Ante- and *post-mortem* factors influencing impala (*Aepyceros melampus*) meat quality

by

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DECLARATION

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SUMMARY

The aim of this research was to investigate the influence of sex, muscle (*Longissimus thoracis et lumborum*/LTL, *biceps femoris*/BF, *semimembranosus*/SM, *semitendinosus*/ST, *infraspinatus*/IS, and *supraspinatus*/SS), production system (intensive, semi-extensive and extensive), and *post-mortem* ageing on the meat quality of impala (*Aepyceros melampus*) to provide baseline data for the South African game industry. This was done by gathering data on the carcass yields, overall meat quality (physical attributes and chemical composition) and sensory meat quality of impala, as well as investigating the optimum *post-mortem* ageing period for maximum tenderness of LTL steaks.

The sex-muscle comparison (Trial 1) consisted of 11 male and 11 female impala that were culled from a semi-extensive production system in the Central Sandy Bushveld region near Modimolle in Limpopo, South Africa. No sexual dimorphism ($P > 0.05$) was recorded for the undressed (36.4 ± 1.30 kg males; 37.8 ± 1.30 kg females) or dressed carcass weights (21.6 ± 0.82 kg males; 21.0 ± 0.82 kg females). However, male impala had a higher ($P = 0.004$) mean dressing percentage than females (59.1 ± 0.76 % vs. 55.6 ± 0.76 %). For the production system comparison (Trial 2), 12 sub-adult (±15-18 months old) male impala were culled per production system (n = 36). The intensive and semi-extensive production systems were also located near Modimolle, and the extensive production system was located in the Central Rûens Shale Renosterveld region near Bredasdorp in the Western Cape of South Africa. Extensive system impala had higher ($P \leq 0.05$) undressed and dressed carcass weights (46.5 ± 1.12 kg and 26.6 ± 0.79 kg) than intensive (37.9 ± 0.92 kg and 21.9 ± 0.65 kg) and semi-extensive system impala (36.4 ± 0.96 kg and 21.3 ± 0.68 kg, respectively), while the latter two systems did not differ significantly from each other. No differences ($P = 0.364$) were recorded between production systems for the dressing percentages (57.9 ± 0.58 % pooled mean) or total offal yields (39.7 ± 0.48 % pooled mean) of sub-adult male impala.

The physical meat quality attributes of impala were significantly influenced by sex, muscle, and production system. Sex-muscle interactions were found for the CIE a* values, drip loss percentages and cooking loss percentages (Trial 1). Higher ($P = 0.021$) ultimate pH (pH_u) values and lower ($P = 0.002$) Warner-Bratzler shear force (WBSF) values were recorded in male impala than in females. The IS and SS muscles from the forequarter were the most tender, whereas the BF and SM muscles from the hindquarter were the least tender. The pH_u of both sexes, all muscles (Trial 1) and both intensive and semi-extensive system impala (Trial 2) fell within the acceptable normal range (5.6-5.9), but the extensive system impala produced meat with an exceptionally high pH_u (6.2 ± 0.06) due to extrinsic factors caused by the production and culling process. Consequently, extensive system impala produced meat with DFD-like (dark, firm, dry) characteristics, such as the lowest drip loss percentage (0.9 ± 0.14 %), cooking loss percentage (28.1 ± 0.79 %) and darkest, least red and least saturated surface colour (L* = 26.8; a* = 10.0; b* = 5.2; chroma = 11.4). With the exception of the extensive system impala, impala from both sexes, all muscles and both the intensive and semi-extensive systems (Trial 1 & 2) had CIE Lab colour measurements within the acceptable range of expectation for game meat (L* = 30.9-36.8; a* = 11.4-13.6; b* = 6.0-8.8). Furthermore, all fresh impala meat in this study (Trial 1 & 2) produced meat with shear force values < 43 N (range of 19.2-39.3 N)

at 24 hours *post-mortem* and may thus be classified as tender.

The chemical meat quality of impala was also significantly influenced by sex, muscle and production system. Sex-muscle interactions were recorded for all four chemical components (moisture, protein, intramuscular fat/IMF and ash), while a strong negative correlation (r = -0.49; $P < 0.001$) was observed between the protein and IMF content of the muscles (Trial 1). Extensively produced impala were recorded to have LTL muscles with the lowest ($P \leq 0.05$) mean IMF (1.5 ± 0.06 g/100 g) and the highest protein (23.4 ± 0.12 g/100 g) content, whereas intensive system impala had the highest IMF content (2.0 ± 0.05 g/100 g). The proximate composition of all impala meat in this study (Trial 1 & 2) ranged from 74.7-77.0 % moisture, 20.7-23.5 % crude protein, 1.2-2.2 % IMF and 1.1-1.3 % ash content. While the differences between sex, muscle and production system were significant, the differences were marginal and thus may not be of biological consequence with regards to human nutrition. Regardless, all impala meat had a high protein and low IMF content which is considered desirable by health-conscious consumers.

With the differences in dietary regime, management strategies and daily activity between production systems, it can be expected that the sensory profile and fatty acid composition of impala meat will also be influenced by differences in these factors. The influence of production system on sensory meat quality was significant (Trial 2), with the highest ($P \leq 0.05$) sensory ratings for gamey, beef-like, herbaceous and sweet-associated aromas and flavours found in extensive system impala during descriptive sensory analysis (DSA). However, the sensory meat quality of the intensive and semi-extensive system impala from the same production region did not differ ($P > 0.05$) except for a few textural attributes and a higher ($P < 0.05$) gamey flavour intensity found in semi-extensive system impala.

The ideal *post-mortem* ageing period of impala LTL steaks was also determined. The LTL muscles of 11 male and 11 female impala (Trial 1) were divided into eight portions each, with each portion was randomly allocated to age for 1, 2, 4, 6, 8, 10, 12, or 14 days, vacuum-sealed and stored at 4°C. This research found that maximum tenderness (13.5 ± 0.91 N) and improvement of bloomed surface colour of impala LTL steaks was reached at eight days *post-mortem*, whereas prolonged ageing beyond this point resulted in some discolouration and no further improvement in meat tenderness. The ageing of meat to eight days *post-mortem* also successfully negated the initial significant differences in tenderness between the sexes. Therefore, it is recommended that impala LTL steaks should be vacuum-aged at 4°C for eight days to achieve optimum tenderness and minimize variability between individual animals irrespective of sex.

OPSOMMING

Die doelwit van hierdie navorsing was om die invloed van geslag, ses spiere (*Longissimus thoracis et lumborum*/LTL, *biceps femoris*/BF, *semimembranosus*/SM, *semitendinosus*/ST, *infraspinatus*/IS, en *supraspinatus*/SS), produksiestelsel (intensief, semi-extensief en ekstensief) en nadoodse veroudering op die vleiskwaliteit van rooibokke (*Aepyceros melampus*) te ondersoek om sodoende basiese data rakende die vleisproduksie potensiaal van rooibokke aan die Suid-Afrikaanse wildbedryf te verskaf. Hierdie doel was uitgerig deur data te versamel oor die karkas opbrengste en algehele vleiskwaliteit (fisiese eienskappe en chemiese samestelling) van rooibokke soos beïnvloed deur geslag, spier en produksiestelsel, sowel as om die sensoriese profiele en vetsuur-samestellings van sub-volwasse rooibok ramme vanaf drie verskillende produksiestelsels te ondersoek, en die ideale verouderingsperiode van vakuum-verpakte LTL snitte vir maksimum sagtheid te bepaal.

