogenised liver and LTL samples as well as defatted and incinerated bone samples from each giraffe were used for mineral analysis. The bones were defatted using petroleum ether, before being incinerated for 24 h at 600°C and crushed into a fine powder. All samples then underwent microwave digestion in Teflon vessels with Ultra Pure HNO_3 and H_2O_2 using a MARS microwave digester with the settings as follows, power level: 1600W, 100 %; ramp time: 25 min; pressure: 800 psi; hold time 10 min. The samples were cooled and diluted 10x in order to reduce the acid concentration.

The samples underwent major, minor and trace element analysis, by inductively coupled plasma atomic emission spectroscopy (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS). For ICP-AES, a Thermo iCAP 6000series (Thermo Scientific) was used, with the settings: RF power: 1350 W; Carrier gas (Argon): 0.65 L/min; Aux gas (Argon): 1.0 L/min; Nebuliser: 2 ml/min micro mist; Internal standard used: 1ppt Yttrium. For ICP-MS an Agilent 7900 ICPMS was used with the following settings: RF Power: 1600 W; Carrier gas (Argon): 0.83 L/min; Sample depth: 10 mm; Make-up gas: 0.15 L/min; Helium flow: 5 ml/min; Hydrogen flow: 6 ml/min; Nebuliser: 0.4 ml/min micro mist.

6.2.4 STATISTICAL ANALYSIS

The experimental design of this trial took the form of a split plot design with sex as the main plot factor and muscle (LTL, SM, BF, ST, GM, SS, IS, PM) as the sub-plot factor. Statistica Version 13.4 (2018) R (lmer package) was used to perform a univariate analysis of variance (ANOVA) using the General Linear Models (GLM) procedures on the parameters for the proximate analyses (moisture, ash, IMF, protein, and mineral content). Deviations form normality were assessed by means of the Shapiro-Wilk test on the standardised residuals from the model (Shapiro & Wilk, 1965). Where observations diverged too far from the model value, they were removed as outliers. For the comparison of sex and muscle effects, Fisher's least significant difference was calculated at the 5 % significance level (Lyman Ott & Longnecker, 2010).

6.3 RESULTS

There was a significant interaction between the effect of sex and muscle on the moisture (P = 0.044), protein (P = 0.045) and ash content (P = 0.042) of giraffe meat, however, not on the intramuscular fat (IMF) content (P = 0.790) as seen in Table 6.1. Due to these interactions the proximate composition parameter values of each muscle are reported separately for both sexes in Table 6.2. The moisture content was significantly higher in males than in females for the ST (male: 78.0 ± 0.22 g/100 g; female: 77.0 ± 0.38 g/100 g) and the GM (male: 77.9 ± 0.18 g/100 g; female: 76.5 ± 0.37 g/100 g), while the protein content was significantly higher in females than males for the ST (male: 20.6 ± 0.23 g/100 g; female: 21.4 ± 0.44 g/100 g) and GM (male: 20.2 ± 0.23 g/100 g; female: 21.3 ± 0.28 g/100 g). The IMF content, was higher in females than in males only for the SS muscle, and was the lowest in the ST (1.1 ± 0.08 g/100 g), while the LTL, GM, SS and PM had the highest IMF contents. The ash content was significantly higher in females than in males for the GM (male: 1.1 ± 0.01 g/100 g; female: 1.2 ± 0.04 g/100 g) and the SS (male: 1.0 ± 0.01 g/100 g; female: 1.1 ± 0.02 g/100 g).

Table 6.1 Level of statistical significance (*P-values*) for the main effects of sex and muscle and their interaction for the proximate composition (g/100 g) of eight muscles from giraffe (n = 15)

Parameter	***P-value***		
	Sex	**Muscle**	**S*M**
Moisture (%)	**0.046**	**<0.001**	**0.044**
Protein (%)	0.226	**<0.001**	**0.045**
Intramuscular fat content (IMF) (%)	0.100	**<0.001**	0.790
Ash (%)	0.050	**<0.001**	**0.042**

Table 6.2 Means (± standard error) of the proximate composition (g/100 g) of eight muscles from giraffe (n = 15) as influenced by sex and muscle. Both main effects and interactions have been included for all parameters

Parameter (g/100 g)	Muscle	Pooled for sex	Sex	
		(n = 15)	Male (n = 7)	Female (n = 8)
Moisture	LTL[1]	76.5^{e} ± 0.19	76.6^{c} ± 0.29	76.4^{c} ± 0.26
	SM[2]	76.8^{de} ± 0.19	77.0^{bc} ± 0.24	76.6^{c} ± 0.30
	BF[3]	77.0^{de} ± 0.24	77.0^{bc} ± 0.41	76.9^{c} ± 0.26
	ST[4]	77.5^{bc} ± 0.24	78.0^{a} ± 0.22	77.0^{c} ± 0.38
	GM[5]	77.2^{cd} ± 0.26	77.9^{a} ± 0.18	76.5^{c} ± 0.37
	SS[6]	77.9^{ab} ± 0.17	78.1^{a} ± 0.26	77.7^{ab} ± 0.21
	IS[7]	78.1^{a} ± 0.16	78.3^{a} ± 0.20	77.8^{a} ± 0.23
	PM[8]	76.9^{de} ± 0.20	76.9^{c} ± 0.36	76.9^{c} ± 0.16
Pooled for muscle		77.2 ± 0.09	77.5^{a} ± 0.12	77.0^{b} ± 0.11
Protein	LTL	21.4^{a} ± 0.25	21.4^{a} ± 0.41	21.3^{ab} ± 0.29
	SM	21.4^{a} ± 0.16	21.2^{a} ± 0.27	21.5^{a} ± 0.15
	BF	21.1^{ab} ± 0.24	21.1^{ab} ± 0.41	21.2^{ab} ± 0.28
	ST	21.0^{ab} ± 0.26	20.6^{bc} ± 0.23	21.4^{a} ± 0.44
	GM	20.7^{b} ± 0.23	20.2^{cd} ± 0.23	21.3^{ab} ± 0.28
	SS	19.9^{c} ± 0.20	19.9^{d} ± 0.30	20.0^{cd} ± 0.26
	IS	20.0^{c} ± 0.16	19.9^{d} ± 0.22	20.2^{cd} ± 0.22
	PM	21.1^{ab} ± 0.24	21.2^{a} ± 0.41	21.0^{ab} ± 0.27
Pooled for muscle		20.8 ± 0.09	20.7 ± 0.13	21.0 ± 0.12
IMF	LTL	1.6^{a} ± 0.09	1.4^{abcde} ± 0.13	1.7^{a} ± 0.11
	SM	1.3^{c} ± 0.09	1.2^{de} ± 0.08	1.5^{cd} ± 0.16
	BF	1.3^{c} ± 0.08	1.3^{de} ± 0.08	1.4^{d} ± 0.14
	ST	1.1^{d} ± 0.08	1.0^{f} ± 0.08	1.2^{ef} ± 0.13
	GM	1.5^{ab} ± 0.10	1.4^{bcde} ± 0.12	1.7^{abc} ± 0.16
	SS	1.5^{abc} ± 0.11	1.3^{de} ± 0.11	1.7^{ab} ± 0.17
	IS	1.4^{bc} ± 0.07	1.3^{de} ± 0.10	1.5^{abcd} ± 0.09
	PM	1.4^{abc} ± 0.10	1.3^{bcde} ± 0.09	1.5^{abcd} ± 0.19
Pooled for muscle		1.4 ± 0.03	1.3 ± 0.04	1.5 ± 0.05

Table 6.2 Continued

Parameter (g/100 g)	Muscle	Pooled for sex	Sex	
		(n = 15)	Male (n = 7)	Female (n = 8)
Ash	LTL	1.1^{b} ± 0.02	1.1^{cde} ± 0.01	1.1^{bcde} ± 0.04
	SM	1.2^{ab} ± 0.02	1.2^{ab} ± 0.03	1.1^{bcde} ± 0.02
	BF	1.1^{b} ± 0.02	1.1^{def} ± 0.01	1.2^{abcd} ± 0.03
	ST	1.2^{ab} ± 0.01	1.1^{cde} ± 0.01	1.2^{abc} ± 0.02
	GM	1.1^{b} ± 0.02	1.1^{ef} ± 0.01	1.2^{abcd} ± 0.04
	SS	1.0^{c} ± 0.02	1.0^{g} ± 0.01	1.1^{ef} ± 0.02
	IS	1.0^{c} ± 0.02	1.0^{g} ± 0.03	1.0^{fg} ± 0.02
	PM	1.2^{a} ± 0.02	1.2^{abc} ± 0.02	1.2^{a} ± 0.04
Pooled for muscle		1.1 ± 0.01	1.1 ± 0.01	1.1 ± 0.01

Abbreviations: LTL[1] = *Longissimus thoracis et lumborum*, SM[2] = *semimembranosus,* BF[3] = *biceps femoris,* ST[4] = *semitendinosus,* GM[5] = *gluteus medius*, SS[6] = *supraspinatus,* IS[7] = *infraspinatus,* PM[8] = *Psoas major*. [a-g]Means with different superscripts within a parameter for muscle and sex differ significantly from each other ($P \leq 0.05$). [#a-e]Means with different superscripts within a parameter for muscle differ significantly ($P \leq 0.05$).

The mineral composition was analysed separately for the bone, liver and meat (LTL). Some of the minerals were not present in all body parts. While arsenic (As) was not present in levels above the lowest detection limits (LODs) in any body part, tin (Sn) and silicon (Si) were not found in levels above the LODs for the liver or the LTL, and silver (Ag), cadmium (Cd), mercury (Hg) and lead (Pb), while found in the bone and liver were not found in levels above the LODs in the LTL. Sex had an effect only on the lead (Pb) levels in the bone, with higher levels in males than the females. For the liver sex had an effect on the silver (Ag) levels, with a higher content in the females than the males. The LTL had differences between the sexes for several minerals; barium (B), aluminium (Al), vanadium (V), copper (Cu), zinc (Zn) and sodium (Na) all had a higher concentration in males than in females.

Table 6.5 The major, minor and trace element content of the bone, liver and LTL of giraffe, as influenced by sex

Mineral	Limit of Detection (µg/kg tissue)	Bone			Liver			LTL		
		Male (n = 8)	Female (n = 7)	*P-value*	Male (n = 8)	Female (n = 7)	*P-value*	Male (n = 8)	Female (n = 7)	*P-value*
B	139.6	9812.6 ± 584.73	8844.7 ± 561.87	0.257	1023.8 ± 86.95	941.5 ± 56.96	0.457	**1023.0 ± 87.71**	**717.1 ± 64.16**	**0.017**
Al	156.2	11086.0 ± 5492.62	3644.7 ± 596.64	0.231	997.4 ± 209.21	920.2 ± 174.78	0.785	**1058.5 ± 134.17**	**482.1 ± 64.07**	**0.003**
V	1.1	18.1 ± 6.35	7.7 ± 0.45	0.151	11.4 ± 5.58	5.2 ± 0.26	0.322	**4.4 ± 0.40**	**3.2 ± 0.21**	**0.017**
Cr	28.0	887.1 ± 491.67	196.4 ± 23.11	0.214	391.4 ± 99.76	248.0 ± 70.75	0.275	272.3 ± 139.34	137.2 ± 72.87*[(5)]	0.487
Mn	13.2	578.8 ± 66.30	504.8 ± 38.27	0.370	2384.1 ± 80.44	2277.1 ± 87.83	0.384	123.7 ± 15.86	85.4 ± 5.66	0.051
Fe	56.5	23662.1 ± 5133.19	16764.2 ± 2631.28	0.273	73083.3 ± 4853.47	87123.3 ± 13637.47	0.325	15976.8 ± 1144.22	13786.9 ± 1188.21	0.208
Co	1.1	13.0 ± 2.63	9.6 ± 0.72	0.263	86.1 ± 3.17	85.7 ± 2.41	0.920	3.7 ± 0.96	3.5 ± 1.12	0.866
Ni	0.7	202.2 ± 54.12	231.1 ± 40.04	0.682	2.4 ± 55.79	118.6 ± 35.68	0.241	131.6 ± 67.63	581.7 ± 385.71	0.241
Cu	5.3	1094.2 ± 190.72	769.7 ± 133.56	0.199	21874.3 ± 2479.27	19176.5 ± 2363.69	0.449	**1063.3 ± 74.73**	**805.5 ± 24.20**	**0.009**
Zn	5.5	130020.6 ± 3828.56	123261.9 ± 4021.0	0.246	35535.8 ± 848.03	36057.7 ± 1255.54	0.730	**30107.7 ± 2064.10**	**23394.3 ± 1729.44**	**0.029**
As	5.1	-	-		-	-		-	-	
Se	1.6	25.9 ± 3.24	23.7 ± 1.40	0.563	313.4 ± 15.72	334.8 ± 18.75	0.394	98.0 ± 3.81	116.4 ± 18.45	0.316
Sr	14.7	230856.2 ± 18607.24	230973.1 ± 24689.38	0.997	31.4 ± 3.15	61.6 ± 22.48	0.178	28.2 ± 4.04	21.5 ± 1.70	0.173
Mo	0.7	125.7 ± 13.65	98.6 ± 18.79	0.256	993.2 ± 32.78	907.26 ± 37.67	0.107	21.3 ± 4.61	10.77 ± 1.07	0.057

Table 6.5 Continued

Mineral	Limit of Detection (µg/kg tissue)	Bone			Liver			LTL		
		Male (n = 8)	Female (n = 7)	*P-value*	Male (n = 8)	Female (n = 7)	*P-value*	Male (n = 8)	Female (n = 7)	*P-value*
Ag	4.0	63.7 ± 14.50	28.2 ± 8.55	0.064	**6.4 ± 0.89**	**22.3 ± 7.50**	**0.042**	-	-	
Cd	1.6	8.0 ± 3.45*(6)	2.1 ± 0.14*(5)	0.158	9.3 ± 1.78	6.0 ± 0.89	0.135	-	-	
Sn	2.4	11.2 ± 3.02	11.7 ± 5.34	0.934	-	-		-	-	
Sb	0.7	33.2 ± 13.85	15.1 ± 2.80	0.253	10.1 ± 4.63	4.5 ± 2.46	0.328	4.1 ± 0.75	2.9 ± 0.79	0.274
Ba	0.9	185834.1 ± 8203.37	189793.2 ± 11277.81	0.777	32.7 ± 2.77	74.1 ± 36.20	0.242	22.3 ± 3.37	14.4 ± 1.27	0.060
Hg	0.7	2.6 ± 0.55	1.5 ± 0.27*(6)	0.125	5.8 ± 0.72	6.0 ± 0.79	0.858	-	-	
Pb	5.1	**204.2 ± 34.23**	**109.9 ± 18.47**	**0.037**	12.9 ± 1.85	8.9 ± 0.89	0.082	-	-	
Ca	10	436252.1 ± 2254.85	431341.0 ± 3409.02	0.240	45.1 ± 1.95	94.2 ± 39.62	0.206	41.3 ± 4.10	35.6 ± 0.74	0.228
K	10	1374.0 ± 127.92	1314.8 ± 143.42	0.762	3255.8 ± 48.72	3294.01 ± 112.49	0.749	4100.81 ± 43.82	4007.3 ± 70.37	0.267
Mg	10	9363.5 ± 130.36	9135.1 ± 133.52	0.244	162.3 ± 2.08	164.28 ± 5.07	0.716	250.0 ± 2.35	243.9 ± 3.67	0.171
Na	10	11670.7 ± 244.51	11918.1 ± 91.98	0.387	723.8 ± 24.29	780.1 ± 46.10	0.282	**381.5 ± 11.11**	**343.5 ± 6.18**	**0.013**
P	10	212082.6 ± 634.28	209584.6 ± 1074.67	0.059	3515.5 ± 57.90	3555.6 ± 91.58	0.710	2261.6 ± 22.68	2230.5 ± 26.70	0.388
Si	5	34.4 ± 13.31	16.5 ± 0.68	0.233	-	-		-	-	

Values with * have values below the LOD; (#) number of values above the LOD; - indicates too many values were below LOD for statistical significance

6.4 DISCUSSION

The objective of this study was to determine the influence of the sex and muscle type on the chemical meat quality of giraffe, through proximate analysis. In general lean skeletal muscle is made up of approximately 75 % moisture, 20 % protein, 1-10 % IMF and 1 % carbohydrates, vitamins and minerals, usually quantified as the ash content (Huff-Lonergan & Lonergan, 2005; Listrat *et al*., 2016). These percentage compositions vary by species, sex and muscle, as well as the diet which the animals consume. For giraffe the average composition across sex and muscle was 77.2 ± 0.09 % moisture, 20.8 ± 0.09 % protein, 1.4 ± 0.03 % IMF and 1.1 ± 0.01 % ash, which is in alinement with that of other lean meat, with slightly higher moisture content and IMF on the lower end of the range. Giraffe meat was very lean with no visible intramuscular fat. Poor water-holding capacity was reported in the physical analyses of Chapter 5, however, meat in this study has a slightly higher moisture content than lean meat of other species. There were significant interactions between sex and muscle for the moisture, protein and ash contents, but not for the IMF content (Table 6.1 and 6.2).

The moisture content of the giraffe meat ranged from 76.4 - 78.3 g/100 g, with the LTL, SM and BF having the lowest moisture contents, while the SS and IS had the highest moisture contents. Anecdotally the SM had the highest total moisture loss and the LTL had one of the lowest total moisture losses (Chapter 5). There is little research on the various muscles of game meat, however many studies report the chemical composition of only the LTL. Therefore, if one compares the moisture content of the LTL of the giraffe 76.5 ± 0.19 g/100 g, it is similar to the moisture content of the LTL of the eland (75.6-77.8 g/100 g; Laubser, 2018) and the blue wildebeest (75.9-78.5 g/100 g; Van Heerden, 2018). The LTL of the giraffe, however, had a higher moisture content than those of the impala (75.5 ± 0.12 g/100 g; Engels, 2019), springbok (65.3-65.8 g/100 g; North & Hoffman, 2015), kudu (75.7-75.8 g/100 g; Hoffman *et al*., 2009) and blesbok (73.9-76.1 g/100 g; Neethling, Hoffman & Britz, 2014).