Die geslag- en spiervergelyking (Eksperiment 1) het bestaan uit 11 ramme en 11 ooie wat geoes was uit ‘n semi-ekstensiewe produksiestelsel in die Sentrale Sanderige Bosveld area naby Modimolle in die Limpopo provinsie van Suid-Afrika. Geen geslagsverskille ($P > 0.05$) was gevind vir die intakte karkasgewigte (36.4 ± 1.30 kg vir ramme; 37.8 ± 1.30 kg vir ooie) of karkasgewigte (21.6 ± 0.82 kg vir ramme; 21.0 ± 0.82 kg vir ooie) van rooibokke nie. Manlike rooibokke het egter ‘n hoër gemiddelde uitslagpersentasie as vroulike rooibokke getoon (59.1 ± 0.76 % teenoor 55.6 ± 0.76 %). Vir die produksiestelsel vergelyking (Eksperiment 2) was 12 sub-volwasse (±15-18 maande oud) rooibok ramme geoes per produksistelsel ($n = 36$), met beide die intensiewe en semi-ekstensiewe produksiesisteme naby Modimolle geleë en die ekstensiewe produksiestelsel geleë in die sentrale rûens skalie Renosterveld naby Bredasdorp in die Wes-Kaap provinsie van Suid-Afrika. Ekstensiewe rooibokke het hoër ($P \leq 0.05$) intakte karkasgewigte en karkasgewigte (46.5 ± 1.12 kg en 26.6 ± 0.79 kg) as intensiewe (37.9 ± 0.92 kg en 21.9 ± 0.65 kg) en semi-ekstensiewe rooibokke (36.4 ± 0.96 kg en 21.3 ± 0.68 kg, onderskeidelik) gehad, terwyl die laasgenoemde twee sisteme se rooibokke nie betekenisvol van mekaar verskil het nie. Daar was ook geen verskille ($P = 0.364$) tussen die drie produksiestelsels vir die uitslagpersentasies (57.9 ± 0.58 % saamgestelde gemiddeld) of totale afval opbrengste (39.7 ± 0.48 % saamgestelde gemiddeld) van sub-volwasse rooibok ramme nie.

Die fisiese vleiskwaliteitseienskappe van rooibokke was betekenisvol beïnvloed deur geslag, spier, en produksiesisteem. Betekenisvolle interaksies was gevind tussen geslag en spier vir die CIE a* waardes, drupverlies en kookverlies persentasies (Eksperiment 1). Rooibok ramme het hoër ($P = 0.021$) finale pH (pH_u) waardes en laer ($P = 0.002$) Warner-Bratzler skeurkrag waardes gehad as ooie. Die IS en SS spiere van die voorkwart was die sagste in beide geslagte, terwyl die BF en SM spiere vanaf die agterkwart die taaiste was. Alhoewel die pH_u waardes van beide geslagte, alle spiere (Eksperiment 1) en beide die intensiewe en semi-ekstensiewe rooibokke (Eksperiment 2) binne die normale omvang geval het (5.6-5.9), het rooibokke vanaf die ekstensiewe produksiestelsel vleis produseer met buitengewone hoë pH_u waardes (6.2 ± 0.06) as gevolg van ekstrinsieke faktore veroorsaak deur die produksie- en oesproses. Die vleis van ekstensief geproduseerde rooibokke het gevolglik DFD-kenmerke (donker, ferm, droog) getoon, insluitend die laagste drupverliespersentasie (0.9 ± 0.14 %), kookverliespersentasie (28.1 ± 0.79 %) en die donkerste, minder rooi en minder

versadigde oppervlakkleur (L* = 26.8; a* = 10.0; b* = 5.2; chroma = 11.4). Met die uitsondering van die ekstensief geproduseerde rooibokke, was die CIE oppervlakkleurmates van rooibokvleis van beide geslagte, alle spiere, en beide die intensiewe en semi-ekstensiewe produksiestelsels (L* = 30.9-36.8; a* = 11.4-13.6; b* = 6.0-8.8) binne die verwagte omvang wat as aanvaarbar geag word vir wildsvleis. Daarbenewens was all vars rooibokvleis in hierdie studie (Eksperiment 1 & 2) se skeurkragwaardes (19.2-39.3 N) laer as die 43 N afsnypunt en kan dus as sag geklassifiseer word.

Die chemiese vleiskwaliteit van rooibokvleis was ook betekenisvol deur geslag, spier en produksiestelsel beïnvloed. Interaksies tussen geslag en spier was vir al vier chemiese eienskappe (vog-, proteïen-, intramuskulêre vet- (IMF), en asinhoud) gevind, terwyl ‘n sterk negatiewe korrelasie (r = -0.49; $P < 0.001$) tussen die proteïen- en IMF-inhoud van die spiere gevind was (Eksperiment 1). Ekstensief geproduseerde rooibokke se LTL spiere het die laagste ($P \leq 0.05$) gemiddelde IMF-inhoud (1.5 ± 0.06 g/100 g) en die hoogste proteïen-inhoud (23.4 ± 0.12 g/100 g) gehad, terwyl rooibokke vanaf die intensiewe produksiestelsel die hoogste IMF-inhoud (2.0 ± 0.05 g/100 g) gehad het. Die proksimale samestelling van alle rooibokvleis in hierdie studie (Eksperiment 1 & 2) het gewissel van 74.7-77.0 % vog-, 20.7-23.5 % proteïen-, 1.2-2.2 % IMF- and 1.1-1.3 % asinhoud. Terwyl daar betekenisvolle verskille tussen geslag, spiere en produksiestelsels was, was die verskille numeries klein en mag dus nie van biologiese waarde tot menslike voeding wees nie. Ongeag hiervan het alle rooibokvleis in hierdie studie ‘n hoë proteïen- en lae IMF-inhoud gehad wat as gunstig deur gesondheidsbewuste verbruikers beskou word.

Met die verskille in voeding, bestuurspraktyke en daaglikse aktiwiteit tussen produksiestelsels, kan daar verwag word dat hierdie faktore ook verskille in die sensoriese profiel en versuursamestelling van rooiblokvleis kan veroorsaak. Produksiestelsel het die sensoriese vleiskwaliteit van rooibokke beduidend beïnvloed (Eksperiment 2), met die hoogste ($P \leq 0.05$) intensiteit van wilde, bees-agtige, kruid-agtige, en soet-geassosiëerde aromas en geure gevind in ekstensief geproduseerde rooibokvleis tydens sensoriese analise. In teenstelling met ekstensiewe rooibokke, het rooibokvleis vanaf beide die intensiewe en semi-ekstensiewe produksiestelsels in dieselfde produksie area nie beduidend verskil nie, met die uitsondering van ‘n paar tekstuur-verwante eienskappe en ‘n betekenisvolle hoër intensiteit vir wildsgeur wat in semi-ekstensief geproduseerde rooibokke gevind is.

Die ideale vleisverouderingstydperk vir LTL snitte van rooibokke was ook deur hierdie navorsing vasgestel. Die LTL spiere van 11 rooibok ramme en 11 ooie (Eksperiment 1) was opgedeel in agt snitte elk, met elke LTL snit lukraak ingedeel om vir 1, 2, 4, 6, 8, 10, 12, of 14 dae the verouder, vakuum-verpak en gestoor teen 4°C. Hierdie studie het bepaal dat die maksimum sagtheid (13.5 ± 0.91 N) en verbetering in oppervlakkleur van rooibok LTL snitte teen agt dae behaal is, terwyl verdere veroudering van die vleis verkleuring veroorsaak het en geen verdere verbetering in sagtheid getoon het nie. Die veroudering van rooibokvleis vir agt dae het ook die aanvanklike betekenisvolle verskille in taaiheid tussen geslagte uitgeskakel. Dit word daarom aanbeveel dat rooibok LTL snitte vir agt dae vacuum-verouder moet word teen 4°C om maksimum sagtheid te behaal en ook produkunivormheid te verbeter deur verskille tussen individuele diere te verminder, ongeag hul geslag.