The protein content of the giraffe meat ranged from 19.9 – 21.5 g/100 g, with a significant interaction between the sex and muscle. The SS and the IS had the lowest protein across the sexes, while the LTL, SM, ST, BF and PM had the highest protein content across sexes. The ST and GM both had significantly higher protein contents in females than in males which correlates with a lower moisture content in these two muscles in the females than in the males, they were the only two muscles to differ for sex for these parameters. If one compares the protein content of the LTL (21.4 ± 0.25 g/100 g) with that of other game species it compares favourably with protein content from most other game species with impala (22.5 ± 0.15 g/100 g; Engels, 2019), ostrich (22.2 ± 1.13 g/100g; Paleari *et al*., 1998), blesbok (19.0-23.1 g/100 g; Neethling *et al*., 2014) and blue wildebeest (19.3-22.3 g/100

g; Van Heerden, 2018), however substantially lower than the values recorded for springbok (31.1 ± 0.45 g/100 g; North & Hoffman, 2015). Game meat typically has a favourable protein content relative to traditional livestock species, although this may be due to a higher IMF percentage in domestic species, this makes it a healthy alternative to commercially produced red meat.

There was no significant interaction between the effect of the sex and the muscle on the IMF content of the giraffe meat, which ranged from 1.0-1.7 g/100 g. Sex did not have an effect on the fat content, despite many studies finding females to have a higher fat content than males (fallow deer, Fitzhenry, 2016; impala, Hoffman *et al*., 2009; eland, Hoffman *et al*. 2015; springbok, North & Hoffman, 2015; blesbok, Smit, 2004; black wildebeest and blue wildebeest, Van Schalkwyk, 2004). This may be because the giraffe were pubescent and not exhibiting sexual dimorphisms yet. The muscle did have an effect on the fat content with the LTL, GM, SS and PM having the highest fat content and the ST the lowest. When comparing the IMF of the LTL (1.6 ± 0.09 g/100 g) to that of other game species it is similar to that of impala (1.7 ± 0.06 g/100 g; Engels, 2019), ostrich (1.6 ± 0.60 g/100 g; Paleari *et al*., 1998), eland (1.45-1.48 g/100 g; Laubser, 2018), kudu (1.48-1.49 7g/100 g; Hoffman *et al*., 2009) and wildebeest (1.6-2.1 g/100 g; Van Heerden, 2018), but lower than that of blesbok (2.3-3.4 g/100 g; Neethling *et al*., 2014). IMF is very season and location dependant however, and these factors should be considered when comparing species, this is especially important between sexes as males will have a lower fat content than usual during rut, while females' fat content will fluctuate during gestation. The fat content of game species is generally considerably lower than that of the conventional meat species, with a favourable saturated fatty acid to polyunsaturated fatty acid (SFA:PUFA) ratio. The fatty acid profile will be discussed in Chapter 7.

The ash content is an indication of the mineral and vitamin content, or the inorganic components of the meat, the mineral composition will be discussed later. There was an interaction between the effects of sex and muscle for the ash content. The ash content of the giraffe meat ranged from 1.0-1.2 g/100 g, therefore despite the differences, the magnitude was very small. While the GM and SS had a significantly higher ash content in females than in males the other muscles did not differ for sex. The SM, ST and PM had the highest ash content across the sexes and the SS and IS the lowest. When comparing the ash content of the LTL (1.1 ± 0.02 g/100 g) to other game species it was similar to impala (1.24 ± 0.01 g/100 g; Engels, 2019), blue wildebeest (0.99-1.1 g/100 g; Van Heerden, 2018), eland (1.0-1.1 g/100 g; Laubser, 2018) and kudu (1.1-1.2 g/100 g; Hoffman *et al*., 2009).

The mineral composition of the bone, liver and meat was compared between sexes (Table 6.5) and there were differences for specific minerals between the sexes for each body part. The mineral content of bone is determined by a balance between bone formation and resorption, which is affected

by age, diet and physiological state. The diet of giraffe contains a ratio of calcium to phosphorus (Ca:P) of approximately 7.7:1, which is much lower than it would be for grazers, where it is normally closer to 2:1. With phosphorus levels this low in the diet, it would result in clinical signs of phosphorus deficiency, such as pica, in cattle (McDowell, 1992; Underwood & Suttle, 1999), a form of which, osteophagia, has been broadly documented in giraffe. Giraffe have been observed chewing both other giraffe bones as well as those of other species (Hall-Martin, 1975; Langman, 1978; Nesbit-Evans, 1970; Wyatt, 1971), which suggests they are deficient in phosphorus. In our study the bone of the giraffe high levels of calcium, strontium, phosphorus, barium and zinc (Table 6.5). Calcium and phosphorus generally occur in a 2:1 ratio which was also found to be the case for the giraffe in this study and therefore indicates no P deficiency. The only significant difference between the two sexes in the bone minerals was for the levels of lead (P = 0.037) which was twice as high in males (204.2 ± 34.23 µg/kg) as in the females (109.9 ± 18.47 µg/kg), which may be due to diet, metabolism or physiological differences between the sexes. The bone had higher levels of most of the macro minerals, than the liver and meat, having higher levels of zinc, magnesium, sodium and phosphorus, while the liver had the highest levels of iron and the meat had the highest potassium levels.

The liver had a significantly higher ash content than the other organs (2.0 ± 0.14 g/100 g) (Chapter 4) which is also significantly higher than the ash content of the meat of the giraffe, (1.00-1.21 g/100 g; Table 6.2). As ash is a measure of the mineral content, this means that the liver has a higher mineral content than the meat. The liver had very high iron, zinc and copper level. The only significant difference between sexes was for the levels of silver (P = 0.042), which was higher in females (22.3 ± 7.50 µg/kg) than in males (6.4 ± 0.89 µg/kg), which may be due to differences in diet, metabolism of physiological functions between the two sexes.

Meat contains many essential macro-minerals, specifically high levels of potassium and phosphorus as well as moderate sodium and magnesium levels, with a lower content of calcium (Ortega-Barrales & Fernández-de Córdova, 2015). Meat also contains a range of essential micro-minerals including iron, copper, zinc, cobalt, manganese, selenium and molybdenum, of which some are only found in muscle tissue, or in a more bioavailable form than in plant tissues (Ortega-Barrales & Fernández-de Córdova, 2015). There are limited studies on the mineral composition of game species, and those that have been done are generally limited to only a few minerals. Hoffman, Kroucamp and Manley (2007) reported no differences between sex for any of the minerals analysed for springbok, however, the levels of boron, aluminium, vanadium, copper, zinc and sodium were found to be higher in males than in females for the giraffe. Hoffman and colleagues (2007) reported higher contents of calcium, potassium, magnesium, sodium and phosphorus in springbok than in the LTL of the giraffe. In contrast, Hoffman and colleagues reported lower levels of iron, copper and zinc

than in giraffe. Iron, copper and zinc are all important to the human diet, making giraffe meat a good source of these micro-minerals as well as other macro- and micro-minerals.

6.5 CONCLUSION

The study aimed to determine the effect of sex and muscle on the proximate composition of giraffe meat, as well as the effect of sex on the mineral composition of the bone, liver and meat of the giraffe. The study also aimed to create a wider data base on the meat quality of giraffe meat, as little to nothing is known about it. Significant interactions were found between sex and muscle for all proximate parameters (moisture, protein and ash), other than the IMF content, for which only muscle had an effect. As there was an age difference of ± 3.5 years between some of the giraffe in this study it is recommended to repeat the study with giraffe of different age groups in order to quantify the effect that age has on the proximate composition. There was a sex effect on a few of the minerals of the bone, liver and the LTL of the giraffe, which were most likely due to dietary, metabolic or physiological differences between the sexes. The bone had a calcium to phosphorus ratio of 2:1 which is similar to the bone of other species despite a diet low in phosphorus. The liver of the giraffe was found to be high in manganese, and the liver and meat were both found to contain high levels of iron which are essential to the human diet. Further study is recommended on the effect of age on the mineral composition of the giraffe bone, liver and meat. Giraffe meat has a high moisture content, a low IMF and a high protein content on a par with that of other game species, containing many macro- and micro-minerals that are required in the human diet, making it a healthy meat to consume.

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CHAPTER 7

THE INFLUENCE OF SEX ON THE SENSORY AND FATTY ACID PROFILE OF GIRAFFE (*Giraffa camelopardalis angolensis*) MEAT

ABSTRACT

The objective of this study was to assess the influence of sex on the descriptive sensory (100-point line scale) and fatty acid profiles of giraffe *Longissimus thoracis et lumborum* (LTL) muscles. The instrumental tenderness of the giraffe meat was considered tough (Warner-Bratzler shear force >53 N), however, this did not have a strong correlation (r = -0.616; *P* = 0.011) with sensory tenderness reported by the panellists (~52). The males had higher gamey (male: 66.0 ± 1.61; female: 63.0 ± 3.44; *P* = 0.042) and metallic (male: 21.0 ± 1.86; female: 19.0 ± 1.26; *P* = 0.023) aromas, while the females had a higher liver-like flavour (male: 0.5 ± 0.93; female: 1.5 ± 0.69; *P* = 0.027) than males. The panellists reported to find high intensities of the metallic (~23), sour- (~14) and sweet- (~25) associated and black pepper (~9) attributes of the giraffe meat in this study. The meat from both giraffe sexes had low intramuscular fat (IMF) contents (1.4 - 1.7 %). The polyunsaturated fatty acid to saturated fatty acid (PUFA:SFA) ratios (male: 1.0 ± 0.21; female: 0.6 ± 0.30) were above the recommended minimum, for health benefits, of 0.45 and the n-6:n-3 PUFA ratios (male: 3.8 ± 0.41; female: 3.5 ± 0.54) were lower than the recommended maximum of 4:1. The atherogenicity index was significantly higher in females (0.6 ± 0.15) than males (0.4 ± 0.09), however, both were still low, and therefore another indication of a healthy fatty acid profile. Therefore, the meat of giraffe is acceptable, as pertaining to their sensory attributes, and is healthy in terms of the fatty acid profile.

Keywords: Giraffe, Game meat, Sensory, Aroma, Flavour, Texture, Tenderness

7.1 INTRODUCTION

In the wild, the giraffe populations are kept in check by predation, with approximately one in two calves born being killed by lions before reaching one year of age (Lee *et al*., 2016). However, on a game ranch, giraffe have no natural predators and it is therefore necessary to cull surplus animals to prevent exceeding the carrying capacity. Giraffe carcasses yield a large quantity of meat (Chapter 3), of acceptable physical and nutritional quality. Furthermore, giraffe meat is high in protein and low intramuscular fat (IMF) content, which is desirable to the health conscious consumer (Chapters 5 & 6; Hoffman, Kritzinger & Ferreira, 2005). Currently the meat of culled giraffe is predominantly sold into

low income sectors as processed products, such as boerewors (a type of sausage), however, there has not yet been any research on the sensory profile of the fresh meat.

The sensory attributes of meat are not limited to the flavours perceived when consuming the meat, but rather a combination of its effect on all of the human senses, including the aroma, flavour, texture, juiciness and appearance of the meat. These sensory attributes are all influenced by the physical and chemical characteristics of the meat, which in turn are affected by a combination of intrinsic (e.g. species; sex; age) and extrinsic factors (e.g. anti-mortem stress; season; diet) (Calkins & Hodgen, 2007; Melton, 1990; Neethling, Hoffman & Muller, 2016).

The IMF content of meat has a large effect on its sensory profile as the fatty acids result in a range of different flavour precursors (Wood *et al.*, 2003, 2008). The stronger flavours associated with game meat is largely due to the higher concentration of polyunsaturated fatty acids (PUFA) in these species, with the concentration of specific PUFAs mainly responsible for the species specific differences (Swanson & Penfield, 1991; Wood *et al*., 2003). Game meat tends to be very lean, with female having slightly more IMF than males of the same species (Daszkiewicz, Janiszewski & Wajda, 2009; Daszkiewicz *et al*., 2012; Hoffman *et al*., 2005; Hoffman, Mostert & Laubscher, 2009; Lawrie & Ledward, 2006). Sex may also affect the concentrations of saturated fatty acids (SFA) and PUFA, with females tending to have a higher percentage of SFA while males tend to have relatively more PUFA (Fisher *et al*., 2000; Sampels, Pickova & Wiklund, 2005; Hoffman *et al*., 2005; Wood *et al*., 2008; Daszkiewicz *et al*., 2012; Neethling, Britz & Hoffman, 2014). This may be the reason for the, sometimes unpleasant, flavour and aroma associated with meat from mature males. There has only been anecdotal information on this in game species, where a “male/urine like” flavour and odour is associated with males in rut. Despite the health concerns associated with fat in the diet, it has been found that having a diet containing meat with higher PUFA:SFA ratios is beneficial to human health (World Health Organization, 2003; Zeraatkar *et al*., 2019).

There is also evidence that the meat of females may be more tender than that of males of the same species (Hoffman, Kroucamp & Manley, 2007; Daszkiewicz *et al*., 2012). This study aims to quantify the effect of sex on the sensory meat quality (aroma, flavour and texture attributes), physical meat quality (thaw loss, cooking loss and instrumentally measured tenderness) and fatty acid profile of young giraffe (± 4 years of age).

7.2 METHODS AND MATERIALS

7.2.1 EXPERIMENTAL LOCATION AND ANIMALS

Sixteen giraffe (*Giraffa camelopardalis angolensis*), eight male and eight female (average age ± 4 years old), from the Otjozondjupa region of Namibia were culled by standard culling procedures, using a head shot (Ethical approval: ACU-2018-7366, Stellenbosch University; Namibian shoot and sell permit number: 118690). The carcasses were transported to the abattoir where they were skinned, eviscerated and dressed as described by Ledger (1963). For a more detailed description of the process, refer to Chapter 3. The warm carcasses were placed in chillers for ± 24 h at ± 4°C.

7.2.2 PROCESSING AND SAMPLING

On processing of the cold carcasses, the *Longissimus thoracis et lumborum* (LTL) muscle, consisting of the *longissimus lumborum* muscle and the *longissimus thoracis* muscle was removed from the left side of each carcass. These muscles were de-membraned, and a section of approximately 1 kg was cut from each, from the anterior end of the *longissimus thoracis* muscle, weighed and placed into separate bags before being vacuum-packed for the sensory testing. A second section was cut just below this from six of the same muscles, at random, for use in sensory training. These samples were all vacuum-packed and aged for seven days in a chiller (at ± 4°C) before being frozen (at approximately -20°C) until descriptive sensory analysis (DSA). All samples were kept frozen for approximately 6 months, which is in alignment with the standard industry practices, as southern African game meat is often frozen for extended periods of time during export shipment (Dahlan & Norfarizan Hanoon, 2008).

7.2.3 SENSORY ANALYSIS

7.2.3.1 Sample preparation and physical measurements

For DSA, the meat from sixteen giraffe was used, where the sex was the treatment with eight replications for males and eight replications for females, as one LTL muscle per giraffe was considered a replication. Each session consisted of the comparison between the LTL muscle from one male and one female. Approximately 48 h prior to the respective sensory training or testing sessions, the meat samples were removed from the freezer and thawed (at ± 4°C). On the day of the respective session, the meat was removed from the vacuum bag, patted dry to remove any excess moisture and weighed to determine thaw loss (AMSA, 2015).

Each sample was placed into an oven roasting bag (Glad®) and onto a foil-covered oven roasting pan. A thermocouple probe attached to a digital handheld temperature monitor (Hanna Instruments, South Africa), was inserted into the centre of each meat sample, the bags were fastened shut with a twist tie around the probe. The samples were then placed into an oven (Hobart, France)

preheated to 160°C (AMSA, 2015), until their internal temperature reached 72°C. The cooked meat samples were removed from the roasting bags and allowed to cool for 10 min. The samples were then patted dry and weighed to determine the cooking loss as a percentage of the raw sample (AMSA, 2015).

The cooled (and cooked) meat samples were cut into 1 cm slices, the outer surface trimmed off before cutting into 1 cm^3 cubes which were individually wrapped in small aluminium foil squares and placed into ramekins (four cubes per ramekin) for each sensory panel member. These samples were reheated for 10 min at 100°C prior to the start of the sensory tasting session. The ramekins were placed into water baths preheated to 70°C in the tasting venue, in order to maintain the temperature of the samples throughout the session (AMSA, 2015).

The tenderness of the cooked sensory samples was measured instrumentally, by determining the Warner-Bratzler shear force (WBSF) of 3-4 steaks cut from each cooked LTL muscle, during the preparation for the descriptive sensory analysis. It was ensured that these steaks were cut in a representative manner, throughout the meat sample, each measuring approximately 2 cm thick. Six 1 x 1 x 2 cm rectangular cuboid sections were cut from each sample (i.e. each replicate per treatment), taking one or two from each of the steaks to ensure that they were representative of the entire steak, care was taken to avoid any visible membranes in the cuboids. These cuboids were cut in such a manner that the muscle fibres ran along the length of the rectangle. The WBSF (N) of each of these cuboids was determined using an Instron Universal Testing Machine (Instron UTM, Model 2519-107) which used a 1 mm thick Warner-Bratzler blade (1.2 mm thick with a triangular opening, 13 mm at the widest point and 15 mm high) to cut through the middle of each cuboid, perpendicular to the grain. The average of six WBSF readings was used to determine the WBSF (N) of the LTL muscle of each giraffe.

7.2.3.2 Descriptive sensory analysis (DSA)

Descriptive sensory analysis (DSA) was conducted at the sensory facilities of the Food Science Department of Stellenbosch University. A trained and experienced sensory panel of ten people were selected to assess the sensory profile of giraffe meat. A training period, of three days, with two sessions a day took place prior to the trial itself, during which the panellists were trained according to the AMSA (2015) guidelines using a combination of the ballot and consensus methods, as described by Lawless and Heymann (2010). Several reference samples were used to train the panel for the aromas, flavours, and textures expected in the giraffe meat (Table 7.1). Each panel member was given four 1 cm^3 cubes per reference sample, as well as four 1 cm^3 cubes from six of the giraffe that were randomly selected for training of the panel. After panel training the final questionnaire was refined

and consisted of 26 sensory attributes for the giraffe meat (Table 7.2). These sensory attributes consisted of ten aroma attributes, ten flavour attributes and six texture attributes.

The sensory testing phase (i.e. data collection) consisted of two sessions a day for four days, in which one male and one female giraffe were tested per session. The testing was conducted in a light and temperature controlled room (± 21°C), where each panel member was seated at a separate booth equipped with a computer with Compusense® Five (Compusense, Guelph, Canada) software installed. For DSA the test re-test method was used (AMSA, 2015) in which each panel member received the samples from each sex in a completely randomised order. The panellists were then asked to rate the meat samples on an unstructured line scale ranging from zero (representing "low intensity") to 100 (representing "high intensity") for each of the sensory attributes (AMSA, 2015). The panellists were supplied with distilled water, apple slices and unsalted crackers for palate cleansing between samples.

7.2.4 FATTY ACID ANALYSIS

A sample from the LTL muscle of each giraffe was homogenised as described in Chapter 6 and refrozen in separate vacuum bags at -20°C until analysis. Prior to fatty acid analysis, all samples were thawed overnight at ± 4°C. The total fat content of the samples was determined using the method described by Folch, Lees and Sloane-Stanley (1957), using a chloroform : methanol (2:1; v/v) solution containing butylated hydroxytoluene (BHT) as an anti-oxidant at a concentration of 0.001 %. The fat extracts were dried in a rotary evaporator under a vacuum, the extracts were then dried overnight in a vacuum oven at 50°C with phosphorus pentoxide used as a moisture absorbent. The total extractable intramuscular fat was gravimetrically determined from the fat that was extracted and expressed as percentage fat (w/w) per 100 g of tissue. The fat free dry matter (FFDM) was determined by weighing back the residue, from the Folch extraction that remained on a pre-weighed filter paper, after drying it. The FFDM was then expressed as a percentage of the total sample as % FFDM (w/w) per 100 g of tissue. The moisture content of the sample was then determined by subtraction (100 % - % lipid - % FFDM) and expressed as % moisture (w/w) per 100 g of tissue. The extracted fat was stored in polytope glass vials at -20°C until further fatty acid analysis.

A lipid aliquot (± 30 mg) of lipid were converted to methyl esters by base-catalysed transesterification, in order to avoid conjugated linoleic acid (CLA) isomerisation, with sodium methoxide (0.5 M solution in anhydrous methanol) during 2 h at 30°C, as proposed by Alfaia *et al*. (2007), Kramer, Blackadar & Zhou (2002) and Park *et al*. (2001). The fatty acid methyl esters (FAMEs) from the lipids were quantified using a Varian 430 flame ionization gas chromatography, with a fused silica capillary column, Chrompack CPSIL 88 (100 m length, 0.25 mm ID, 0.2 µm film thicknesses). The

analysis was performed using an initial isothermic period (40°C for 2 min). The temperature was then increased at a rate of 4°C/min until reaching 230°C. This was followed by an isothermic period of 230°C for 10 min. FAMEs n-hexane (1 µl) were then injected into the column using a Varian CP 8400 Autosampler (Varian, Inc., Mitchell Drive, Walnut Creek, USA). The injection port and detector were both maintained at 250°C. Hydrogen, at 45 psi, functioned as the carrier gas, while nitrogen was the makeup gas. Galaxy Chromatography Data System Software recorded the chromatograms.

The FAME profiles of the samples were determined by comparing the retention times of FAME peaks from samples with those of standards obtained from Supelco (Supelco 37 Component Fame Mix 47885-U, Sigma-Aldrich Aston Manor, Pretoria, South Africa). CLA standards were obtained from Matreya Inc. (Pleasant Gap, Unites States). These standards included: cis-9, trans-11 and trans-10, cis-12-18:2 isomers.

The individual fatty acid values were expressed as the proportion of the total of all fatty acids present in the sample. The fatty acid data obtained were used to calculate the following totals and ratios of FAs: total SFA's; total monounsaturated fatty acids (MUFA's); total PUFAs; PUFA:SFA ratio; MUFA:SFA ratio; Δ9 desaturase index (C18:1c9/C18:0); total omega-6 PUFA; total omega-3 PUFA; and the n-6:n-3 PUFA ratio. Atherogenicity index (AI) was calculated as: AI = (C12:0 + 4 x C14:0 + C16:0)/(MUFA + PUFA) (Chilliard *et al.,* 2003).

7.2.5 STATISTICAL ANALYSIS

This trial was a completely random experimental design, with eight male and eight female giraffe, culled randomly. Where sex was the treatment, the LTL muscles from each giraffe served as the replicates, thus each treatment had eight replicates. The DSA results obtained from the panellists was monitored with PanelCheck Software (Version 1.4.0, www.panelcheck.com) to ensure the panel members were in consensus and produced repeatable results. This DSA data as well as the data obtained from physical, and chemical analysis of the giraffe meat was then analysed with SAS software (Version 9.4; SAS Institute Inc., Cary, USA), using the General Linear Models procedure to perform a univariate analysis of variance (ANOVA). The Shapiro-Wilk test was performed on the standardized residuals in order to test for any deviations from normality (Shapiro & Wilk, 1965). Fisher's least significant difference was calculated at a 5 % significance level in order to compare the means for the sexes (Lyman Ott & Longnecker, 2010). Pearson's Correlation coefficient (r) was used to quantify correlations between parameters, with a probability level of 5 % ($P \leq 0.05$) considered to be significant for all tests.

Table 7.1 Reference samples used during the training phase of the descriptive sensory analysis (DSA) of giraffe meat

Reference sample	Reference for	Final internal temperature	Scale
Beef fillet	Beef-like aroma and flavour, fatty aroma and texture, initial juiciness, sustained juiciness, tenderness, residue, mealiness	72°C	0 = low intensity; 100 = high intensity
Beef rib-eye	Beef-like aroma and flavour, fatty aroma and texture, initial juiciness, sustained juiciness, tenderness, residue, mealiness	72°C	0 = low intensity; 100 = high intensity
Beef liver	Liver-like aroma and flavour	No probe was used	0 = low intensity; 100 = high intensity
Lechwe (*Kobus leche*) steak	Gamey aroma and flavour	74°C	0 = low intensity; 100 = high intensity
Black wildebeest (*Connochaetes gnou*) steak	Gamey aroma and flavour	72°C	0 = low intensity; 100 = high intensity
Old bull giraffe (*Giraffa camelopardalis*)	Gamey aroma and flavour, fatty aroma and flavour, fatty mouth feel	73°C	0 = low intensity; 100 = high intensity
Giraffe diaphragm	Metallic aroma and flavour, toughness	72°C	0 = low intensity; 100 = high intensity

Table 7.2 Descriptions and scales of the sensory attributes (aroma, flavour and texture) decided upon for the descriptive sensory analysis of giraffe meat

Sensory attribute	Description of attributes	Scale
Aroma and flavour		
Overall intensity	The intensity of the aromas on the first few sniffs	0 = low intensity; 100 = high intensity
Gamey*	Aroma/flavour associated with the cooked meat of wild animals	0 = low intensity; 100 = high intensity
Beef-like*	Aroma/flavour associated with a cooked beef steak	0 = low intensity; 100 = high intensity
Liver-like*	Aroma/flavour associated with pan-fried liver	0 = low intensity; 100 = high intensity
Metallic*	Aroma/flavour associated with blood/raw meat	0 = low intensity; 100 = high intensity
Fatty*	Aroma/flavour associated with cooked fat	0 = low intensity; 100 = high intensity
Black pepper*	Aroma/flavour associated with black pepper	0 = low intensity; 100 = high intensity
Sour-associated aroma	Aroma associated with vacuum-packed, aged game meat	0 = low intensity; 100 = high intensity
Sour-associated taste	Taste associated with vacuum-packed, aged game meat	0 = low intensity; 100 = high intensity
Sweet-associated aroma	Sweet-associated aroma of the browning on the surface of roasted meat	0 = low intensity; 100 = high intensity
Sweet-associated taste	Taste of the browning on the surface of roasted meat	0 = low intensity; 100 = high intensity
Salty taste	Taste associated with sodium ions	0 = low intensity; 100 = high intensity
Off aroma	Aroma associated with barnyard (combination of urine and hay)	0 = low intensity; 100 = high intensity
Off flavour	Flavour associated with barnyard (combination of urine and hay) sometimes followed by bitter after taste	0 = low intensity; 100 = high intensity
Texture		
Initial juiciness	The amount of liquid that seeps out of the cube when pressed, perpendicular to the grain, between thumb and fore-finger	0 = dry; 100 = extremely juicy
Mealiness	The meat disintegrates into small gritty pieces in your mouth with very few chews (3-4 chews)	0 = none; 100 = abundant
Tenderness	The perceived tenderness after mastication (after 5 chews)	0 = tough; 100 = extremely tender
Sustained juiciness	The amount of moisture perceived during mastication (after 10 chews)	0 = dry; 100 = extremely juicy
Residue	The amount of tissue remaining in your mouth after mastication (after 10 chews)	0 =none; 100 = abundant
Fatty mouth feel	The lingering oily feel in your mouth after eating a piece of fat	0 = none; 100 = extremely oily

*Sensory attribute was evaluated for both aroma and flavour.

7.3 RESULTS

There were no significant differences between sex for any of the physical parameters (Table 7.3). The pH_u reported was taken at 24 h post-mortem for the LTL muscle as a whole, as an indication of whether the meat could be classified as dark, firm and dry (DFD). The thaw loss, cooking loss and WBSF were all determined on the sensory samples, as these samples were aged, frozen and thawed, the cooking loss and WBSF values were expected to differ from those of the fresh meat.

Table 7.3 Mean (± standard deviation) of the physical parameters of the *Longissimus thoracis et lumborum* (LTL) muscle of giraffe as influenced by sex

Parameter	Sex		*P-value*
	Male	Female	
Thaw loss (%)	16.3 ± 2.31	17.3 ± 3.22	0.477
Cooking loss (%)	35.2 ± 2.47	33.6 ± 1.88	0.164
WBSF (N)	67.5 ± 13.24	60.5 ± 15.93	0.359
pH_u[1]	5.6 ± 0.16	5.6 ± 0.15	0.728

[1]Values for the fresh meat, taken from Chapter 5, Table 5.3.

The majority of the aroma attributes did not differ between the sexes, with the exception of gamey aroma ($P = 0.042$) and metallic aroma ($P = 0.023$) that were both higher in males than in females (Table 7.4). Similarly, most of the flavour attributes did not differ between sexes except for liver-like flavour that was higher in females than in males ($P = 0.027$), whilst there were no differences for sex in the texture attributes. Even though these three attributes differed between sexes, the magnitude of the differences were minimal (Table 7.4).

The overall aroma intensity values (~67) were similar to those for gamey aroma (~65), which was the aroma attribute present at the highest intensity in giraffe meat, followed by beef-like aroma (~38.4) (Table 7.4). The gamey flavour (~64) was also the flavour attribute present at the highest intensity in giraffe meat, followed by the beef-like flavour (~39) whilst both metallic flavour (~25) and sweet-associated (~25.2) taste which were present at lower intensities (Table 7.4).

Table 7.4 Mean (± standard deviation) of the sensory ratings of the *Longissimus thoracis et lumborum* (LTL) meat of giraffe as influenced by sex

Sensory characteristic	Sex		*P-value*
	Male	Female	
Aroma			
Overall intensity	68.3 ± 1.81	66.6 ± 1.57	0.056
Gamey aroma	66.0 ± 1.61	63.0 ± 3.44	**0.042**
Beef-like aroma	38.4 ± 2.60	38.1 ± 1.48	0.820
Liver-like aroma	1.1 ± 0.63	1.0 ± 1.04	0.738
Metallic aroma	21.0 ± 1.86	19.0 ± 1.26	**0.023**
Fatty aroma	10.4 ± 1.61	11.6 ± 0.68	0.071
Black pepper aroma	8.0 ± 1.15	7.6 ± 1.35	0.485
Sour-associated aroma	12.4 ± 2.16	11.6 ± 1.67	0.421
Sweet-associated aroma	24.5 ± 2.40	25.8 ± 4.09	0.441
Off aroma	0.6 ± 0.50	0.8 ± 0.54	0.353
Flavour			
Gamey flavour	64.5 ± 1.75	64.6 ± 1.24	0.926
Beef-like flavour	39.4 ± 2.34	39.7 ± 1.44	0.737
Liver-like flavour	0.5 ± 0.93	1.5 ± 0.69	**0.027**
Metallic flavour	25.6 ± 1.91	25.6 ± 1.77	0.971
Fatty flavour	13.2 ± 0.71	12.6 ± 0.75	0.117
Black pepper flavour	9.8 ± 1.15	10.1 ± 2.24	0.670
Sour-associated taste	14.5 ± 1.92	15.9 ± 1.98	0.176
Sweet-associated taste	24.7 ± 1.98	25.2 ± 1.71	0.626
Salty taste	10.0 ± 0.03	10.0 ± 0.03	0.636
Off flavour	0.3 ± 0.46	0.6 ± 0.52	0.149
Texture			
Initial juiciness	40.8 ± 4.39	44.2 ± 6.32	0.239
Mealiness	11.6 ± 3.97	18.5 ± 8.25	0.053
Tenderness	49.0 ± 4.93	55.3 ± 6.90	0.052
Sustained juiciness	44.9 ± 3.29	46.9 ± 4.17	0.323
Residue	33.4 ± 8.26	27.1 ± 9.84	0.189
Fatty mouth feel	13.1 ± 1.47	12.9 ± 1.29	0.727

Table 7.5 Pearson's correlation coefficients (r) of significance between sensory attributes of giraffe meat

Parameter	Mealiness		Tenderness		Sustained juiciness		Residue		Shear force		Cooking loss		pH_u	
	r^1	*P*	r^1	*P*	r^1	*P*	r^1	*P*	r^1	*P*	r^1	*P*	r^1	*P*
Initial juiciness	0.729	**0.001**	0.763	**0.001**	0.526	**0.037**	-0.748	**0.001**	-0.790	**0.000**	-0.607	**0.013**	-0.560	**0.024**
Mealiness	-	-	0.762	**0.001**	0.602	**0.014**	-0.765	**0.001**	-0.709	**0.002**	-0.489	0.055	-0.349	0.185
Tenderness			-	-	0.692	**0.003**	-0.838	**<0.0001**	-0.616	**0.011**	-0.607	**0.013**	-0.530	**0.035**
Sustained juiciness					-	-	-0.783	**0.000**	-0.611	**0.012**	-0.705	**0.002**	-0.623	**0.010**
Residue							-	-	0.684	**0.042**	0.761	0.541	0.694	0.331
Shear force									-	-	0.530	**0.035**	0.533	**0.033**
Cooking loss											-	-	0.575	**0.020**

[1]Pearson's correlation coefficient

There was a negative correlation between the sensory tenderness and the instrumental shear force (r = - 0.616; *P* = 0.011) (Table 7.5). The pH_u was positively correlated to WBSF (r = 0.533; *P* = 0.033) and negatively correlated with sensory tenderness (r = -0.530; *P* = 0.035) (Table 7.5). The cooking loss was negatively correlated to the initial (r = -0.607; *P* = 0.013) and sustained juiciness (r = -0.705; *P* = 0.002), as well as the sensory tenderness (r = -0.607; *P* = 0.013), and positively correlated with the instrumental shear force (r = 0.530; *P* = 0.035) (Table 7.5).

Of the saturated fatty acids, palmitic and stearic acid were in the highest proportions and stearic acid was found to be higher in male than in females. Myristic acid and palmitic acid were higher in females than in males (Table 7.6). The total MUFA's were higher in females than in males, as *cis*-oleic acid was higher in females, and made up the majority of the MUFA's. The total PUFA were higher in males than females, with linoleic acid making up the highest proportion thereof. Linoleic, alpha-linolenic acid, arachidonic acid, eicosapentaienoic acid and docosapentaenoic acids were all higher in males. The PUFA:SFA and PUFA:MUFA ratios were both higher in males than females. The total n-3 and n-6 PUFA were also higher in males than females. The atherogenicity index was found to be higher in the females than in the males.