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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
cm	Centimetre
DFD	Dark, firm, dry
DSA	Descriptive sensory analysis
FAME	Fatty acid methyl esthers
g	Gram
GIT	Gastro-intestinal tract
ha	Hectare
IMF	Intramuscular fat
IS	*Infraspinatus* muscle
Kg	Kilogram
LSMeans	Least square means
LTL	*Longissimus thoracis et lumborum* muscle
m	Metre
mm	Millimetre
MUFA	Monounsaturated fatty acids
N	Newton
n	Number
n6:n3	Omega-6 to omega-3 ratio
pH_u	Ultimate pH
PUFA	Polyunsaturated fatty acids
PUFA:SFA	Polyunsaturated to saturated fatty acid ratio
r	Pearson's correlation coefficient
RSA	Republic of South Africa
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.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 BACKGROUND

The global human population is expected to increase to nine billion within the next few decades (Tscharntke et al., 2012) and is accompanied by a rising demand for meat production worldwide (Meissner, Scholtz, & Palmer, 2013). Thus food production will have to increase by more than 50 % by 2050 to meet these expanding needs (Ingram, Ericksen, & Liverman, 2010). Despite the fact that worldwide food production has stayed ahead of demand for the past fifty years, there are presently approximately one billion people that do not have sufficient food, and a further one billion that are undernourished (Misselhorn et al., 2012). Southern Africa is currently a net importer of food, and its population is predicted to reach two billion people in the next 30 years, thus creating a necessity to increase the production of meat protein sources to address food insecurity (Conceicao, Fuentes-Nieva, Horn-Phathanothai, & Ngororano, 2011).

Climate change is an increasingly important factor that directly impacts food security by means of reduced food production potential and decreasing the availability of food, with overall agricultural productivity expected to decline by 9-21% in developing countries, such as South Africa, by 2050 (Misselhorn et al., 2012). An aspect of agricultural production that is affected by climate change is red meat production, as beef cattle are particularly vulnerable to desertification caused by the changing environmental temperatures and rainfall patterns resulting from climate change (Otieno & Muchapondwa, 2016). In addition to the impact of climate change, desertification is also aggravated by overgrazing due to the bulk-grazing feeding behaviour of livestock. The latter also has the consequence of increasing bush encroachment, which has a detrimental influence on commercial cattle production in the bushveld region of South Africa (Owen-Smith & Cooper, 1985; Van der Merwe, Saayman, & Krugell, 2004). The South African livestock industry is further challenged by livestock theft, expenses associated with disease control in cattle (Van der Merwe et al., 2004) and the fact that the majority of land available for traditional livestock production has already been utilized with limited prospects for future expansion (Hoffman, 2008). The meat produced by the limited number of domesticated livestock species may thus not be capable of meeting the South African population's expanding demand for animal protein. Therefore, it is necessary to explore non-traditional alternative sources for meat production to address food insecurity (Cawthorn & Hoffman, 2014; Conceicao et al., 2011).

Increased utilization of indigenous South African game species for meat production may offer a practical solution to these challenges (Hoffman & Cawthorn, 2012). Indigenous game species have evolved over millennia to be well-adapted to the arid and semi-arid South African environments, with improved utilization of low-quality vegetation, lower susceptibility to overgrazing and better parasite and disease resistance than traditional domestic livestock (Oberem & Oberem, 2016). Additionally, game species are less susceptible to livestock theft as a result of the more stringent fencing requirements, larger camps and the overall less domesticated nature of game animals (Snijders, 2012).

Game animals have also been found to generate higher net farm profit margins than livestock (Berry, 1986; Child, Musengezi, Parent, & Child, 2012) and the game farming industry has made a significant contribution to the expansion of wildlife conservation, economic growth and job creation (Bothma, Sartorius Von Bach, & Cloete, 2016; Taylor, Lindsey, & Davies-Mostert, 2016). Consequently, the financial and ecological advantages presented by game farming has resulted in a substantial shift in land-use allocation from traditional domestic livestock farming to the farming of indigenous game animals (Child et al., 2012). This was accompanied by a vast expansion in the South African game industry and the increased utilization of various types of production systems to optimize animal production (Taylor et al., 2016). In particular, semi-extensive and intensive production systems are utilized for the practice of selective breeding on game farms which aim to produce superior animals with higher sale values, such as rare colour variants or animals with exceptional horn characteristics (Bothma et al., 2016). The intensification of production systems, and consequently higher animal turnover, has resulted in a surplus of "split" animals (recessive gene carriers of colour variant genes) and colour variants with inferior horn characteristics, which are generally culled for meat production (Hoffman, 2007). Furthermore, most game farms are not populated by natural predators and therefore the regular culling of surplus game animals is required to control animal numbers and prevent overgrazing (Hoffman, Crafford, Muller, & Schutte, 2003; Kritzinger, Hoffman, & Ferreira, 2003). With the substantial expansion in the South African game industry and the consequent increase of game animals available for culling, the production and sale of South African game meat has the potential to expand significantly and potentially contribute to improving food security within South Africa.

1.2 MOTIVATION FOR RESEARCH

Meat is an important component of the human diet as a source of concentrated protein with a high biological value (Bender, 1992; Listrat et al., 2016). Even so, red meat from domesticated livestock is often associated with health issues related to the high cholesterol and intramuscular fat (IMF) content of these species, which is of particular concern to health-conscious consumers (Higgs, 2000; Wilcox et al., 2009). Game meat has been found to have a high protein and low IMF content (Hoffman, 2000, 2007; Hoffman, Kritzinger, & Ferreira, 2005; Van Zyl & Ferreira, 2004), and the meat from indigenous South African game animals may therefore be considered a healthy alternative protein source to red meat obtained from domestic livestock (Hoffman et al., 2005; Hoffman, Van Schalkwyk, & Muller, 2008; Ledger, 1963). In addition, game meat produced without the use of growth stimulants or dipping/external parasite control in South African production systems may be classified as "organic" (Hoffman, 2000). However, there is a common perception among consumers that game meat is tough and dry due to low product uniformity and there is a lack of quality standards and knowledge on the proper cooking methods (Radder & Le Roux, 2005). Meat quality is influenced by a variety of *ante-* and *post-mortem* factors, including species, slaughter age and sex of the animal, environmental and dietary factors, slaughtering conditions and the *post-mortem* processing of meat (Listrat et al., 2016). However, limited research has been published on the influence of these factors on game meat. Therefore, it is necessary to research the meat quality and nutritive value of each potential species when considering non-domesticated species, such as game animals, for meat production as a means of contributing to food security. Determination of these aspects of game meat, and the factors that

affect them, is imperative for the improvement of productivity and to produce game meat products with consistent quality (Cawthorn & Hoffman, 2014).

The impala (*Aepyceros melampus*) has been identified as an indigenous game species that is well-suited for continuous culling and meat production due to its abundance, rapid reproduction rate and wide distribution across South Africa (Fairall, 1983; Hoffman, 2000; Taylor et al., 2016). The impala is also a popular species for the breeding of colour variants, such as the black impala, and has been utilized in a variety of different production systems for the practice of selective breeding (Taylor et al., 2016). Consequently, there is a surplus of impala that are available to be culled for meat production. However, the influence of production system on the carcass yields, meat quality and sensory profile of impala has not yet been investigated. Furthermore, research on the influence of sex and the commercially important muscles on meat quality and nutritional content of impala meat is limited, and the influence of *post-mortem* ageing of the meat on meat tenderness has not yet been determined.

1.3 RESEARCH QUESTION, AIMS AND OBJECTIVES

The primary research question of this study is therefore: Does the sex, muscle and production system (*ante-mortem*) of impala and *post-mortem* ageing of *Longissimus thoracis et lumborum* (LTL) steaks have an influence on impala meat quality? The aim of the research was to investigate whether sex, muscle and production system (intensive, semi-extensive and extensive) had an influence on the carcass yield and meat quality (physical and chemical) of South African impala. This research also aimed to determine the influence of production system on the sensory meat quality of sub-adult male impala and the influence of sex on the optimum *post-mortem* ageing period for maximum meat tenderness. The objectives of this study was as follows:

1. Evaluate available literature to determine the suitability of impala as a meat source and identify shortcomings within the literature for further research (Chapter 2).
2. Determine the carcass yields of impala as influenced by sex (Trial 1) and production system (intensive, semi-extensive and extensive; Trial 2) (Chapter 3).
3. Investigate the influence of sex and muscle (Trial 1) and production system (Trial 2) on the physical meat quality parameters of impala (Chapter 4).
4. Determine the effect of sex and muscle (Trial 1) and production system (Trial 2) on the chemical composition of impala meat (Chapter 5).
5. Determine the influence of production system on the sensory profile and fatty acid composition of sub-adult (±15-18 months old) male impala by means of descriptive sensory analysis (DSA) and fatty acid methyl ester (FAME) analysis (Chapter 6).
6. Investigate the influence of *post-mortem* ageing on the physical meat quality of vacuum-aged LTL steaks derived from both male and female impala for a 14-day ageing period to determine the optimum *post-mortem* ageing period for maximum meat tenderness (Chapter 7).