Table 7.6 Means (± standard deviation) of the fatty acid profile (%) of *Longissimus thoracis et lumborum* (LTL) meat of giraffe as influenced by sex

Fatty Acid	**Sex**		***P-value***
	Male	**Female**	
Total fat (%)[1]	1.1 ± 0.20	1.4 ± 0.52	0.141
Fatty acids (%)[2]			
C10:0 (Capic)	0.0 ± 0.03	0.1 ± 0.07	0.104
C14:0 (Myristic)	1.8 ± 0.48	2.5 ± 0.58	**0.027**
C15:0 (Pentadecyclic)	0.7 ± 0.06	0.6 ± 0.14	**0.018**
C16:0 (Palmitic)	18.2 ± 1.98	24.0 ± 3.92	**0.002**
C17:0 (Heptadecanoic)	0.8 ± 0.14	0.8 ± 0.16	0.395
C18:0 (Stearic)	18.5 ± 1.44	15.6 ± 1.49	**0.002**
C19:0 (Nonadecanoic)	0.0 ± 0.04	0.0 ± 0.02	0.283
C20:0 (Arachidic)	0.1 ± 0.04	0.0 ± 0.04	0.426
C23:0 (Tricosanoic)	0.0 ± 0.03	0.0 ± 0.03	0.788
Total SFA	40.1 ± 2.81	43.6 ± 3.95	0.057

Table 7.6 Continued

Fatty Acid	Sex		*P-value*
	Male	**Female**	
C14:1n9c (Myristoleic)	0.0 ± 0.00	0.1 ± 0.09	**0.029**
C16:1n9c (Palmitoleic)	0.8 ± 0.32	1.8 ± 0.77	**0.005**
C17:1 (Heptadecenoic)	0.2 ± 0.03	0.2 ± 0.08	0.174
C18:1n9t (Oleic)	0.3 ± 0.17	0.2 ± 0.11	0.156
C18:1n9c (Oleic)	17.9 ± 3.57	28.5 ± 7.10	**0.002**
C18:1n11t (Vaccenic)	1.5 ± 0.10	1.5 ± 0.61	0.887
C22:1n13c (Erucic)	0.8 ± 0.16	0.5 ± 0.25	**0.018**
Total MUFA	21.5 ± 3.70	32.7 ± 7.23	**0.002**
C18:2 n-6 (Linoleic)	23.1 ± 3.36	14.0 ± 6.09	**0.002**
C18:3 n-6 (Gamma-linolenic)	0.2 ± 0.04	0.1 ± 0.07	0.324
C18:3 n-3 (Alpha-linolenic)	5.0 ± 0.97	3.2 ± 1.24	**0.006**
C20:2 n-6 (Eicosadienoic)	0.0 ± 0.03	0.0 ± 0.01	0.202
C20:4 n-6 (Arachidonic)	7.1 ± 1.58	4.3 ± 2.19	**0.013**
C20:5 n-3 (Eicosapentaienoic)	1.5 ± 0.39	1.0 ± 0.51	**0.034**
C22:5 n-3 (Docosapentaenoic)	1.2 ± 0.30	0.8 ± 0.39	**0.021**
C22:6 n-3 (Docosahexaenoic)	0.4 ± 0.11	0.3 ± 0.17	0.153
Total PUFA	38.4 ± 6.31	23.7 ± 10.46	**0.004**
PUFA:SFA ratio	1.0 ± 0.21	0.6 ± 0.30	**0.007**
PUFA:MUFA ratio	1.9 ± 0.49	0.9 ± 0.68	**0.004**
Total n-6 PUFA	30.3 ± 4.80	18.5 ± 8.28	**0.004**
Total n-3 PUFA	8.1 ± 1.69	5.3 ± 2.26	**0.012**
n-6:n-3 PUFA ratio	3.8 ± 0.41	3.5 ± 0.54	0.271
Atherogenicity index	0.4 ± 0.09	0.6 ± 0.15	**0.011**

[1]As % of the meat; [2]As % of total fatty acids
Abbreviations: SFA = Saturated fatty acids (includes C10:0, C14:0, C15:0, C16:0, C17:0, C18:0, C19:0, C20:0 and C23:0); MUFA = Monounsaturated fatty acids (includes C14:1n9c, C16:1n9c, C17:1, C18:1n9t, C18:1n9c, C18:1n11t and C22:1n13c); PUFA = Polyunsaturated fatty acids (includes C18:2n6, C18:3n6, C18:3n3, C20:2n6, C20:4n6, C20:5n3, C22:5n3 and C22:6n3); n-3 PUFA = Omega-3 fatty acid; n-6 PUFA = Omega-6 fatty acid; IMF = Intramuscular fat.

The total SFA content was negatively correlated to the metallic aroma, whilst total MUFA was negatively correlated with overall aroma intensity, gamey aroma and metallic aroma (Table 7.7). The total PUFA, (n-3) and (n-6), as well as the PUFA:SFA and PUFA/MUFA ratios were all correlated with higher overall aroma intensity, gamey aroma and metallic aroma (Table 7.7). Stearic acid was the only SFA to have a significant correlation with any of the sensory attributes, having a positive correlation with the gamey aroma. Several of the individual PUFA's had significant correlations with the sensory

attributes, however, positive correlations were only found with overall aroma intensity, gamey aroma, metallic aroma and sour-associated aroma. The individual fatty acids found to have significant correlations with these aroma attributes, and found in a concentration of more than 1 % of the total fatty acids were linoleic, alpha-linolenic, arachidonic, eicosapentaienoic and docosapentaenoic acids.

Table 7.7 Pearson's correlation coefficients (r) of significance between the sensory attributes and the fatty acid profile

	Overall aroma intensity		**Gamey aroma**		**Metallic aroma**		**Sour-associated aroma**	
	r[1]	***P-value***	**r[1]**	***P-value***	**r[1]**	***P-value***	**r[1]**	***P-value***
Stearic acid	0.493	0.053	0.560	**0.024**	0.452	0.079	0.133	0.623
SFA	-0.409	0.115	-0.330	0.212	-0.543	**0.030**	-0.445	0.084
MUFA	-0.630	**0.009**	-0.615	**0.011**	-0.632	**0.009**	-0.428	0.098
Linoleic acid	0.588	**0.017**	0.532	**0.034**	0.584	**0.018**	0.400	0.125
Alpha-linolenic acid	0.589	**0.016**	0.540	**0.031**	0.653	**0.006**	0.357	0.175
Arachidonic acid	0.551	**0.027**	0.549	**0.028**	0.673	**0.004**	0.566	**0.022**
Eicosapentaienoic acid	0.499	**0.049**	0.504	**0.047**	0.641	**0.007**	0.552	**0.027**
Docosapentaenoic acid	0.475	0.063	0.519	**0.039**	0.690	**0.003**	0.525	**0.037**
PUFA	0.584	**0.018**	0.546	**0.029**	0.630	**0.009**	0.453	0.078
(n-3)	0.585	**0.017**	0.542	**0.030**	0.613	**0.012**	0.448	0.082
(n-6)	0.556	**0.025**	0.540	**0.031**	0.668	**0.005**	0.449	0.081
PUFA:SFA	0.584	**0.017**	0.517	**0.040**	0.627	**0.009**	0.467	0.068
PUFA/MUFA	0.647	**0.007**	0.534	**0.033**	0.641	**0.007**	0.452	0.079

[1]r (Pearson's correlation coefficient)

7.4 DISCUSSION

The aim of this study was to generate baseline data on the sensory attributes for giraffe meat and to specifically compare the effect of sex on the physical measurements, sensory attributes and fatty acid profile of the LTL muscle.

One of the females was older than the rest, her age was judged as 9 years by a professional hunter, and her data was therefore removed from the previous chapters to avoid the effect of age. However, the data from this animal was kept in this chapter in order to balance the experimental design. Nonetheless, following statistical analysis, it was found that her data points were not outliers. This may be due to the large variation in the data for the giraffe in this study in general. During the training period it was found that it was hard to reach a consensus on the characteristics of the meat,

especially for texture, as there was a considerable amount of variation, even between cubes cut from the same muscle. This may be due to the connective tissue running through the LTL muscle of giraffe, which was impossible to avoid completely when cutting the meat cubes for sensory analysis (Supplementary Fig. 2). The connective tissue may have been present in cubes and could explain some of the variation (see high standard deviation values in Table 7.4).

The normal pH_u range is considered to be below pH 6.06, with 5.6 taken as the standard for red meat, and DFD traits only exhibited above pH 6.06 (Braggins, 1996; Shange, Gouws & Hoffman, 2019). As the pH_u of the giraffe meat was found to range from 5.23-5.76, it could be classified as normal. The pH_u was found to be positively correlated with the cooking loss and the WBSF and negatively correlated with the initial and sustained juiciness, as well as sensory tenderness. However, as the pH_u did not have a large standard deviation (male: 5.6 ± 0.16; female: 5.6 ± 0.15), showing there was minimum variation, and the group was fairly small, these correlations may be due to the presence of slight individual outliers. It is therefore unlikely that these differences in cooking loss, shear force, juiciness and tenderness were caused by the difference in pH_u. As the pH_u was not high enough to cause DFD, it did not affect the cooking loss as may have been expected, from what Engels (2019) reported, where a high negative correlation was found between the pH_u and the cooking loss, however, some of the impala (*Aepyceros melampus*) in that trial were classed as DFD meat.

The thaw loss (~16 %) was found to be higher than impala (8 %) (Engels, 2019), but comparable with that of fallow deer (*Dama dama*) averaging between 14.6 % and 22.9 % for pasture fed deer (Hutchison *et al*., 2012). The cooking loss (~34 %) was more comparable with that of impala (29.9 %) (Engels, 2019) as well as that of eland (*Taurotragus oryx*) (36.5 %) (Needham *et al*., 2019). The total moisture loss accounted for an approximately 50 % loss in weight. Cooking loss was found to have a strong negative correlation with both initial and sustained juiciness, and tenderness, and a strong positive correlation with WBSF. As sustained juiciness is a direct result of lower moisture loss through thaw and cooking loss this correlation was expected. It has been postulated that consumers may perceive juicier meat to be more tender than less juicy meat (Lagerstedt *et al*., 2008). As there is a moderate negative correlation between the tenderness and the WBSF ($r = -0.616$; $P = 0.011$), the instrumental measure therefore illustrates the trend of the sensory tenderness. The negative correlation between the tenderness and the WBSF was not as high as may have been expected, which may be due to the large variation in the meat quality within the sample. The WBSF values were found to be substantially higher than for fresh meat (Chapter 5) where the LTL muscles averaged ~30 N for both males and females, whereas the frozen and thawed meat in this study was found to average ~65 N in females, approximately two times that of fresh meat. The meat samples used in this trial were also aged for seven days prior to freezing, which is known to improve the tenderness of meat, whereas

the fresh meat was not aged, the sensory samples were therefore expected to have a lower WBSF. The higher WBSF readings for the aged, frozen and thawed meat may be due to the freezing of the meat, as this was reported to decrease the tenderness in ostrich meat (Leygonie, Britz & Hoffman, 2012) and was found to be the trend in impala meat as well (Engels, 2019). Although it is more likely due to the difference in cooking method between the two trials (Chapter 5, Methods and materials) as cooking method has a significant impact on the texture of cooked meat (Palka, 1999). The cooking loss of the frozen and thawed meat was found to be slightly lower than that of the fresh meat (fresh meat: ~37.5 %) (Chapter 5, Table 5.3). However, the thaw loss (~17 %) was far greater than the drip loss (2.2 %) (Chapter 5, Table 5.3), resulting in a greater total moisture loss. As ice crystals form in the meat they disrupt the myofibrillar structure, decreasing water holding capacity, resulting in greater moisture losses in particular during thawing (Gonzalez-Sanguinetti, Anon & Calvelo, 1985). The greater thaw loss results in less moisture left to be lost during cooking, which may explain the lack of difference in cooking loss between the thawed and fresh meat. The greater moisture losses may result in tougher meat, as there is a negative correlation between the cooking loss and tenderness, however, this may again be due to the 'halo' effect, whereby human assessors often perceive juicier meat to be more tender (Shorthose & Harris, 1991; Hopkins *et al*., 2006). Also, with higher thaw and cooking losses, the collagen within the fixed muscle surface area will be higher than that from the fresh samples and this would have led to higher WBSF values. Additionally, the cooking method and the instrument used for determining the WBSF of the fresh meat (Chapter 5) differed to what was used for the sensory samples, which may explain part of the difference. The cooking method used for the fresh meat (Chapter 5) traps the moisture lost during the cooking process around the meat, and it is consequently boiled in its own juices, in contrast to the method employed in this study, where the meat was placed on a raised roasting pan, to ensure the meat did not sit in its own juices while cooking. Therefore the fresh meat was, in effect boiled, while the thawed meat was roasted. The lower threshold for meat to be classified as tough is 52.7 N (Destefanis *et al.,* 2008), and as the WBSF values for this trial ranged from 45.4 – 96.7 N, it would be classified as intermediately tender to tough. These WBSF values were similar to those for frozen and thawed eland meat (Needham *et al*., 2019). While fresh giraffe meat is considered tender (Chapter 5), frozen and thawed giraffe meat is considered to be tough, and will be discriminated against by consumers (Destefanis *et al*., 2008). This underlines the importance of researching the meat quality characteristics of different game species, and creating a standard to which game meat should be produced, as well as standardising the cooking methods used in the preparation thereof. As game meat is often frozen during exportation (Gonzalez-Sanguinetti *et al*., 1985; Dahlan & Norfarizan Hanoon, 2008), the negative effects on giraffe meat must be considered, and the procedures of freezing and thawing giraffe meat need to be researched further.

In addition, alternative options such as exporting fresh vacuum-packed cuts should also be investigated. However, the sensory tenderness (male: 49.0; female: 55.3) did compare favourably with that of impala (57.5-63.8; Hoffman *et al*., 2009; Neethling, 2016) and eland (male: 40.1; female: 35.5; Needham *et al.,* 2019).

The sensory residue had a strong positive correlation with the WBSF, indicating that tough meat would have a higher residue after mastication (10 chews), as it requires more chewing to break it down into small enough pieces to swallow. The residue also had a strong negative correlation with initial and sustained juiciness, as well as tenderness and mealiness, indicating that a tender piece of meat with a higher juiciness will require less chewing to break down and swallow.

Of the sensory attributes only the gamey and metallic aromas and liver-like flavour were found to differ for sex. The overall aroma intensity also tended towards significance (P = 0.056), with males tending to have a more intense aroma (Table 7.4). Gamey and metallic aromas were both higher in the males than the females, and these traits and the overall intensity, were highly correlated with both the PUFA:SFA and PUFA/MUFA ratios (Table 7.5), which were also higher in males. As PUFAs are flavour precursors, the difference in concentration between the sexes may result in the difference in these aromas, as aroma and flavour are directly related (Mottram, 1998). The liver-like flavour was found to be higher in females than males. However, it must be remembered that the scale of measure was on a 1-100 intensity scale, therefore both the difference between sex, and the perception of the flavour itself, were negligible (male: 0.5 ± 0.93; female: 1.5 ± 0.69) and may not be noticeable to the average consumer. The difference may also be due to the frequency of the liver-like flavour being perceived in the meat blocks between the sexes, as opposed to the intensity thereof. A liver-like flavour was picked up by at least one panel member for every female, while it was only found to be present in two of the males, however, the panellists never reported it to be above 10 on the 100 point scale. The metallic aroma and gamey aroma had a positive correlation, while the metallic flavour was negatively correlated with the beef-like aroma. The beef-like flavour was negatively correlated with the gamey flavour. This shows that the higher the metallic traits, the more gamey the meat is perceived and the less beef-like. Both metallic and liver-like aromas are unwanted sensory attributes of meat (Yancey *et al*., 2006). There were no sex differences for any of the texture parameters. Although the mealiness (P = 0.053) and tenderness (P = 0.052) did tend to be higher in females than males. Age has also been found to have an effect on the tenderness of meat as older animals have more heat-stable and less soluble collagen in their muscles (Lepetit, 2007), as well as the development of more cross-links between collagen molecules and fibrils (Lepetit, 2007). This results in the meat from older animals being less tender than that of younger animals. Older animals also tend to have larger muscle fibre diameters, which also contributes to tougher meat as found by Kandeepan *et al.*

(2009) on buffalo meat. As giraffe have been found to have large muscle fibre diameters (Hall-Martin, Von La Chevallerie & Skinner, 1997) their meat may be expected to be tough. It may be of interest to further investigate how age affects the sensory texture and instrumental tenderness values of giraffe meat. Despite one of the females in this study being older than all the rest, her data was not found to be an outlier for any of the parameters.

When comparing the sensory attributes to other studies, it is important to consider the panel, as well as the fact that the scale on which the traits are rated will be calibrated differently between trials, despite attempts to calibrate it with reference samples during the training period. However, the majority of the panel members in this study had experience in previous sensory trials carried out on meat. In order to minimize the effect the panel may have on the results, the overall sensory attributes of giraffe meat will be compared to trials carried out with the same core panel. The overall aroma intensity was found to be similar to that of other game meat which ranged from 59.4 to 72.1 for the six species (springbok (*Antidorcas marsupialis*), gemsbok (*Oryx gazella*), blesbok (*Damaliscus pygargus phillipsi*), impala, red hartebeest (*Alcelaphus buselaphus caama*) and kudu (*Tragelaphus strepsiceros*)) studied by Neethling (2016), and that of eland, which averaged 64.2 and 66.6 for male and female, respectively (Needham *et al.,* 2019). The gamey and beef-like aromas and flavours were in alignment with the six species of Neethling's study, however, Needham and colleagues found eland to have much lower gamey attributes, and higher beef-like traits. Giraffe had a higher metallic aroma and flavour than the six species in Neethling's study, with springbok and blesbok having the closest measurements. North and Hoffman (2015) found that the metallic aroma and flavours increases with post-mortem ageing of springbok LTL muscles, and postulate that this may be due to proteolysis and denaturation during ageing and cooking causing the release of iron from myoglobin and heam-complexes. This would increase the concentration of free iron in the meat, which may increase the intensity of the metallic attributes (Geldenhuys, Hoffman & Muller, 2014). As the giraffe meat in this trial was aged for 7 days prior to freezing, this may have contributed to the elevated metallic attributes. Giraffe were found to have a few aroma and flavour attributes that were substantially higher than those of other game species, namely, black pepper, sour-associated and sweet-associated aromas and taste (sweet-associated, is sometimes described as a sweetcorn aroma/flavour). Giraffe had a black pepper aroma of ~7.8 and a black pepper flavour of ~10.0, while this is considered as low intensities on the 0-100 scale, it is a lot higher than the values reported by Neethling (2016). Neethling reported values between 0.0 and 0.4 for aroma, and did not report having found black pepper flavour in the six game species studied. This black pepper flavour may be due to exclusively browsing *Vachellia* and *Senegalia* (previously collectively known as *Acacia*) trees, however, as it was not reported in kudu (Neethling, 2016), or eland (Needham *et al*., 2019) which both commonly browse the same trees, this

may not be the case. The sour-associated aroma was ~12.0 for giraffe meat, while ranging from 1.1-2.0 in the six game species studied by Neethling (2016). The sour-associated taste was ~15.2 for giraffe, while Neethling did not report a sour-associated taste. The sour-associated attributes may be due to wet ageing (ageing in moisture and gas impermeable vacuum bags) which results in an anaerobic environment, favouring lactic acid bacteria, that are responsible for the production of lactic acid (Li *et al*., 2013). The sweet-associated aroma was ~25 for giraffe, and while not reported for the six species in Neethling's study, it was found to be ~14 in the LTL muscle of eland (Needham *et al.,* 2019). A sweet-associated aroma was also found in horse meat, where it was reported to range from 34.6-41.4 (Diaconu *et al*., 2015), however, this study was not carried out with the same panel. However, Sweet-associated attributes were observed by the Authors in an unpublished study on zebra (*Equus quagga*). The sweet-associated flavour was found to be ~25 in giraffe, while it ranges from 1 to 2 in impala and springbok, respectively of Neethling's six species (2016). Eland were found to have a relatively high sweet-associated flavour of ~11 for their LTL muscle (Needham *et al*., 2019). The liver-like aroma and flavour of giraffe was found to be lower than that of the eland (Needham *et al.,* 2019) or the other six game species (Neethling, 2016).

The sensory profile of giraffe meat may be affected by the seasonal changes in the available browse. Du Toit, Bryant and Frisby (1990), found that the changes in intensity of browsing on *Vachellia* and *Senegalia* trees, which may be a result of seasonal changes on the availability of other vegetation due to drought and changing population densities, influences the nutritional quality and concentration of tannins in the regrowth. Du Toit and colleagues (1990) found that heavy browsing intensity resulted in more nutritious regrowth, with lower tannins than lightly browsed trees. The concentration of the tannins in the trees browsed by the giraffe may affect the fatty acid profile and thus the sensory profile of the meat, and cause different sensory characteristics to be more or less prominent during times of drought as opposed to times of plenty. Studies on the effects of diets high in tannins, on fatty acid production and meat quality in ruminants have reported contradictory results, on the precise effect, however, there seems to be consensus that they have an effect (Morales & Ungerfeld, 2015).

While the lean portion of the meat is responsible for the general meat-like flavour, the fatty acid profile is responsible for the species specific flavours of the cooked meat (Wasserman & Spinelli, 1972). The IMF content of the giraffe was found to be below 3 g/100 g which is the level at which it is considered to be low (Food Advisory Committee, 1990) (male: 1.4 ± 0.37g/100 g; female: 1.7 ± 0.30 g/100 g), a health benefit common to most game species. IMF level affects the fatty acid composition, as the triacylglycerols increase with fatness, and are more saturated than the phospholipids of the muscle membranes, which remain more constant (Marmer, Maxwell, & Williams, 1984). The PUFA:SFA ratio was above 0.7 for males, which is the level above which there are considered to be

health benefits (Wood *et al.,* 1999; Raes, De Smet & Demeyer, 2004). Although females had a slightly lower ratio (0.6 ± 0.30), it was still above the recommended minimum of 0.45 for a healthy diet. According to Wood and colleagues (1999) and Raes and colleagues (2004), a healthy human diet should contain fats with a n-6:n-3 PUFA ratio lower than 4.0, and giraffe meat from both sexes were found to have ratios below 4.0. The atherogenicity index was also found to be low, as this is an indication of the tendency of the fatty acid profile to lead to atherosclerosis (Ulbricht & Southgate, 1991), this is beneficial. The atherogenicity index was significantly higher in females (0.6 ± 0.15) than males (0.4 ± 0.09), however, both were significantly lower than that of chicken meat (0.7-0.9; Nkukwana *et al*., 2014). The meat of giraffe can therefore be considered healthy in terms of its fat content.

There is little research into the effects of the dietary regime of game species on their sensory profile, however, Hoffman and colleagues (2005) noted that the fatty acid profile differed between two populations of impala where the one mainly browsed and the other mainly grazed. Neethling (2016) compared the fatty acid profiles of six game species (springbok, gemsbok, blesbok, impala, red hartebeest and kudu) from the same biome in South Africa, but with a range of different feeding habits, with gemsbok exclusively grazing, kudu exclusively browsing, and the rest mixed feeders, grazing and browsing to different extents. Neethling (2016) found that there were large differences in the fatty acid profiles of the six different game species, although the degree to which this was influenced by dietary strategy was not entirely clear. As giraffe are browsers, eating a diet of predominantly *Vachellia* and *Senegalia* trees, their fatty acid profile may be expected to differ from that of grazing game species. The giraffe in this study were kept in a large area where the prevailing vegetation was comprised of *Vachellia* and *Senegalia* trees. However, as giraffe are ruminants, not all fatty acids consumed are directly incorporated into the tissue lipids in the same manner as they would be in monogastric animals, although some unsaturated fats do pass unchanged through the rumen (Wood & Enser, 1997).

Female giraffe tended to be higher in saturated fatty acids (SFAs) than males (Table 7.6; P = 0.057). Of the SFAs, females were higher in mystric and palmic acids, while males were higher in pentadecyclic and stearic acids. Stearic and palmitic acids are normally the main SFA's in red meat (Higgs, 2000), which was found to be the case for giraffe meat as well, where palmitic (male: 18.2 %; female: 24.0 %) and stearic (male: 18.5 %; female: 15.6 %) acids made up the largest percentages of the total fatty acids. While SFA's are generally associated with health risks, stearic acid does not elevate the cholesterol levels, although palmitic acid is known to do so (Higgs, 2000). As there is a low IMF content in giraffe and palmitic acid only makes up 18.2-24.0 % of this, the potential negative effect

thereof will be negligible. The IMF content was made up predominantly of SFA's, making up ~40 % in males and ~44 % in females.

Females were significantly higher in monounsaturated fatty acids (MUFA's) (P = 0.002) than males (Table 7.6), this was also observed in gemsbok, blesbok and impala (Neethling, 2016). MUFA's made up 21.5 ± 3.70 % and 32.7 ± 7.23 % of the IMF content of males and females, respectively. Of the MUFA's females were higher in myristoleic, palmitoleic and oleic acids, and males were higher in erucic acid. Oleic acid made up the majority of the MUFA content for both sexes (male: 17.9 ± 3.57 %; female: 28.5 ± 7.10 %), which was also the case in springbok, gemsbok, blesbok, impala, red hartebeest and kudu (Neethling, 2016).

Males were significantly higher in PUFAs (male: 38.4 ± 6.31 %; female: 23.7 ± 10.46 %) (P = 0.004), which is also the case in springbok and blesbok (Neethling, 2016). There was a large amount of variation especially for females in the present study, which may be due to physiological differences, or the age variation. Linoleic acid was the most abundant PUFA, with a significantly higher content in males (23.1 ± 3.36 %) than females (14.0 ± 6.09 %) (P = 0.002). This was also the case in springbok and blesbok, while female impala had a higher linoleic acid content than males. Alpha-linolenic (male: 5.0 ± 0.97 %; female: 3.2 ± 1.24 %) and arachidonic acids (male: 7.1 ± 1.58 %; female: 4.3 ± 2.19 %) also made up a considerable percentage of the PUFA content. Alpha-linolenic acid is classified as an essential fatty acid, as it cannot be synthesised by the body (Bezard *et al*., 1994), it is also the most important n-3 fatty acid for human health, as it negates cardiovascular deterioration (Simopoulos, 1991). Alpha-linolenic acid is also one of the main fatty acids found in grass (Marmer *et al*., 1984), and it has been reported that gamma-linolenic and alpha-linolenic acid were in higher concentrations in a population of impala that predominantly grazed, over a population that predominantly browsed (Hoffman *et al*., 2005). However, in Neethling's study (2016) there were no obvious trends between the ratios of the linoleic acid isomers and the feeding habits of the six game species. The concentrations of linoleic, gamma-linolenic and alpha-linolenic acid of giraffe were similar to those of both the browsing and grazing populations of impala (Hoffman *et al.,* 2005).

The total SFA content was found to be negatively correlated with the metallic aroma, while the total MUFA content was found to have a negative correlation with overall aroma intensity as well as gamey and metallic aromas. The total PUFA content as well as the PUFA:SFA and PUFA:MUFA ratios, had positive correlations with overall aroma intensity and gamey and metallic aromas, which shows that the PUFAs are responsible for the aromas associated with the gamey attributes of meat. As the PUFA concentration was higher in males, this also accounts for the higher gamey and metallic aromas in male giraffe. PUFAs have also been linked to gamey and metallic attributes of Egyptian geese

(Geldenhuys *et al*., 2014). There were only a few significant correlations found between the specific fatty acids and sensory attributes. Although there were correlations between a few of the fatty acids that were present in low quantities (<1 %), it is doubtful that these fatty acids in such a small concentration had an influence on these sensory attributes, therefore only the fatty acids >1 % will be discussed. Stearic acid was found to have a positive correlation with gamey aroma (r = 0.560; *P* = 0.024), and was the only SFA that had a correlation with any of the sensory attributes. Linoleic acid was positively correlated with overall aroma intensity (r = 0.588; *P* = 0.017), gamey aroma (r = 0.532; *P* = 0.034) and metallic aroma (r = 0.584; *P* = 0.018). Alpha-linolenic acid was also correlated with overall aroma intensity (r = 0.589; *P* = 0.016), gamey aroma (r = 0.540; *P* = 0.031) and metallic aroma (r = 0.653; *P* = 0.006); it has also been correlated with the gamey and metallic attributes of Egyptian geese (Geldenhuys *et al.,* 2014). Arachidonic acid was found to be correlated with the overall aroma intensity (r = 0.551; *P* = 0.027), gamey aroma (r = 0.549; *P* = 0.028), metallic aroma (r = 0.673; *P* = 0.004), as well as sour associated aroma (r = 0.566; *P* = 0.022); PUFA's are prone to oxidation, resulting in a sour flavour and aroma, which may explain these correlations. Eicosapentaienoic acid was correlated with overall aroma intensity (r = 0.499; *P* = 0.049), gamey aroma (r = 0.504; *P* = 0.047), metallic aroma (r = 0.641; *P* = 0.007) and sour-associated aroma (r = 0.552; *P* = 0.027). Docosapentaenoic acid was also correlated with gamey aroma (r = 0.519; *P* = 0.039), metallic aroma (r = 0.690; *P* = 0.003) and sour-associated aroma (r = 0.525; *P* = 0.037). Reactions between these fatty acids and the other organic compounds in the meat, during cooking process, are responsible for the meats' species specific flavours (Mottram, 1998).

7.5 CONCLUSION

Giraffe meat had a high thaw loss after a six-month freezing period, resulting in far higher total purge losses than in fresh meat. This resulted in it being substantially tougher than the fresh meat studied in Chapter 5, which was classified as tender. Further research should aim to quantify the effects of freezing and investigate alternative methods of storage for export, such as vacuum-packaging, and allowing the meat to age at low temperatures (-2 to 2°C) during transport. Further research should also aim to quantify the effect of cooking methods on the WBSF of game meat. The sensory tenderness was comparable to that of other game species, although there was a high level of variation, even between the samples from the same muscle. The giraffe LTL muscle was observed to have thick connective tissue running through it, which may account for the textural variation. The meat was in alignment with the overall beef-like and gamey aroma and flavour intensities of several other game species. Sex had very little effect on the sensory profile of giraffe meat in this study. The metallic,

sweet- and sour- associated and black pepper attributes of both sexes were found to be substantially higher than in other game species. The low intramuscular fat content and favourable PUFA:SFA and n-6:n-3 PUFA ratios were found to be suitable for the recommendations of a healthy human diet. The main fatty acids that made up the fatty acid profile of giraffe meat were stearic, palmitic, oleic and linoleic acid, while alpha-linolenic and arachidonic acid had slightly lower concentrations. Overall giraffe meat was found to have a unique sensory profile, with unfavourably high WBSF but a positive fatty acid profile for a healthy human diet.

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CHAPTER 8

POST-MORTEM AGEING OF GIRAFFE (*Giraffa camelopardalis angolensis*) MEAT AS INFLUENCED BY SEX AND MUSCLE

ABSTRACT

The objective of this study was to determine the ideal ageing period to optimum tenderness of *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM) and *Biceps femoris* (BF) steaks from male and female giraffe. The muscles of eight male and seven female giraffe were divided into 10 steaks each, and each steak was randomly allocated to age for 1, 5, 9, 14, 18, 22, 26, 30, 34 or 38 days in vacuum-sealed bags at ± 4°C. At each time point, the pH, surface colour, weep loss, cooking loss and Warner-Bratzler shear force (WBSF) were determined for the respective steaks. Significant interactions between the sex, muscle and days post-mortem were observed for the Warner-Bratzler shear force (WBSF), CIE a*, CIE b*, hue-angle and chroma, while the CIE L* values were affected by an interaction between the muscle and days post-mortem. The pH remained stable throughout the first 30 days of the ageing period (5.5 – 5.6), before declining significantly. The weep loss progressively increased throughout the ageing period, however, the cooking loss, only affected by muscle, remained constant throughout. The tenderness improved until day 22 (19.1 ± 0.30 N) of the ageing period, where after it plateaued and the colour improved, in terms of redness and saturation, until day 18 (L* = 44.1 ± 0.29; a* = 15.7 ± 0.19; b* = 15.3 ± 0.08; hue-angle = 44.8 ± 0.39; chroma = 22.0 ± 0.15), thereafter discolouration occurred. Therefore it is recommended to vacuum-age giraffe meat for 18 days in order to improve tenderness and colour and minimise the negative effects of increased weep loss.

Keywords: Post-mortem ageing, game meat, giraffe, tenderness

8.1 INTRODUCTION

There is a growing demand for food production to feed the growing population of southern Africa, with the population of Africa predicted to surpass two billion within the next few decades, which will leave southern Africa in a dire state, as it is already a net importer of food, with a poor economy and wide spread undernourishment (Conceicao *et al*., 2011). As animal products contain many nutrients in more readily available forms than from plant sources (Higgs, 2000; Lin *et al*., 1989; Ortega-Barrales & Fernández-de-Córdova, 2015), it is vital to optimise the production thereof. It is also important to

utilise the available land wisely for animal production, as Africa is largely dry and arid, conditions that many domestic livestock species are not adapted to. However, Africa has an abundance of indigenous species, which are naturally adapted to the climatic conditions and available vegetation. These species can play a role in addressing the food insecurities, however, there is limited research on the meat quality of these various species (Cawthorn & Hoffman, 2014; Conceicao *et al*., 2011).

An issue with increasing the production of indigenous species for meat production is consumer preference and perceptions. Consumers have become accustomed to meat from domestic species, and may discriminate against meat that does not look or taste the same. Game meat tends to be darker than that of traditional commercially produced meat species (Neethling *et al*., 2019; Shange, Gouws & Hoffman, 2019), which may put consumers off purchasing it.

Due to the variation in the methods used to slaughter game species, there is often a large amount of variation in meat quality of game meat, as the quality is largely affected by the ante-mortem stress (Listrat *et al*., 2016), which depends on the efficiency of the hunters/culling team. Consumers therefore often perceive game meat as tough and dry, due to the product variation as well as lack of any quality standards and the lack of knowledge of how to prepare game meat (Radder & Le Roux, 2005; Wassenaar, Kempen & Van Eeden, 2019). In order to increase the marketability of game meat, it is necessary to consistently produce meat of high quality and to counter the consumer perception of the toughness of the meat. Post-mortem ageing of meat is known to improve the tenderness of the meat (Dransfield, 1993) through a combination of enzymatic activities, resulting in the breakdown of the structural proteins over time. The ageing period to optimum tenderness is species dependant, as the concentrations of the various enzymes varies by species. In order to improve the quality of game meat the optimum ageing period for each species needs to be investigated.

While across central and east Africa the giraffe numbers are dropping, in southern Africa, in South Africa and Namibia specifically, their populations are growing exponentially due to an increasing number of game ranches breeding them (Marais *et al*., 2018; Muller *et al*., 2018). As their populations are kept in check by predators in the wild, when they are fenced into camps with no natural predators present, their populations grow at an exponential rate, necessitating culling to prevent surpassing the carrying capacity. Due to their large bulk, each animal yields a large amount of meat (Chapter 3), however, there has been very little research into the quality of giraffe meat. By all accounts from farmers who have eaten fresh giraffe meat, it is tough and they normally only use it in processed products, such as boerewors (a traditional South African sausage). The tenderness of the fresh giraffe meat was found to be comparable with that of the fresh meat of other game species (Chapter 5) and

classified as tender by conventional standards, as it was <43 N (Destefanis *et al*., 2008). However, there was found to be a large amount of variation between the samples, with some samples classified as intermediate tender (>43 N) (Chapter 5), therefore post-mortem ageing may result in a more uniform product, of more acceptable tenderness. Thus this study aims to determine the ageing time to optimum tenderness for giraffe meat, in order to improve its eating quality, while maintaining sufficient moisture for juicy meat, and an appealing colour to produce a product that is appealing to the consumer.

8.2 METHODS AND MATERIALS

8.2.1 EXPERIMENTAL LOCATION AND ANIMALS

Fifteen young giraffe (8 male, 7 female; average age ± 3.7 years old) were harvested on Mount Etjo farm in the Otjozondjupa region of Namibia as part of their annual cull to control the population growth they experience as a result of the lack of natural predators for the giraffe on the farm. The giraffe were culled by head shot and exsanguinated in the field (Ethical approval: ACU-2018-7366, Stellenbosch University; Namibian Shoot and sell permit number: 118690), before being transported back to the abattoir where they were skinned, eviscerated and dressed as described by Ledger (1963). Refer to Chapter 3 for more details.