The results from this study will provide baseline data to the South African game industry with regards to standardisation of meat quality and whether the aforementioned factors should be considered when marketing impala meat.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In South Africa, the agriculture sector is challenged by the substantial amounts of arid and semi-arid regions in the country that are unsuitable for profitable cattle farming due to low rainfall and limited vegetation resources (Otieno & Muchapondwa, 2016). As a result, the land-use allocation in these areas has seen a substantial shift from domestic livestock farming to the farming of indigenous game animals in an effort to utilize the financial and ecological advantages presented by game farming (Bothma & Van Rooyen, 2005; Child, Musengezi, Parent, & Child, 2012; Otieno & Muchapondwa, 2016). Indigenous game species have evolved over millennia to be well-adapted to the arid South African environments, with improved utilization of low-quality vegetation, lower susceptibility to overgrazing and better parasite and disease resistance than traditional domestic livestock (Oberem & Oberem, 2016). Furthermore, once private ownership of game animals was granted by the implementation of the Game Theft Act (105 of 1991), game farming in South Africa could evolve into a fast-growing industry (Child, 1991; Van der Merwe, Saayman, & Krugell, 2004).

The South African game industry is based on four pillars, namely hunting, ecotourism, breeding and meat production (Oberem & Oberem, 2016; Van der Merwe et al., 2004). Initial success was due to hunting and ecotourism, followed by expansion into breeding and live sales of high value game species and colour variants, such as the black impala and the golden wildebeest (Bothma, Sartorius Von Bach, & Cloete, 2016; Oberem & Oberem, 2016). In the early 2000's, live sales of game animals and the breeding of rare or endangered game species made the second largest contribution to the profits of game farm tourism and comprised approximately 30 % of the total revenue produced by South African game farms (Van der Merwe et al., 2004). These animals are usually bred in intensive or semi-extensive production systems which enable optimum selective breeding, where the goal is to produce offspring with superior genetics (such as increased horn size) to increase live sales (Taylor, Lindsey, & Davies-Mostert, 2016). With the expansion in the utilization of intensive breeding practices, the South African game industry became the fastest growing agricultural division in the country, with an annual growth rate of 6.8 % and a current land utilization of approximately 25 % of South Africa's total land area (Taylor et al., 2016).

The intensification of breeding systems and expansion of the game industry has been accompanied by a high game animal production turnover, which has resulted in a surplus of animals with recessive genes for colour variation (also known as "splits") that do not qualify for live sales (Hoffman, 2007; Taylor et al., 2016). In addition, most game farms are not populated by natural predators which regulate the number of game animals, and therefore the regular culling of surplus game animals is required to control animal numbers and prevent overgrazing (Hoffman, Crafford, Muller, & Schutte, 2003; Kritzinger, Hoffman, & Ferreira, 2003). These surplus animals can be used for meat production (Hoffman, 2007); a pillar that is becoming increasingly important for the financial sustainability of game farming (Berry, 1986; Bothma et al., 2016; Hoffman, Kritzinger, & Ferreira,

2005b).

In comparison to live sales, trophy hunting and recreational hunting, Berry (1986) found that game meat production generated the highest net revenue for biomass weight. In addition, meat from indigenous South African game animals is considered a healthy alternative protein source to red meat obtained from domestic livestock (Hoffman et al., 2005b; Hoffman, Van Schalkwyk, & Muller, 2008) due to its low intramuscular fat and high protein content (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012; Hoffman, 2000b, 2007; Van Zyl & Ferreira, 2004; Von La Chevallerie, 1972). South African game meat may also be classified as organic in production systems that do not make use of growth stimulants including antibiotics (Hoffman, 2000b). In combination with the increased demand for game meat by health-conscious consumers and the increase in game animals available for culling, the production and sale of South African game meat has the potential to expand significantly (Bekker, Hoffman, & Jooste, 2011; Bothma et al., 2016). Furthermore, the sustainable utilization of game meat resources (including offal) could meet the requirements of the South African consumer market, with the potential annual production of thousands of tonnes of game meat (McCrindle, Siegmund-Schultze, Heeb, Zárate, & Ramrajh, 2013).

To determine the meat production potential of game animals, it is necessary to determine all aspects of the carcass yields and meat quality of relevant game species, as well as the *ante*- and *post-mortem* factors that influence these aspects. The impala (*Aepyceros melampus*) has been identified as a game species that is well-suited for meat production (Fairall, 1983; Hoffman, 2000b) and the potential of this species for meat production in South Africa will be reviewed within this chapter.

2.2 DESCRIPTION OF THE IMPALA (*Aepyceros melampus*)

The impala is a medium sized antelope that is indigenous to southern Africa (Averbeck, 2002; Selier, Hoffman, & Castley, 2016). Impala form part of the *Bovidae* family, the *Aepycerotini* tribe and the *Aepyceros* genus with *melampus* as the only species (Selier et al., 2016). The species currently has three formally accepted sub-species with discernible morphological differences, and the following sub-species are credited by the Rowland Ward trophy register: the common southern impala, *Aepyceros melampus melapus* (includes the former sub-species *Aepyceros melampus johnstoni*, *Aepyceros melampus katangae* and *Aepyceros melampus holubi*); the central and eastern African impala, *Aepyceros melampus suara* (includes the former sub-species *Aepyceros melampus rendilis*); and the black-faced impala (*Aepyceros melampus petersi*) that is indigenous to south-western Africa and only occurs in north-western Botswana, northern Namibia and southern Angola (Furstenburg, 2016; Nersting & Arctander, 2001). However, only the common impala (*Aepyceros melampus melampus*) and the black-faced impala (*Aepyceros melampus petersi*) are accepted on the grounds of molecular genetics (Nersting & Arctander, 2001; Selier et al., 2016).

Impala have a two-tone brown colouration, with a brick-red saddle clearly divided from a tan-coloured lower body, with a white abdomen, neck, and undertail (Estes, 2012). Shoulder height is approximately 90 cm in males and 84 cm in females, with an average mature live weight of 57 kg (48-65 kg) in males and 45 kg (38-52 kg) in females, although the mean live weight differs from region

to region (Furstenburg, 2005; Hoffman, 2000b). Impala males reach their adult weight between 30 and 36 months of age, whereas females reach this weight earlier at between 24 and 30 months of age (Furstenburg, 2005; Roettcher & Hofmann, 1970). Mean life expectancy ranges from 10-12 years (Furstenburg, 2005). Horn development begins at three months of age for male impala, while female impala are hornless (Averbeck, 2002; Hoffman et al., 2005b; Roettcher & Hofmann, 1970). The horns of male impala have an S-curve, with ornamental rings and smooth tips that are wide apart in adults (Estes, 2012).

As is apparent through the allocation of their various sub-species, impala have a wide range of distribution throughout central, eastern and southern Africa (Mason, 1976; Murray, 1982; Selier et al., 2016) and inhabit open and mixed woodland areas as their natural habitat (Averbeck, 2002; Mooring & Hart, 1997a).The impala has become the most abundant herbivore game species on South African wildlife ranches, accounting for 24.1 % of all animals counted (Selier et al., 2016; Taylor et al., 2016). In terms of abundance, the impala is followed by the kudu (*Tragelaphus strepsiceros;* 11.8 %) and the springbok (*Antidorcas marsupialis;* 11.6 %; Taylor et al., 2016). The impala was found to be prevalent on more than 80 % of the properties surveyed to determine the ecological role of wildlife farming (Taylor et al., 2016). The growth, development, reproduction and feeding behaviour of the impala has been the focus of many research studies in Africa, although the majority of earlier studies focused only on impala from one research location or farm in central, eastern or southern Africa (Anderson, 1975; Anderson, 1982; Fairall, 1983; Fairall & Braack, 1976; Hanks, Cumming, Orpen, Parry, & Warren, 1976; Howells & Hanks, 1975; Roettcher & Hofmann, 1970; Sachs, 1967; Spinage, 1971). Most of these research studies observed impala in their natural environments, usually with freedom to exhibit natural movement patterns and with exposure to predators (Fairall, 1983).