8.2.2 PROCESSING AND SAMPLING

The carcasses were chilled for approximately 24 h at ± 4°C, before the muscles were removed and processed further. Three muscles from the right side of each carcass were removed for post-mortem ageing, the *Longissimus thoracis et lumborum* muscle (LTL), *Semimembranosus* muscle (SM) and *Biceps femoris* muscle (BF). Ten steaks of approximately 100-200 g, approximately 2 cm thick were cut from each of these muscles from each animal. Each of these steaks was randomly allocated to an ageing day from 1 – 38. The day 1 steaks, were processed straight away, as described in Chapter 5. The other steaks were vacuum-sealed in composite plastic bags (70 µm nylon and polyethylene; oxygen permeability of 30 $cm^3/m^2/24h/1atm$, carbon dioxide permeability of 105 $cm^3/m^2/24h/1atm$ and moisture vapour transfer rate of 2.2 $g/m^2/24h/1atm$) and kept refrigerated at ± 4°C until the respective ageing day.

It was decided to have a long 38 day ageing period for the giraffe, as it had been described as tough by farmers who only use the meat in processed products (Table 8.1).

Table 8.1 Experimental layout of the post-mortem ageing trail per main effect (sex and ageing period)

Number of animals	Sex	Ageing period (days post-mortem)									
8	Male	1	5	9	14	18	22	26	30	34	38
7	Female	1	5	9	14	18	22	26	30	34	38

8.2.3 PHYSICAL ANALYSIS

8.2.3.1 Moisture loss

The total moisture loss was determined by the combined measurements of cumulative purge loss and cooking loss percentages. The drip loss was used for day 1 purge loss (determined as described in Chapter 5), after which the weep loss was determined. The weep loss for days 5-38 was measured by blotting the respective steak from each muscle for the respective day dry with paper towelling and weighing it. The weep loss percentage was calculated as the percentage loss of the initial weight of each steak.

The cooking loss for each muscle sample was determined in the same manner as described in Chapter 5, by cooking each steak in a preheated water bath at 80°C for 1 h, after the weep loss, pH and colour had been measured.

8.2.3.2 Acidity (pH)

The acidity (pH) of each steak on the respective ageing day, was measured after determining the weep loss, by the methods described in Chapter 5, using a (two-point calibration using standard buffers of pH 4 and pH 7) Accsen pH 70+DHS® portable pH meter (Accsen Instrumental, Barcelona, Spain).

8.2.3.3 Colour

The colour of each steak was measured after each steak had been weighed back for weep loss and allowed to bloom for ± 30 min. A calibrated Colour-guide 45°/0° colorimeter (model 6801, BYK-Gardner GmbH, Geretsried, Germany; aperture diameter size: 11mm; illuminant/observer angle: D-65/10°) was used, taking five measurements at random on the cut surface as described in Chapter 5. The reported lightness (CIE L*), red-green spectrum (CIE a*) and blue-yellow spectrum (CIE b*) values were then used to calculate the hue-angle (colour definition) and chroma values (saturation/colour intensity) for each steak by using the following equations:

$$Hue - angle\ (°) = tan^{-1}\left(\frac{b^*}{a^*}\right)$$

$$Chroma\ (C^*) = \sqrt{(a^{*2} + b^{*2})}$$

8.2.3.4 Warner-Bratzler shear force (WBSF)

After the cooking loss and colour had been determined, the cooked steaks were used for determining the Warner-Bratzler shear force (WBSF) as an indication of the tenderness of each muscle on the respective day. This was done as described in Chapter 5 with a portable Instron machine, fitted with a Warner-Bratzler blade, and testing the WBSF of six 1.27 cm diameter cylindrical cores per steak. The recorded measurements, in kg/1.27 cm ϕ, were then converted to Newton (N) by means of the following equation:

$$Warner - Bratzler\ shear\ force\ (N) = \frac{(F\ x\ 9.81)}{Area}$$

$$Where\ F = \ kg/1.27cm\ \phi$$

$$and\ area = \ \pi(\frac{1.27}{2})^2$$

8.2.4 STATISTICAL ANALYSIS

Statistica Version 13.4 (2018) R (lmer package) module was used to perform statistical analyses on the data. Mixed model ANOVA was used with animal as random effect, and muscle, sex, day, and all interaction terms as fixed effects. For post hoc testing Fisher Least Significant Difference (LSD) was used for the multiple comparison test differences (Lyman Ott & Longnecker, 2010). Outliers were identified by the use of normal probability plots, and removed where necessary. The 5 % probability level was used ($P \leq 0.05$) as an indication of significance.

8.3 RESULTS

There was a significant interaction between the sex, muscle and day for the WBSF, and CIE a*, CIE b*, chroma and hue-angle (Table 8.2). CIE L* was affected by a second order interaction of muscle and day. pH and purge loss were only affected by day and the cooking loss was only affected by the muscle.

Table 8.2 Level of statistical significance (*P-values*) for the main effects of sex, muscle and day (post-mortem) and their interaction for the physical parameters of giraffe meat during the 38 day ageing period

Parameter	Sex	Muscle	Day	S*M	S*D	M*D	S*M*D
pH	0.588	0.842	**<0.001**	0.301	0.336	0.089	0.989
Purge loss (%)	0.968	0.254	**<0.001**	0.826	0.563	0.490	0.488
Cooking loss (%)	0.260	**<0.001**	0.318	0.502	0.658	0.686	0.208
Shear force (N)	0.177	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.007**	**0.017**
L*	0.727	**<0.001**	**<0.001**	0.148	0.203	**<0.001**	5.327
a*	0.868	**<0.001**	**<0.001**	0.655	0.602	**<0.001**	**<0.001**
b*	0.732	**0.001**	**<0.001**	0.755	0.095	**<0.001**	**0.030**
Chroma	0.960	**<0.001**	**<0.001**	0.560	0.895	**<0.001**	**<0.001**
Hue-angle	0.805	**<0.001**	4.079	0.462	**0.003**	**<0.001**	**<0.001**

Days post-mortem was found to be the only factor to have an effect on the pH of the giraffe meat, this effect is presented in Figure 8.1. There were minor fluctuations in the pH between 5.5 and 5.6, from day 1 to day 30, after which it dropped significantly to pH 5.4 ± 0.02 for day 34 and 38 (Table 8.3).

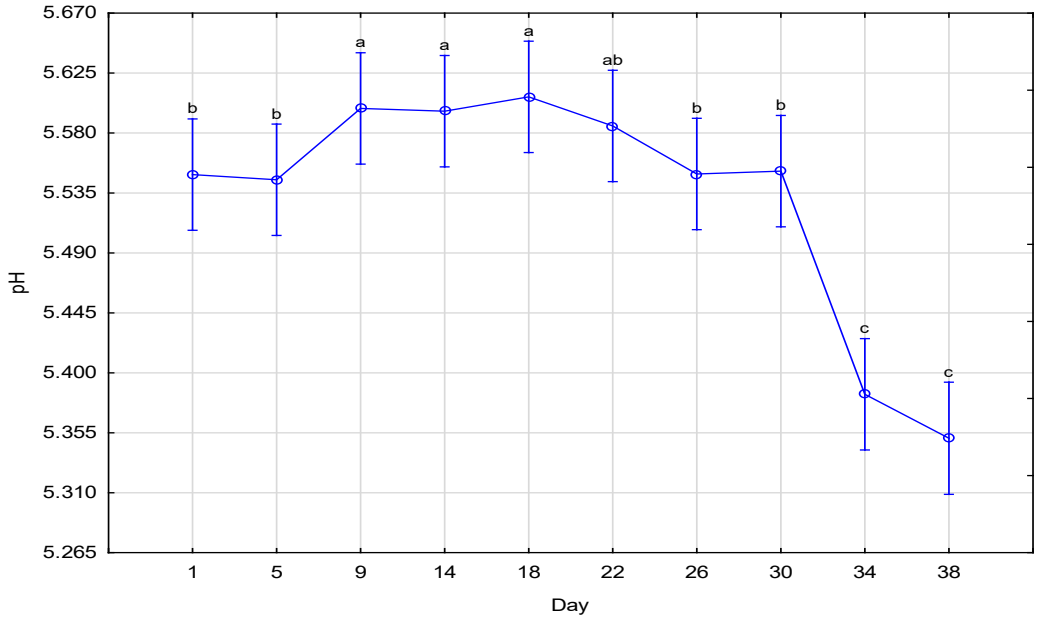

Figure 8.1 The effect of days post-mortem on the pH of giraffe meat during a 38 day ageing period. [a-c]Means with different superscripts differ from one another ($P < 0.05$)

Days post-mortem was found to be the only factor to affect the cumulative purge loss of the giraffe meat, this effect is presented in Figure 8.2. Day 1 had the lowest purge loss (2.8 ± 0.18 %), and day 5 had more than double this purge loss (5.8 ± 0.20 %). The purge loss increased steadily from day 5 for the remainder of the ageing period, with an 8.7 ± 0.31 % loss on day 38.

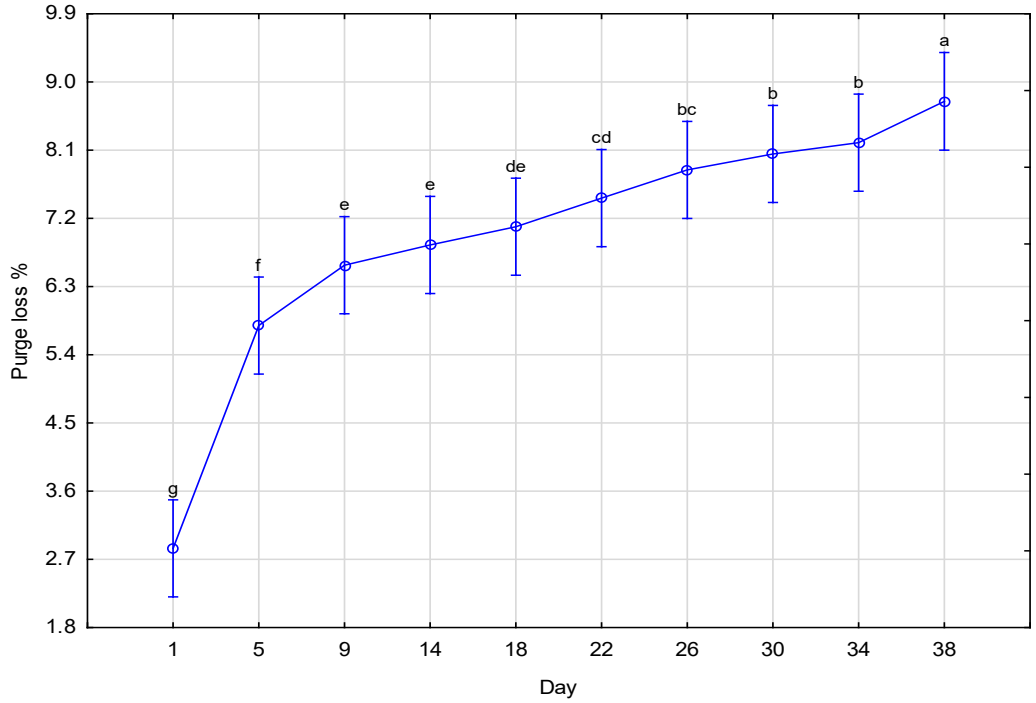

Figure 8.2 The effect of days post-mortem on the purge loss % of giraffe meat during a 38 day ageing period. [a-g]Means with different superscripts differ from one another ($P < 0.05$)

The cooking loss was not affected by days post-mortem, it was only affected by the muscle type (Fig. 8.3). The LTL had the lowest cooking loss (38.8 ± 0.52 %) and the SM (42.5 ± 0.15 %) and BF (43.5 ± 0.19 %) both had significantly higher cooking losses, throughout the ageing period.

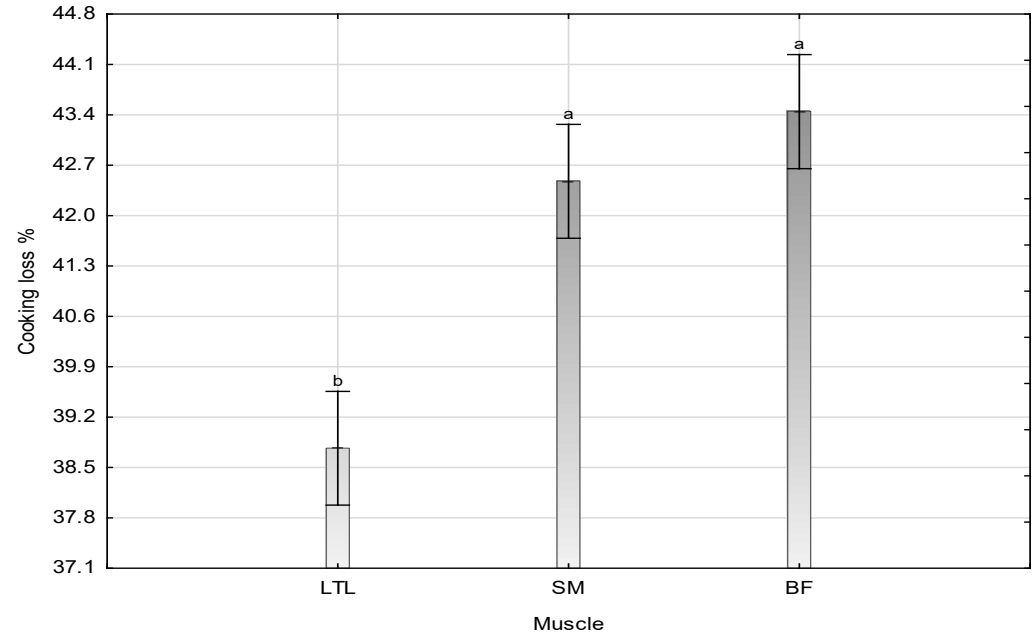

Figure 8.3 The effect of muscle on the cooking loss % of giraffe meat during a 38 day ageing period. [a,b]Means with different superscripts differ from one another ($P < 0.05$)

Table 8.3 Physical parameters (mean ± standard error) of the LTL, SM and BF of giraffe as affected by day, sex and muscle showing main effects only

Main effects		pH	Weep loss (%)	Cooking loss (%)	WBSF	L*	a*	b*	Hue-angle	Chroma
Sex	Male	5.5 ± 0.01	6.9 ± 0.15	41.8 ± 0.23	27.5 ± 0.21	43.2 ± 0.13	14.6 ± 0.07	14.3 ± 0.05	44.7 ± 0.18	20.6 ± 0.07
	Female	5.5 ± 0.01	7.0 ± 0.15	41.3 ± 0.37	25.8 ± 0.22	42.7 ± 0.14	14.8 ± 0.09	14.2 ± 0.06	44.2 ± 0.21	20.6 ± 0.09
Muscle	LTL[1]	5.5 ± 0.01	6.7 ± 0.19	38.8^{b} ± 0.52	25.9^{b} ± 0.27	41.6^{b} ± 0.11	15.1^{b} ± 0.07	13.9^{b} ± 0.07	42.6^{b} ± 0.19	20.6^{b} ± 0.08
	SM[2]	5.5 ± 0.01	7.1 ± 0.18	42.5^{a} ± 0.15	28.1^{a} ± 0.25	40.9^{c} ± 0.12	16.1^{a} ± 0.08	14.5^{a} ± 0.07	42.1^{b} ± 0.19	21.7^{a} ± 0.08
	BF[3]	5.5 ± 0.01	7.1 ± 0.19	43.5^{a} ± 0.19	26.2^{b} ± 0.26	46.4^{a} ± 0.18	12.9^{c} ± 0.10	14.5^{a} ± 0.06	48.7^{a} ± 0.25	19.4^{c} ± 0.10
Day	1	5.6^{b} ± 0.01	2.8^{g} ± 0.18	42.8^{a} ± 1.43	31.7^{a} ± 0.48	38.5^{f} ± 0.30	14.7^{bc} ± 0.18	11.4^{f} ± 0.12	38.1^{f} ± 0.49	18.7^{e} ± 0.15
	5	5.5^{b} ± 0.02	5.8^{f} ± 0.20	40.2^{c} ± 0.55	28.7^{b} ± 0.54	40.6^{e} ± 0.29	15.2^{ab} ± 0.17	12.9^{e} ± 0.11	40.7^{e} ± 0.38	20.0^{d} ± 0.15
	9	5.6^{a} ± 0.01	6.6^{e} ± 0.23	40.9^{bc} ± 0.47	29.2^{b} ± 0.50	41.9^{d} ± 0.20	15.2^{ab} ± 0.17	13.9^{d} ± 0.11	42.7^{d} ± 0.35	20.6^{cd} ± 0.16
	14	5.6^{a} ± 0.01	6.8^{e} ± 0.27	41.2^{abc} ± 0.44	26.0^{cd} ± 0.41	43.7^{bc} ± 0.25	15.5^{a} ± 0.16	15.0^{ab} ± 0.09	44.2^{c} ± 0.31	21.7^{ab} ± 0.14
	18	5.6^{a} ± 0.01	7.1^{de} ± 0.22	41.3^{abc} ± 0.39	27.0^{c} ± 0.51	44.1^{bc} ± 0.29	15.7^{a} ± 0.19	15.3^{a} ± 0.08	44.8^{c} ± 0.39	22.0^{a} ± 0.15
	22	5.6^{ab} ± 0.02	7.5^{cd} ± 0.23	41.5^{abc} ± 0.43	24.2^{e} ± 0.38	45.1^{a} ± 0.31	14.5^{c} ± 0.20	15.1^{ab} ± 0.09	46.8^{b} ± 0.43	21.0^{bc} ± 0.16
	26	5.5^{b} ± 0.02	7.8^{bc} ± 0.22	41.6^{abc} ± 0.44	24.9^{de} ± 0.38	44.3^{ab} ± 0.28	14.6^{bc} ± 0.17	15.0^{ab} ± 0.08	46.1^{b} ± 0.36	21.0^{bc} ± 0.13
	30	5.6^{b} ± 0.02	8.0^{b} ± 0.23	41.7^{abc} ± 0.72	24.7^{e} ± 0.37	44.2^{abc} ± 0.24	14.4^{c} ± 0.16	14.8^{bc} ± 0.08	46.2^{b} ± 0.36	20.8^{cd} ± 0.13
	34	5.4^{c} ± 0.02	8.2^{b} ± 0.31	42.0^{abc} ± 0.39	26.5^{c} ± 0.44	44.2^{abc} ± 0.29	14.1^{c} ± 0.18	14.9^{ab} ± 0.08	47.1^{ab} ± 0.40	20.6^{cd} ± 0.14
	38	5.4^{c} ± 0.02	8.7^{a} ± 0.31	42.5^{ab} ± 0.83	24.1^{e} ± 0.50	43.1^{c} ± 0.29	13.1^{d} ± 0.15	14.4^{c} ± 0.09	48.0^{a} ± 0.38	19.1^{e} ± 0.23

[1]*Longissimus thoracis et lumborum,* [2]*Semimembranousus,* [3]*Biceps femoris.*

[a-g]Means with different superscripts within main effects differ significantly at $P < 0.05$

The WBSF of the meat was affected by a third order interaction between the sex, muscle and day. Despite this interaction, there were few significant differences for sex or muscle at any time point during the ageing period. Sex did not have an overall effect on the WBSF (P = 0.177), but muscle did (P = 0.007). The interaction between muscle and days post-mortem is therefore shown in Figure 8.4. Overall there was a significant decrease in WBSF within the first five days of the ageing period, and it continued to decline until day 22 after which it plateaued for the remainder of the ageing period. The meat from the SM (28.1 ± 0.25 N) had a higher WBSF than from the LTL (25.9 ± 0.27 N), or the BF (26.2 ± 0.26 N) for the duration of the ageing period.

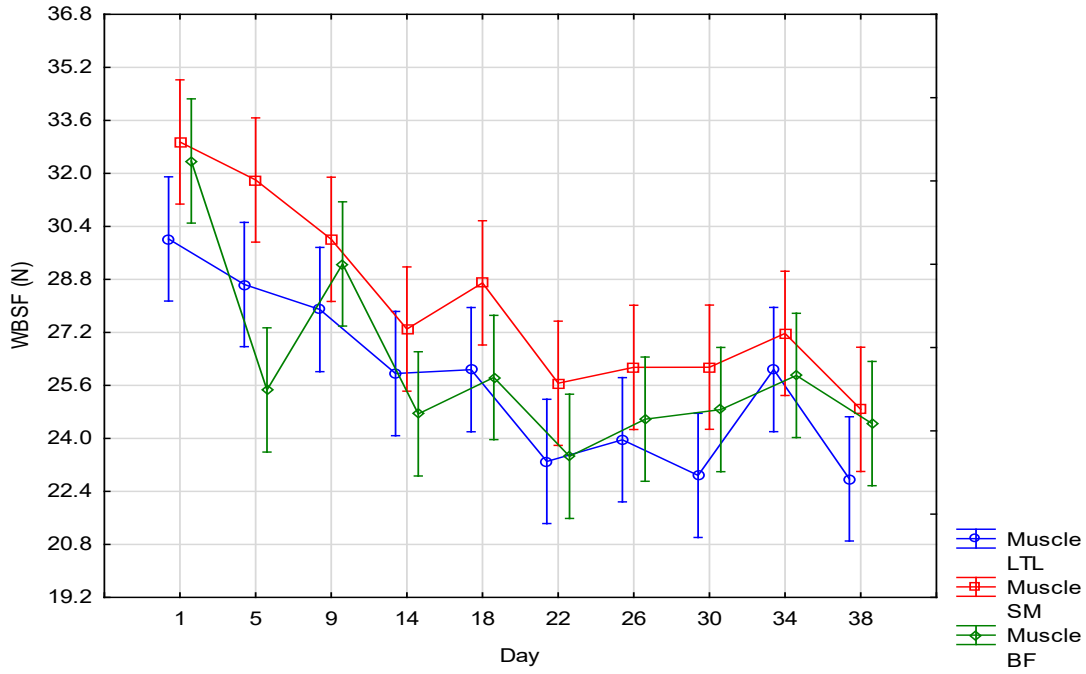

Figure 8.4 The effect of the interaction between muscle and days post-mortem on the WBSF of giraffe meat irrespective of sex.

The interaction between muscle and days post-mortem for the CIE L* values is illustrated in Figure 8.5. The BF had higher L* values throughout the ageing period, with the lowest L* value for BF recorded on day 1, there was a steady increase until day 22, before dropping again on day 26, it then maintained a similar lightness for the remainder of the ageing period (Table 8.3). The LTL and SM both followed a similar trend, with the lowest L* values recorded on day 1, there was a steady increase until day 14 from where the readings remained relatively constant. The SM tended to have the highest a* values for both sexes, until day 18 for males, after which the LTL had similar values for the rest of the ageing period, while for females, it remained the highest. The BF had the lowest a* values for both sexes throughout the ageing period. For both sexes the LTLs tended to increase in a* values until day 18, followed by a steady decline until day 38. The b* values were also affected by the third order interaction, with the LTL, SM and BF all increasing steadily over the first 18 days of the ageing period,

with the SM higher than the LTL and BF. All three muscles' b* values then declined over the rest of the ageing period. In the females, the b* values increased steadily over the first 14 days of the aging period, after which they remained fairly constant for the remainder of the ageing period. The BF had the highest hue-angles for both sexes throughout the ageing period, while the LTL and SM had similar values to one another throughout the ageing period (Fig. 8.6). All three muscles for both sexes had the lowest hue-angles on day 1 of the ageing period and the highest values on day 38, except for the BF in males, which had the highest value on day 22. The chroma values for all muscles of both sexes tended to increase until day 14 to day 18, before declining again (Fig. 8.7). The SM tended to have the highest values through most of the ageing period, for both sexes, while the BF tended to have the lowest values for most of the ageing period.

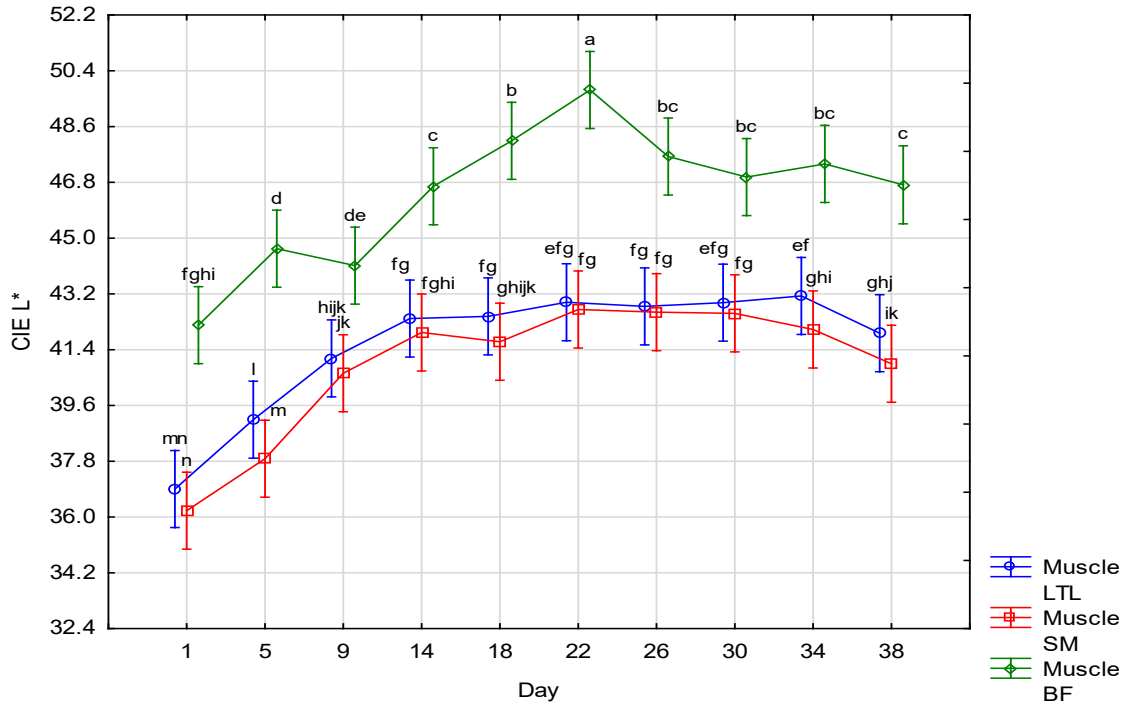

Figure 8.5 The effect of the interaction between sex and muscle on the L* values of giraffe meat during a 38 day ageing period. [a-n]Means with different superscripts differ from one another (P <0.05)

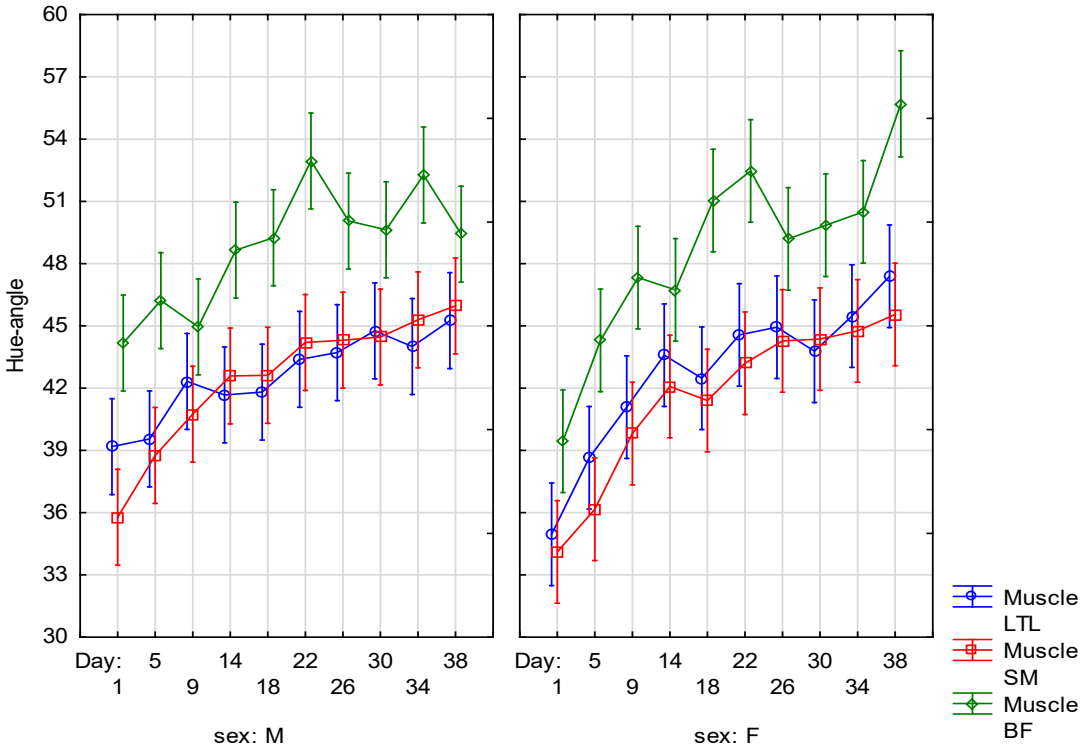

Figure 8.6 The effect of the interaction between sex, muscle and days post-mortem on the hue-angle of giraffe meat during a 38 day ageing period

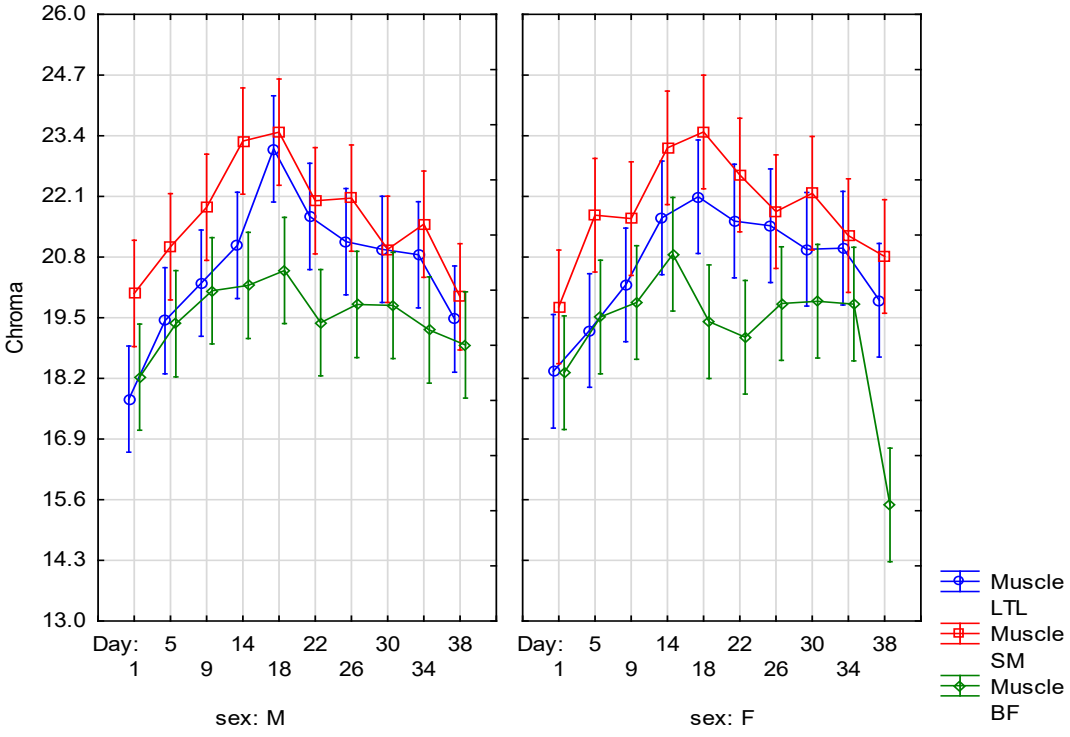

Figure 8.7 The effect of the interaction between sex, muscle and days post-mortem on the chroma of giraffe meat during a 38 day ageing period.

8.4 DISSCUSSION

There were significant second and third order interactions between the sex, muscle and days post-mortem for several of the physical parameters, however, the effect of post-mortem ageing on giraffe meat, irrespective of sex and muscle has not yet been determined. The culling of game is also often haphazard, with the animals culled for management purposes, rather than for the ideal meat quality, thus without taking the sex of the animal into account for its effect on meat quality. It may therefore be of value to focus on the broader picture of the effects of post-mortem ageing on the quality of the meat overall.

The main aim of this study was to quantify the ageing period to optimum tenderness for three major giraffe muscles for both sexes. According to Miller *et al*. (2001), consumers are willing to pay a premium price for meat of guaranteed tenderness, making tenderness arguably the most important qualitative characteristic of meat. Therefore the classification of the tenderness of meat has been studied many times. Destefanis and colleagues (2008) developed a three category rating system, after finding that a sensory panel could not distinguish between the five categories they originally tested. Destefanis and colleagues reported that consumers found meat with a WBSF value above 53 N to be tough, and meat below 43 N to be tender, therefore values between 43 N and 53 N can be considered intermediate tender. The average day 1 WBSF were all below 43 N, which dropped progressively through the ageing period, thus the muscles are considered tender throughout. However, tenderness is not the only physical parameter that post-mortem ageing affects, and therefore the effect on the meat quality as a whole must be considered.

Although the WBSF was affected by a significant interaction between the sex, muscle and days post-mortem there were very few significant differences between the muscles for sex on any specific ageing point, all following a similar trend. The three muscles for both sexes all showed a decrease in WBSF from day 1 to day 22 after which they plateaued (Fig. 8.3). There was some fluctuation around this general trend, and the meat of the giraffe was found to have a large amount of variability in texture, as there were thick visible membranes and connective tissue running through the meat which may affect the WBSF readings. The BF in females showed the greatest tenderisation, decreasing from a WBSF value of 26.4 N to 16.5 N over the 38 day ageing period. The sex did not have an overall effect on the tenderness, however, the muscles did differ for tenderness; the SM was found to have a higher WBSF than the LTL and the BF, for most of the ageing period (Fig. 8.4). When evaluating the meat in general, it was found to have an average day 1 WBSF of 25.0 ± 0.38 N, and a day 38 value of 19.0 ± 0.39 N which did not differ from the average day 22 value (19.1 ± 0.30 N) (Table 8.3). Although the meat was considered to be tender (<43 N) from day 1, ageing did progressively improve the

tenderness until day 22. Commercially the LTL of cattle is typically aged for at least 14 days for improved tenderness, some butchers choosing to age it to 35 days or longer. In game species the optimum tenderness was found to be attained by eight days post-mortem for springbok (*Antidorcas marsupialis*) (North & Hoffman, 2015), after eight days for impala (*Aepyceros melampus*) (Engels, 2019), after 25 days in buffalo (*Syncerus caffer caffer*) (Van As, 2019) and eland (*Taurotragus oryx*) was found to still be tough after 35 days ageing (Needham *et al*., 2020).