2.2.1 Feeding and social behaviour

Impala are classified as mixed feeders, with an ability to both graze and browse which allows them to survive in a variety of habitats across southern Africa (Fairall, 1983; Furstenburg, 2005, 2016; Mason, 1976; Schenkel, 1966; Skinner, Monro, & Zimmermann, 1984). Mixed or intermediate feeders can adapt their diet to include primarily roughage of low quality or concentrated vegetation with higher energy and nutrient content according to seasonal or environmental conditions (Mentis, 1977). The diet of impala consists of both monocotyledons such as *Cynodon dactylon* (Stewart, 1971; Theobald, 2002), *Themeda triandra* (Theobald, 2002), and *Digitaria eriantha* grasses (Skinner et al., 1984), and dicotyledons such as *Acacia* spp. trees and shrubs (Furstenburg, 2016; Rodgers, 1976; Skinner et al., 1984; Theobald, 2002).

While the bulk of their feed intake is comprised of a wide variety of grasses by preference, impala can effectively utilize browsing material consisting of a variety of herbs, shrubs and trees when grazing material is scarce, particularly during the dry season (Fairall, 1983; Meissner & Pieterse, 1996; Owen-Smith & Cooper, 1985; Rodgers, 1976; Stewart, 1971). When browsing, impala select vegetation with higher nutritional quality (Mason, 1976; Rodgers, 1976), particularly in the dry season (usually in winter) when the protein content of browsing material is high (Skinner et

al., 1984). Impala are also able to effectively utilize fallen leaves from deciduous trees, allowing for potentially higher stocking rates than kudu or cattle (Owen-Smith & Cooper, 1985). The movement patterns of impala herds are influenced by the availability of surface water and succulent vegetation, which provides a source of water to impala in dry months (Theobald, 2002; Young, 1972). Impala tend to remain in close vicinity of watering points (within eight kilometres; Theobald, 2002), which may lead to overgrazing of the surrounding area due to their selective feeding habits if water sources are not distributed adequately. This effect can be particularly severe in overpopulated regions, where impala may alter the composition of the flora surrounding their watering points (Young, 1972).

Impala tend to limit their feeding periods strictly to daylight hours and prefer to stay in the shade of trees when daytime temperatures are high (Furstenburg, 2016). While the mixed feeding behaviour of impala allows them to optimize the nutritional quality of the food they consume in natural circumstances (Meissner & Pieterse, 1996; Rodgers, 1976), the breeding and management of impala in more intensive systems may restrict their browsing behaviour or limit impala to the consumption of supplied feed only. In absence of the opportunity to browse, the supplied feed should have a high enough nutritional content and digestibility to compensate for the limited feed intake of small antelope such as impala (Mentis, 1977). Impala require a diet with a low crude-fibre content (< 40 %) and a high protein content that should be adjusted from 8 % in winter (from June to August in South Africa) to 16 % in summer (November to March) when impala females are lactating (Furstenburg, 2016). Impala willingly utilize supplementary feeding and mineral salt licks when provided, and the total daily feed intake of adult impala has been found to range from 0.9 kg dry matter (DM) in the dry winter season to 1.9 kg DM during the rainy summer season (Furstenburg, 2016).

Impala are large herd herbivores that form two main types of groups; female groups which consist primarily of two to 100+ females and their lambs with one dominant impala male, and bachelor male groups of two to 60 male impala, consisting of yearling, adult and occasionally old individual males (Jarman, 1970; Mooring, Mckenzie, & Hart, 1996b; Schenkel, 1966; Shorrocks & Cokayne, 2005). Additional social groups consisting of mixed herds (including males, females and lambs of different ages) have also been recorded, along with single mature impala males that do not form part of any group (Mason, 1976; Mooring et al., 1996b). The size and dynamics of these social groups vary between seasons to adapt to the availability of vegetation (Skinner et al., 1984) and to accommodate interaction of the opposite sexes during the breeding season (Murray, 1982). The adult populations of impala are usually skewed toward a majority of females (65 %; Fairall, 1983), while one or two adult females often form temporary nursing groups for impala lambs on the periphery of the family group (Furstenburg, 2005). Furthermore, impala are gregarious animals that often associate with game species with similar social behaviour, such as waterbuck (*Kobus ellipsiprymnus*), blue wildebeest (*Connochaetes taurinus*) and giraffe (*Giraffa camelopardalis*). This allows impala to improve threat detection and the avoidance of predation (Féron, Tafira, Belemsobgo, Blomme, & De Garine-Wichatitsky, 1998; Furstenburg, 2005).

2.2.2 Age determination and breeding

Impala can be classified into the following broad categories according to age range: juvenile (birth to 12 months), yearling/sub-adult (between 12 and 24 months), and adult/mature (24 months and older), with the defined range for each category often varying between authors (Bourgarel, Fritz, Gaillard, De Garine-Wichatitsky, & Maudet, 2002; Fairall, 1983; Hoffman, Mostert, Kidd, & Laubscher, 2009; Mason, 1976, 1990). The age of an impala may be estimated by a combination of parameters, including horn growth, body size, eye lens weight, tooth eruption and wear, cementum lines, changes in skull shape and ossification of cranial sutures and long bones (Fairall, 1969; Howells & Hanks, 1975; Roettcher & Hofmann, 1970; Spinage, 1971). Upon *post-mortem* examination of tooth eruption, the age of impala can be determined with relatively good accuracy until approximately 30 months of age, after which the accuracy of age determination decreases with establishment of permanent dentition (Roettcher & Hofmann, 1970). However, most age determination methods are only applicable *post-mortem*, whereas hunters must rely on relative body size and horn growth of impala in the field as estimations of age.

Horn size and shape are useful parameters for age determination in impala males, which have a characteristically short tip-to-tip measurement and oval shape in sub-adults (Spinage, 1971), commonly known as “Knypkoppies” in Afrikaans. Using horn length and shape as a guideline, age can be estimated relatively accurately in the field for sub-adult impala males (Roettcher & Hofmann, 1970). Furthermore, a combination of the live weight, horn length and number of grooves on the horns may be used to estimate the relative age of male impala *post-mortem*. Furstenburg (2016) compiled a table of the mean growth rate of the horns and live weight of male impala from birth until six years of age (Table 2.1). This table was compiled from data obtained from previous authors (Brooks, 1978; Fairall & Braack, 1976; Howells & Hanks, 1975), and serves as a broad representation of the horn growth and live weight increase with age of male impala.

However, like many other antelope species, female impala are hornless (Bourgarel et al., 2002; Furstenburg, 2005; Hoffman, 2000b; Hoffman et al., 2005b; Spinage, 1971). Without horn size and shape as a guideline, attempting to estimate the age of female impala by body size is very challenging in the field (Bourgarel et al., 2002; Howells & Hanks, 1975; Roettcher & Hofmann, 1970), especially during culling operations where time is limited. Additionally, body size has been found to be relatively similar or overlapping between yearling/sub-adult and adult female impala (Howells & Hanks, 1975; Mason, 1990), and between juvenile and sub-adult female impala (Féron et al., 1998), respectively. This problem is particularly apparent at the end of the dry season, when adult female impala can appear smaller or thinner than sub-adult females (Bourgarel et al., 2002). Age estimation of female impala is further complicated in environments with dense vegetation that can obscure the presence of ageing criteria such as relative body size and the presence of udders. Therefore, it has been concluded that after 15 months of age, separating yearlings from adult female impala in *ante-mortem* field classification is a very difficult task (Howells & Hanks, 1975). In addition, once impala of both sexes reach maturity at the age of three years and older, their exact ages cannot be differentiated in the field (Brooks, 1978; Fairall, 1969) and can only be determined *post-mortem* with the use of specialized techniques (Fairall, 1985).

Table 2.1 Mean age-related growth rate of body weight and horns of Southern impala males (Furstenburg, 2016).