Although post-mortem ageing is known to improve the tenderness of meat, it does have the negative side effect of cumulative purge loss, from the raw meat (Huff-Lonergan & Lonergan, 2005). Purge loss results in bloody liquid collecting in the packaging, which results in an unappealing packaged product. A high cumulative purge loss will also result in less moisture in the meat, and consequently less juicy cooked meat as well as a loss of saleable weight. In addition to this, a significant amount of protein is also lost through purge loss (Offer and Knight, 1988). The extent of purge loss is affected by the pH of the meat as well as the proteolytic activities of the enzymes in the meat, which is affected by the pH, and affects the integrity of the cytoskeleton, decreasing the water binding capacity (Huff-Lonergan & Lonergan, 2005).

The pH of the meat for this study showed a slight increase from day 1 until day 18 before decreasing again, with a significant drop from day 30 to day 34 (Fig. 8.1; Table 8.3). A slight increase has similarly been observed in several other game species such as impala (Engels, 2019), eland (Needham *et al.,* 2020), and springbok (North, Frylinck & Hoffman, 2015). It has been postulated that this may be due to the enzymatic activity causing fluctuations in the charge of the meat proteins as they undergo proteolysis (Boakye & Mittal, 1993). As ageing progresses lactic acid bacteria produce lactic acid as they are favoured by the anaerobic conditions of wet ageing meat (Li *et al*., 2013). The lactic acid normally forms on the surface of the meat, however, with the structural breakdown during ageing processes this may have penetrated deeper into the meat, causing the pH decline from day 30. The lactic acid may result in a sour/off flavour as found in springbok aged for 28 days (North & Hoffman, 2015).

The purge loss was only affected by the days post-mortem and followed the trend that may be expected during post-mortem ageing, with the largest increase in cumulative purge loss from day 1 to day 5 (Figure 8.2; Table 8.3). This is most probably due to the fact that the day 1 measure was for drip loss, while those for the rest of the ageing period were the weep loss of vacuum-packed steaks, the pressure of which results in a greater moisture loss (Payne *et al*., 1998). From day 5 there was a more gradual increase over the remainder of the ageing period, whereas in literature the purge loss percentage was found to plateau after the first 6-8 days (14 day ageing period of impala; Engels, 2019;

28 day ageing period of springbok; North & Hoffman, 2015). The reason for the plateau in other species and the more gradual increase in giraffe, may be due to the limited volume of liquid which can be released from within the cytoskeleton. The giraffe meat in general was found to have a high moisture loss in relation to other game species, for the physical analysis at 24 h post-mortem for eight different muscles (Chapter 5). Over the ageing period of 38 days the cumulative purge loss was ~9 % for the meat of the giraffe, however, most other studies had shorter ageing periods and plateaued after ± 14 days. The cumulative purge loss of ~7 % at day 14, despite being substantially higher than that for blue wildebeest (*Connochaetes taurinus*) of 3.5 % (Van Heerden, 2018), was comparable with that of springbok (6.0 %) (North *et al.,* 2015) and the 6.5 % for impala (Engels, 2019).

The cooking loss was not affected by the day of the ageing period, it was only affected by the muscle; the LTL had the lowest cooking loss, the SM and BF both had higher cooking losses (Table 8.3). Engels (2019) found that the cooking loss of impala meat was also not affected by the ageing period, however, the losses were far lower than those recorded for giraffe. The cooking loss of the giraffe was more comparable to that of buffalo (Van As, 2019). The LTL (38.0 %) had a significantly lower cooking loss than the SM (41.1 %) and BF (41.1 %). The differences between the cooking losses for the muscles may be as a result of differences in muscle fibre type, between the muscles, due to their differences in function (Spanier & Miller, 1996), this would have to be confirmed through muscle fibre analysis.

The surface colour is an important factor in consumer preference when purchasing meat, as it is seen as an indicator of freshness (Mancini & Hunt, 2005; Troy & Kerry, 2010). As the surface colour was significantly affected by the ageing period, it is important to take the effect into consideration when ageing meat, as discolouration of the meat may negate the positive effect of improved tenderness on the price a consumer will be willing to pay (McKenna *et al*., 2005), although this would only be applicable for bloomed meat. The colour stability is affected by species and muscle (O'Keeffe & Hood, 1982), therefore it is necessary to investigate for each species when investigating the ideal ageing period. The colour parameters were all affected by interactions. The L* values were only affected by a second order interaction between muscle and days post-mortem. The other colour parameters were all affected by a third order interaction between sex, muscle and days post-mortem. The L* values showed an increase from day 1 to day 22 for the LTL and to day 14 for the SM and BF, showing a general increase in lightness for all muscles (Fig. 8.4; Table 8.3). While an increase in lightness is normally seen as an improvement in game meat, as it is generally found to be darker than beef (Shange *et al*., 2019), giraffe meat was found to be a lot lighter than other game species on day 1 (Chapter 5). Despite most publications reporting a consumer preference for lighter meat (Bello Acebrón & Calvo Dopico, 2000; Bernués, Ripoll, & Panea, 2012; Khliji *et al*., 2010), the preference is for bright red, over pale red (Grebitus, Jensen, & Roosen, 2013; Jeremiah, Carpenter & Smith, 1972;

Realini *et al.,* 2014), which may mean that consumers will begin to discriminate against meat with an L* value above a certain point, as may be the case with the BF meat, although no specific cut off could be found in literature. Therefore, further increase in lightness may not be desirable to the consumer. The a* values of all muscles from both sexes showed a slight increase until 18 days, after which they decreased significantly, showing a decline in the redness of the meat (Table 8.3). The b* values increased until day 18 for males and day 14 for females, after which these values remained high, indicating an increase in the yellowness of the meat over the beginning of the ageing period, which is undesirable (Table 8.3). This resulted in a gradual increase in the hue-angle over the course of the ageing period, an increase in which is indicative of unacceptable discolouration (Shange *et al*., 2019) (Table 8.3). The chroma was also found to peak at day 18 before declining, showing that the meat had the highest saturation on day 18 (Table 8.3). Overall this showed that post-mortem ageing had a positive effect on the redness of the surface colour of giraffe meat, up until day 18, with an increase in saturation, although this coincided with an increase in yellow and consequently hue-angle. However, as the overall consumer preference is for brighter, redder meat (Neethling *et al*., 2017), this still constitutes an overall improvement. If aged for more than 18 days the meat will become duller and browner in colour when bloomed and by the end of the ageing period there was observed to be excessive discolouration in some of the steaks (Supplementary Fig. 3) which may be due to microbial spoilage (Shange *et al.,* 2019).

8.5 CONCLUSION

This study aimed to determine the ideal ageing period to optimize tenderness for the LTL, SM and BF muscles of both male and female giraffe. While the tenderness improved until 22 days post-mortem, the percentage moisture loss progressively increased throughout the ageing period and the surface colour of the muscle (after blooming), while improving until day 18, was negatively affected by further ageing. As the giraffe meat was already classified as tender on day 1 post-mortem and had shown significant improvements by day 18, it is recommended not to age giraffe meat for longer than 18 days, in order to negate the negative effects of the purge loss and to avoid discolouration. However, as the ageing is known to affect the sensory quality of meat, it is recommended to investigate the effect thereof, on the sensory profile of the giraffe meat.

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CHAPTER 9

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The aim of the study was to investigate the effect of sex on the carcass yields, proximate composition of the red offal and the sensory profile of giraffe (*Giraffa camelopardalis angolensis*) meat. As well as determining the effect of sex and muscle on the meat quality (physical and chemical), and the effect of post-mortem ageing on the meat of giraffe. The sex had limited effect on the body measurements and carcass weights, which could be explained by the immature age of the giraffe. The giraffe were found to have a good dressing percentage (~57 %), comparable to that of cattle and other game species. Giraffe were also found to yield a large amount of edible offal, which is widely consumed in Africa. The red offal was found to have a relatively high protein content in comparison to both domestic and game species, and a relatively low fat content. The liver had a high mineral content, as indicated by the ash content, and was found to have a favourably high iron content, which is important to the human diet and most readily available from animal sources. The "fifth-quarter" may therefor add value for the carcass and serve as an alternative protein source.

Sex did not affect the meat yields of the giraffe in the study, although it did influence a few of the physical quality characteristics thereof. Sex was found to have a significant interaction with the muscle for the Warner-Bratzler shear force (WBSF), although the average WBSF values for all muscles studied across both sexes were classified as tender (<43 N), there was a large degree of variation between readings. Therefor the effect of post-mortem ageing was investigated, in order to improve the tenderness and improve the uniformity of the meat quality. Post-mortem ageing was found to improve the tenderness and colour with regards to the redness and saturation of the *Longissimus thoracis et lumborum* (LTL), *Semimembranosus* (SM) and *Biceps femoris* (BF) muscles, until 18 days post-mortem, however, it resulted in a large total moisture loss.

The sex also had an effect on the cooking loss and the CIE L* values, while the muscle had an effect on all of the physical parameters. This may be explained by the anatomical location of the muscle, as well as the function thereof, which affects the prevailing muscle fibre types, in turn affecting the myoglobin and glycogen contents. The myoglobin content is largely responsible for the colour in meat and was found to relate to the lightness and hue-angle, with higher total myoglobin in darker, redder muscles. The glycogen content is known to affect the post-mortem pH decline of meat, and it was found that the ultimate pH of all muscles fell within the acceptable range, therefore not exhibiting any signs of dark firm and dry (DFD) meat. However the anatomical position of the muscles

within the carcass cuts affects the rate of cooling, and it was found that there was some visible two toning in the BF, most probably due to heat rigor. The temperature decline was found to be slow as the chillers were full to capacity and due to the shear bulk of the carcass sections, this most probably resulted in heat rigor in the deeper hindquarter muscles, which is characterised by high moisture loss and paler colour. The giraffe meat was found to have a high total moisture loss in general, compared to other game species.

The moisture, protein and ash contents of giraffe meat were all affected by an interaction between the sex and muscle, and the intramuscular fat (IMF) content was only affected by muscle. In general giraffe meat was found to have a slightly higher moisture content than other game species. It also had a high protein and low IMF content which is favourable to for the health conscious consumer. The meat was also found to have high iron, copper and zinc levels, which are all important to the human diet, as well as many other essential marco- and micro- minerals, of which many are found in their most absorbable forms in animal tissue.

During the sensory analysis the sexes were compared, and only a few differences were found for the sensory profile. The males scored higher in gamey and metallic aromas and the females had a higher frequency of perceived liver-like flavour. The meat in general was characterised by relatively high gamey, metallic, sour- and sweet-associated and black pepper aroma/flavour attributes. The sensory samples which were frozen for an extended period of time had a high thaw loss and WBSF (categorised as intermediately tender), which correlated with undesirable texture attributes and a lower sensory tenderness. The fatty acid profile could be classified as healthy in terms of the polyunsaturated fatty acid (PUFA) to saturated fatty acid SFA) ratio and the omega 3 to omega 6 PUFA ratio, as well as the Atherogenicity index which all fell within the healthy limits.

As there has been very little previous research on the carcass composition and meat quality of giraffe, despite this study gathering baseline data thereon, there are still many aspects that require further research. These include: investigations into the effect of age on the carcass conformation and composition, in order to determine how age may affect the proportions of the meat yields.

As brown offal is also commonly consumed in Africa, it would be of value to investigate the yields of edible tissue, buy means of investigating the weights of gastrointestinal tract empty of digesta. As well as determining the nutritional value thereof, by investigating the proximate chemical composition.

As it was found that the giraffe carcass sections, especially the hind quarters, took a long time to cool, thus affecting the meat quality, research should be conducted in order to find the best method

of chilling giraffe carcasses. Giraffe carcasses, due to their great bulk, may also be ideal for further study on the mechanisms and effects of heat rigor.

In order to better understand the effect of muscle on the physical characteristics of the giraffe meat, it is recommended to investigate the muscle fibre types present in the various muscles. This may help to explain the effect of anatomical location and function on the physical characteristics. This may also be able to help understand some of the differences caused by sex, as different muscles may have different functions for each sex.

It is recommended to investigate the effect of age on the sensory profile as it has been found in other game species, that unpleasant aroma and flavour attributes often become more pronounced in older males. It has also been found that post-mortem ageing may affect the sensory profile of the meat, therefore further it is recommended to assess the effect of the 18 day ageing period on the sensory attributes of the meat.

ADDENDUM I
GIRAFFE BODY MEASUREMENTS

Supplementary Table 1. Body and horn measurements of 15 giraffe (*G. c. angolensis*) from the Otjozondjupa region of Namibia

Nr	Sex	Age	Dead Weight (Kg)	Body Length (cm)	Back Length (cm)	Body Depth (cm)	Girth (cm)	Neck Length (cm)	Neck Circumference (cm)	Shoulder to Hoof (cm)	Pin to Hoof (cm)	Front Knee to Hoof (cm)	Back Knee to Hoof (cm)	Scrotal Circumference (cm)	Horns (cm)			
															Length	Min Circumference	Max Circumference	Tip to Tip
1	M	3	562.30	151	101	109	277	130	118	264	222	91	96	24.8	16.5	13.5	31.5	17
2	M	4	649.00	155	83	118	222	119	130	256	222	88	97	28	19	14.5	36	19
3	M	3	662.20	157	94	124	228	123	140	263	228	90	97	28	15	15.5	29	15
4	M	3	600.50	153	98	115	202	122	117	258	218	90	94	23	14.5	13.5	28	16
5	M	2.5	575.90	153	109	120	217	136	120	262	230	88	98	23	13.5	18.8	33	15
6	M	4-6	927.10	177	123	135	258	155	161	304	253	101	113	31	18	15.7	30	17
7	M	4-6	825.80	170	121	135	243	142	145	288	242	95	99	29	19	20	35	18
8	M	3.5	726.30	165	113	128	244	149	152	288	249	99	110	25	18	15	35	19.5
9	F	3.5	605.40	156	99	118	232	131	123	262	227	88	97	-	11.5	12	20	9.5
10	F	4	540.00	154	96	120	233	137	119	249	219	86	92	-	12.5	11	22	16
11	F	3	508.40	136	90	109	210	115	121	239	209	82	88	-	10	10.5	19	9.5*
12	F	4	747.50	171	114	129	246	135	139	264	236	88	97	-	12	12	23	15.5
13	F	9	919.90	189	127	134	254	166	160	288	244	95	109	-	11.5	12.5	25	14
14	F	4	663.00	163	106	129	230	130	145	269	240	90	100	-	12	12	22	15
15	F	4	671.10	160	105	127	221	142	135	262	234	92	102	-	13	13	25	16.5
16	F	3.5	720.00	164	108	125	241	152	142	276	238	92	99	-	10.5	12.5	26	12

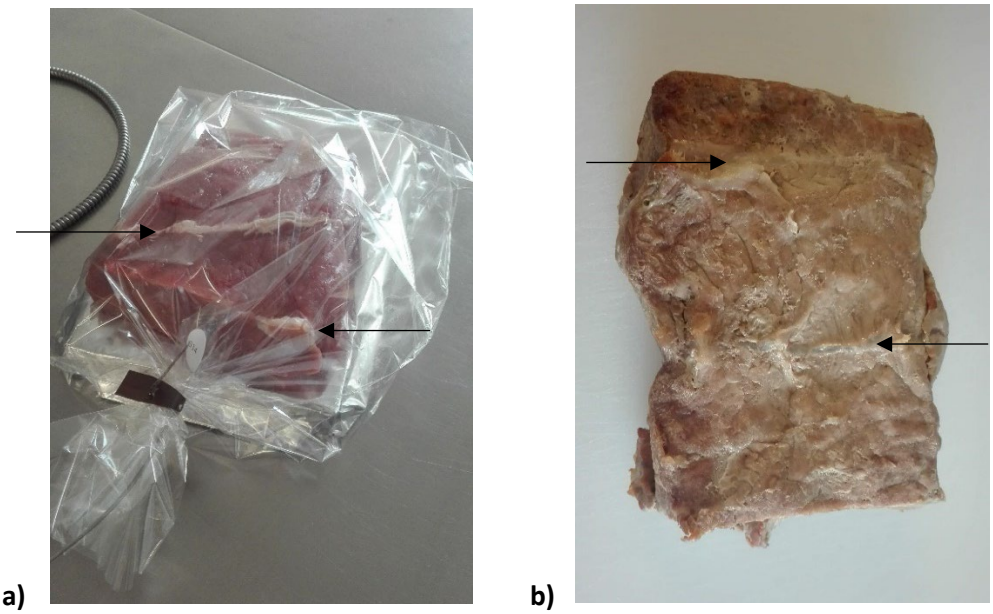
\- N/A

* Skew ossicone

ADDENDUM II

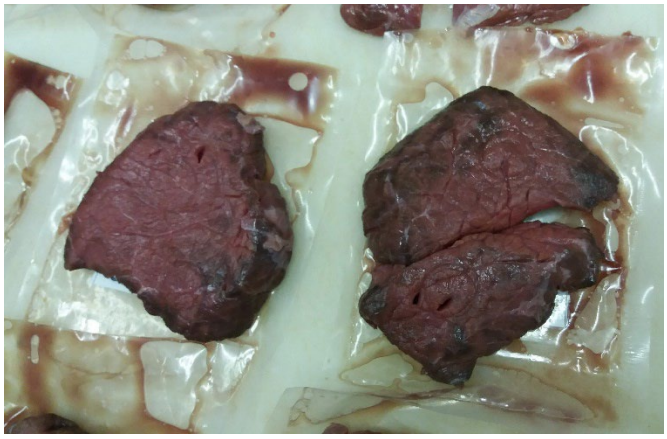
GIRAFFE MEAT IMAGES

Supplementary Figure 1. Membranes running through the *Biceps femoris* muscle of the giraffe



a) **b)**

Supplementary Figure 2. Connective tissue running through the giraffes' *Longissimus thoracis et lumborum* muscle sample used for the Descriptive Sensory Analysis **a.** raw meat sample in roasting bag **b.** cooked meat sample



Supplementary Figure 3. Discolouration of the post-mortem ageing steaks after a 38 day ageing period