Age	Live weight (kg)	Horns	
		Length (cm)	Number of grooves
Birth	4.5	0	0
2 months	7	0	0
4 months	12	0.5 – 4	0
6 months	16	10 – 15	0
1 year	25 – 30	20 – 30	1
1.5 years	30 – 35	32 – 40	4 – 6
2 years	33 – 40	38 – 48	9 – 13
2.5 years	36 – 45	42 – 54	15 – 18
3 years	38 – 50	46 – 58	16 – 22
4 years	40 – 55	50 – 64	18 – 24
5 years	40 – 58	> 52	20 – 24
6 years	40 – 64	> 52	20 - 24

Sexual maturity is attained at 16 months in impala males and at 13 months in females. However, social maturity (age at first mating) only occurs at approximately three years in males and 18 months in females, with gestation lasting approximately 185-205 days (Fairall, 1983; Furstenburg, 2005, 2016). Even in adverse conditions with exposure to predators, female impala have a very high fecundity, with an average of 95 % in adults older than 24 months (Fairall, 1983). Impala are seasonal breeders in southern Africa (Anderson, 1965; Dasmann & Mossman, 1962; Fairall, 1972, 1983; Furstenburg, 2016; Hanks et al., 1976; Jarman, 1970; Mason, 1976) and have one primary breeding season that reaches its peak in May (Anderson, 1965, 1975; Dunham & Murray, 1982; Fairall, 1972, 1983; Furstenburg, 2005; Hanks et al., 1976; Mooring et al., 1996b; Robbel & Child, 1970; Skinner, 1971), with a second, less pronounced breeding season occasionally observed in September/October (Anderson, 1975). The precise timing of the primary breeding season's peak varies from year to year and between different farming regions in southern Africa, with variations attributed to changes in climate and rainfall affecting vegetation (Anderson, 1975; Fairall, 1983). This effect of climate on breeding is reflected by a lambing season that primarily ranges from the summer months of November to January in southern Africa (Dasmann & Mossman, 1962; Dunham & Murray, 1982; Fairall, 1968; Murray, 1981). In contrast, impala from the Lake Mburo area in Uganda have two lambing seasons, from February to April and from August to September due to a bi-modal breeding pattern, presumably as consequence of the two rainy seasons experienced annually in Uganda (Averbeck, 2002).

The impala is also popular choice for the breeding of colour variants, with variants such as the black and saddle-bag impala reaching high values at live game auctions. However, due to the recessive nature of the gene with the marker for black colour variation, black impala tend to be less abundant within extensive systems due to the dominance of the typical red-brown colour (Furstenburg, 2016; Selier et al., 2016). The practice of breeding impala in semi-extensive and intensive production

systems to achieve the desired colour variants has expanded in response to the current high auction and hunting value of these animals. The impala has been found to adapt well to these different production systems for breeding purposes (Furstenburg, 2005; Taylor et al., 2016). While the initial goal was simply the increased breeding of rare colour variants, the recent increase in the number of breeders and the high rate of animal turnover has prompted the aim of breeding to shift toward genetic improvement to produce colour variants with superior characteristics (mainly horn size and shape in the males) that allow these impala to qualify as trophy animals, thus increasing their hunting value (Furstenburg, 2016; Selier et al., 2016). When utilizing these intensive and semi-extensive breeding systems, it is recommended that breeding herds containing one breeding male and a maximum of 30 female impala are placed in a rotating camp system comprised two camps, with a minimum area of 25 ha each (Furstenburg, 2016). Using camps of an adequate size is important, as impala have been reported to struggle to adapt in small camps of less than 20 ha (Furstenburg, 2016). While breeding systems increase the overall productivity of impala, the natural seasonal breeding behaviour of this species has not been reported to be substantially altered by production systems, nor by captivity (Skinner, Moss, & Skinner, 2002). Impala raised in a zoo at the National Zoological Gardens in Pretoria were found to have a similar seasonal breeding cycle to that observed in wild impala, with most lambs born in December/January, although a wider distribution of births was noted with lambs occasionally born in June (Skinner et al., 2002).

2.3 MEAT PRODUCTION POTENTIAL OF THE IMPALA

Considering the abundance, rapid reproduction rate and high fecundity of the impala (Fairall, 1983; Taylor et al., 2016), this game species may be suitable for meat production in South Africa. The impala is well-suited to sustainable culling regimes, with a culling rate of 22 % suggested for more natural populations, but this may be raised to 25-30 % on game farms which practice predator control (Dasmann & Mossman, 1962; Fairall, 1983). Selective culling of male impala and females older than three years may also be beneficial to population growth and productivity, due to the natural surplus of males in impala populations (Fairall, 1985; Averbeck, 2002). With the consequently high productivity and animal turnover associated with breeding systems, the surplus of impala with inferior genetics or recessive genes for colour variation may be culled for meat production (Hoffman, 2007).

The use of wildlife/game species for meat production has proved to be successful in other parts of the world. In New Zealand, deer were initially considered to be pests in the country after their unrestrained introduction in the late 19th century (Wiklund, Farouk, & Finstad, 2014). However, the farming of deer has developed into a particularly well-ascertained and scientifically advanced industry in New Zealand (Chardonnet et al., 2002), with the largest population of farmed deer worldwide at over 830 000 animals, of which the red deer (*Cervus elaphus*) comprises 85 %. With an exported amount of approximately 12 000 tonnes of deer meat in 2017 generating a revenue of 266 million New Zealand dollars, the country is the leading global supplier of farmed venison/game meat (DINZ, 2017). Utilizing indigenous game animals that are similarly abundant, such as the impala, may play a crucial role in improving food security in Africa (Cawthorn & Hoffman, 2014). However, for the implementation of a game species as an additional source of meat, all aspects

concerning the meat production potential of such a species will have to be determined.

Meat produced from game animals is subjected to the same meat production criteria of domestic livestock, such as carcass yield and physical, chemical and sensory meat quality (Hoffman, 2000b; Issanchou, 1996). Knowledge of these factors will create baseline data for the game industry of the nutritional quality, production potential and target markets for impala meat (Hoffman, 2000b). Furthermore, it is important to quantify all aspects of game meat quality to improve overall quality and competition with traditional meat types and meat products (Kohn, Kritzinger, Hoffman, & Myburgh, 2005). South African consumers are inadequately educated concerning the nutritional composition and optimal cooking methods of game meat (Hoffman, Muller, Schutte, & Crafford, 2004), which further highlights the necessity of research and distribution of knowledge in these areas. In a study on the financial viability of the utilization of impala in Uganda, Averbeck (2002) reported that fresh impala meat was sold easily despite a lack of marketing, with the most popular meat cuts including the fillet, sirloin, top rump and topside. It was also deemed more profitable to sell impala carcasses processed, rather than as a complete carcass (Averbeck, 2002). However, with enough research and adequate marketing based on research findings, impala meat production may potentially be utilized and its marketing optimised, to provide a financially viable solution to surplus animals on game farms.

Consequently, the potential of impala for meat production has recently compelled research to expand further toward factors influencing impala carcass yield (Du Plessis et al., 2006; Fairall, 1983; Hoffman, 2000b; Hoffman et al., 2005b; Van Zyl & Ferreira, 2004), muscle characteristics (Kohn et al., 2005) and meat quality (Hoffman, 2000a, 2000b; Hoffman et al., 2005b; Hoffman, Kritzinger, & Ferreira, 2005a; Hoffman et al., 2009; Hoffman, Mostert, & Laubscher, 2009; Kritzinger et al., 2003; Van den Berg, 2009; Van Zyl & Ferreira, 2004; Von La Chevallerie & Van Zyl, 1971). Several of these studies have compared impala from different farming locations (Anderson, 1982; Du Plessis et al., 2006; Hoffman et al., 2005b; Theobald, 2002) and of both the male and female sexes (Anderson, 1982; Du Plessis et al., 2006; Fairall & Braack, 1976; Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009; Theobald, 2002; Van den Berg, 2009; Van Zyl & Ferreira, 2004). Despite the increasing use of intensive and semi-extensive production systems for the breeding of impala (Taylor et al., 2016), the impact of different production systems on the carcass yields and meat quality of impala has yet to be investigated due to the lack of clearly defined production systems in any of the aforementioned studies.

2.3.1 Impala carcass yields

The carcass yield of an animal is an indication of the animal's value for meat production (Ledger, 1963). When culling game animals for meat production, carcass yield becomes important as game animals are sold per kilogram (Hoffman & Wiklund, 2006; Oberem & Oberem, 2016). The description of the carcass yield of an animal consists of the undressed and dressed carcass weights and the dressing percentage. Recording animal live weight is vital for the comparison of growth and potential carcass yield between different populations of the same game species, as well as between animals from the same population that are subjected to a variation of environmental conditions (Howells &

Hanks, 1975). The undressed and dressed carcass weights of impala have been found to be influenced by a variety of factors, including age, sex, body condition, production region and parasites. A dressed carcass is defined as the carcass of an animal after removal of the head, skin, lower limbs (referred to as the "feet" hereafter), the gastro-intestinal tract, viscera and sexual organs (Féron et al., 1998).

2.3.2.1 Effects of age and sex

When meat production per surface area per time unit is the goal, the adult weight of game is of less importance than the growth rate and feed conversion efficiency of the species in question (Von La Chevallerie, 1970). Determining the growth curve of a species is therefore useful in determining not only the maximum meat production potential of the species, but also in determining the optimum age at slaughter from an economical point of view as well as assisting in age determination in cases where the age at slaughter was unknown (Fairall, 1983; Von La Chevallerie, 1970).

The undressed and/or dressed carcass weights of impala at different ages have been measured (Anderson, 1982; Averbeck, 2002; Bourgarel et al., 2002; Du Plessis et al., 2006; Fairall, 1983; Fairall & Braack, 1976; Féron et al., 1998; Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009; Howells & Hanks, 1975; Theobald et al., 2002; Van den Berg, 2009; Van Zyl & Ferreira, 2004). However, the classification of these ages varies substantially between authors. While several of the authors were able to give the ages of the impala accurately in terms of months or years (Anderson, 1982; Averbeck, 2002; Du Plessis et al., 2006; Fairall & Braack, 1976; Hoffman et al., 2005b; Van Zyl & Ferreira, 2004), other authors described the ages of impala in broad categories such as juvenile, sub-adult, adult/mature, and old (Anderson, 1982; Du Plessis et al., 2006; Fairall, 1983; Fairall & Braack, 1976; Hoffman et al., 2009; Sachs, 1967; Theobald et al., 2002; Van den Berg, 2009). Also, the definitions of these categories differed between authors. Sub-adult was defined as ranging from 19-34 months by Du Plessis et al. (2006), while Hoffman et al. (2009) defined sub-adults as impala that have not yet established permanent dentition, with permanent dentition reached at 30 months in males and 24-30 months in females. Other authors do not give an estimation of the age range for the categories that impala were divided into, resulting in cases where male impala classified as "juvenile" have higher undressed carcass weights (54.0-58.3 kg; Theobald et al., 2002) than males classified as adults (e.g. 49.4 kg; Fairall, 1983) in other studies. However, it should be kept in mind that age was often not considered a research treatment in several of these studies.

The growth curve of impala was first described by Howells & Hanks (1975), whom used the Von Bertalanffy growth equation to determine the theoretical asymptotic weight of both male and female impala based on data collected from 332 animals (151 females and 181 males) from Zimbabwe, over a period of approximately nine months. According to the theoretical growth curve, male impala would reach their asymptotic live weight of 56.6 kg at approximately 54 months of age, while females would reach their asymptotic live weight of 43.2 kg at approximately 36 months (Howells & Hanks, 1975). This approach was followed by three other studies that compiled growth curves for 182 male impala also from Zimbabwe (Hanks et al., 1976), as well as from 182 impala in KwaZulu-Natal (Brooks, 1978), and from an unspecified number of 1 323 impala from the Kruger

National Park (Fairall, 1983). A compilation of these theoretical Von Bertalanffy growth equations and the calculated asymptotic ages and live weights for male impala from these studies are presented in Table 2.2.

The asymptotic age of male impala ranged from four to five years, with a relatively similar asymptotic weight (56.6-58.6 kg) determined in three of the studies (Brooks, 1978; Hanks et al., 1976; Howells & Hanks, 1975), whereas a substantially lower asymptotic weight (48.2 kg) was obtained by Fairall (1983). To evaluate the growth of male impala with age, the theoretical live weights were calculated for impala at 18 months and 24 months of age using the four respective Von Bertalanffy equations (Table 2.2). The calculated weights show that impala from the Kruger National Park were consistently lighter than impala from the other three locations, while impala from both locations in Zimbabwe were substantially heavier at both 18 months and 24 months than impala at Mkuzi Game Reserve in South Africa (Table 2.2). The differences between locations for impala live weight with age may be the result of dietary differences between production regions, as Fairall (1983) recorded that the impala from the Kruger National Park were harvested during a period of below average rainfall.

Table 2.2 Theoretical Von Bertalanffy growth equations, asymptotic ages and calculated weights (kg) at different ages as obtained by different authors.

Location	n	Equation	Asymptotic age (years)	Asymptotic weight (kg)	18 month weight (kg)	24 month weight (kg)	Reference
Wankie National Park, ZI	181	$W_t = 56.6(1-e^{-1.13(t+0.68)})^3$	4.5	56.6	43.3	48.8	Howells & Hanks 1975)
Sengwa Wildlife Research Area, ZI	170	$W_t = 59.58(1-e^{-0.95(t+0.83)})^3$	5	59.6	42.1	48.2	Hanks et al. (1976)
Mkuzi Game Reserve, RSA	182	$W_t = 58.2(1-e^{-0.728(t+1.127)})^3$	4	58.2	36.0	42.1	Brooks (1978)
Kruger National Park, RSA	-	$W_t = 48.2(1-e^{-0.728(t+1.127)})^3$	5	48.2	29.8	34.8	Fairall (1983)

Abbreviations: ZI = Zimbabwe; RSA = Republic of South Africa; W_t = Weight in kilograms (kg); t = age in years.

Fairall (1983) found that the growth rate of impala was relatively high, with 75 % of mature live weight obtained by 24 months of age in male impala. This can also be observed in Table 2.2, where the theoretical live weight of impala at 24 months of age ranged from 72.0-86.2 % of the asymptotic weight. Since the growth increments of impala are small after 24 months of age, it would be recommended to cull male impala at approximately 24 months based on the theoretical Von Bertalanffy growth curves obtained (Brooks, 1978; Fairall, 1983; Hanks et al., 1976; Howells &

Hanks, 1975), as the growth rate and feed conversion efficiency would tend to decline after this age. At 24 months of age, the dressed carcass weight of male impala was reported as 22.0 kg, with a dressing percentage of 57.1 % (Fairall, 1983), while “sub-adult” (19-34 months) impala males were recorded to have a mean dressed carcass weight and yield of 28.5 ± 0.8 kg and a 60.9 ± 0.8 % at Mara Research station and a 22.6 ± 0.4 kg dressed weight and 59.2 ± 0.4 % dressing percentage at Messina experimental farm, respectively (Du Plessis et al., 2006). At these relative ages, the yields are considered relatively high and thus culling male impala at this age could be beneficial if meat production is the goal. However, the theoretical mass and live weights for age of male impala differ substantially between these research studies on only four locations (Table 2.2), and the growth curve of female impala has yet to be determined for females from more than one location. Furthermore, the growth curves were determined prior to 1983, and the growth of impala may have been influenced by changes in the environment, intensified breeding and management practices over the last 35 years. To give a more accurate representation of the growth rate of both male and female impala, it would be necessary to use data obtained in multiple locations and over several different time periods to account for differences in live weight that may be caused by seasonal or regional variations.

A scatter plot of the metabolic growth of male and female impala (Figure 2.1) has been compiled from the metabolic weights calculated from the mean live weights of approximately 571 impala from six different locations in South Africa (Kruger National Park, Mara Research Station, Messina/Musina Experimental Farm, Nyala Game Ranch, Overberg Test Range) and Uganda (Lake Mburo region) obtained in previous research (Anderson, 1982; Averbeck, 2002; Du Plessis et al., 2006; Fairall, 1983; Fairall & Braack, 1976; Hoffman et al., 2005b; Van Zyl & Ferreira, 2004). While several other authors have also obtained information on the carcass weights of impala, their results could not be used for the compilation of the metabolic growth curve due to the use of the broader categories for age classification rather than specific ages in months or years. However, these results still provide valuable information on the carcass yields of impala and a compilation thereof can be found in Addendum I.

Metabolic weight is calculated as the live weight of an animal (in kg) to the power of 0.75 and can be used as an index of productivity (Syrstad, 1993). From Figure 2.2, it can be seen that the maintenance requirements of both male and female impala increase linearly with age. At 24 months, the calculated metabolic weight of male impala (15.3 kg) is 67.9 % of the metabolic weight at 54 months (22.5 kg), with the latter considered to be the age at which asymptotic live weight is reached in male impala (Fairall, 1983; Hanks et al., 1976). When considering that 75 % of the mature live weight of male impala is reached at approximately 24 months (Fairall, 1983), it may be more productive to cull impala at this age for meat production, as the maintenance requirements are lower than that of older impala, while still obtaining high undressed carcass weights. This can be particularly effective when utilized in conjunction with the natural surplus of male impala in a population, with reducing male numbers resulting in an increase in productivity (Averbeck, 2002). However, when impala males are being bred for horns size and shape as trophy animals, research would be required to calculate the correlation between horns size/shape of these younger males to that of older trophy

animals. It has been recommended that the optimum age for the culling of female impala is at seven years, at which point their reproductive cycle has peaked and maximum live weight is obtained (Furstenburg, 2005). As the data on live weight and thus metabolic weight of females extend only up to three years in age (Figure 2.1), further research would be required to determine the optimum culling age for female impala. It should also be remembered that these recommended ages for culling are related to the effect of age and carcass yield, but do not consider any of the other factors that are influenced by age such as meat quality.

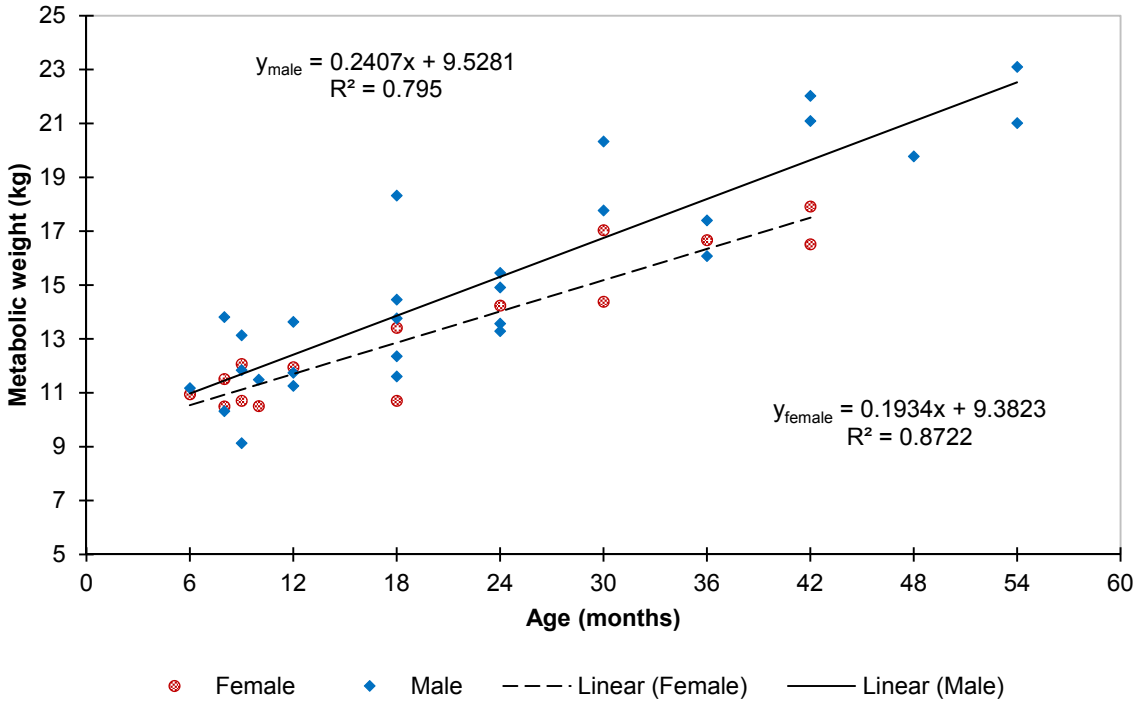

Figure 2.1 Increase in metabolic weight with age for male and female impala, compiled from data obtained from Anderson (1982), Averbeck (2002), Du Plessis et al. (2006), Fairall & Braack (1976) Hoffman et al. (2005b) and Van Zyl & Ferreira (2004).

In addition to age, the sex of an animal can play an important role in meat production potential, as sex has an influence on carcass characteristics, muscle growth and dressing percentages, as well as meat quality characteristics such as meat tenderness and intramuscular fat content (Barton, Bureš, Kott, & Rehák, 2011; Hoffman et al., 2005a). Sexual dimorphism has been recorded between male and female impala for live weights and/or dressed carcass weights, with heavier carcass weights recorded for male impala than females in both sub-adult and adult age classes (Anderson, 1982; Féron et al., 1998; Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009). Furthermore, the asymptotic undressed carcass (live) weight of male impala was recorded to be heavier (56.6 kg) than that of females (43.2 kg), whereas females reach this weight at an earlier age (Howells & Hanks, 1975). However, no sexual dimorphism was found among the undressed carcass weights of very young impala until approximately 10 months of age (Fairall & Braack, 1976), nor between the dressed carcass weights of male and female impala in the “juvenile” age category (Féron et al., 1998). After this age, the sexual dimorphism in live weights of impala has been found to increase as the age of

the impala increases (Blumenschine & Caro, 1986; Hoffman, 2000b). The onset of sexual dimorphism in the live weights of impala appears to coincide with the onset of puberty, which may start around 12-14 months of age, as sexual maturity is attained at 16 months in male impala and at 13 months in females (Furstenburg, 2016). The heavier adult live weights of males in comparison to that of females can also be observed across a variety of farm locations and production regions (Table 2.3), which indicates that the sexual dimorphism of impala at the same age after puberty is prevalent regardless of differences in environmental conditions.

When impala carcasses were divided into standard South African mutton retail cuts, the neck and forequarter cuts of male impala were significantly heavier than those of female impala, whereas hindquarter cuts were heavier in female impala than in males (Hoffman, 2000b). The heavier and thicker necks of male impala may be caused by increased hormone production after puberty, which has been found to stimulate increased fat accumulation in the necks of male impala, particularly prior to the rutting season (Furstenburg, 2016). Additionally, male impala were found to have heavier skin and viscera than females, while the absence of horns in female impala result in lighter head weights (Hoffman, 2000b; Hoffman et al., 2005b; Mostert, 2007). Sexual dimorphism for undressed carcass weights has also been recorded in other game species, such as fallow deer (*Dama dama*; Fitzhenry, 2016), kudu (Hoffman et al., 2009), and eland (*Tragelaphus oryx;* Laubser, 2018).

2.3.2.2 Effect of season, production region and parasites

Seasonal changes throughout the year may influence the carcass weights of game animals by affecting the nutrient availability of the pasture and consequently the nutritional status and diet of the animal. As a result, weight loss often occurs during the South African winter months (May to August) when the available nutrients are insufficient (Wiklund, Pickova, Sampels, & Lundström, 2001). In impala, seasonal changes in body condition and its influence on live weight have been recorded in several studies by assessing fat deposition in bone marrow and/or around the kidneys (Anderson, 1965; Brooks, 1978; Dunham & Murray, 1982; Monro & Skinner, 1979; Van Rooyen, 1993). Body condition is an indication of an animal's ability to survive in their habitat, as well as their meat production potential (Monro & Skinner, 1979). The body condition of impala has been found to be influenced by seasonal changes in both nutritional quality and the sexual cycle of impala, which are related as impala are strictly seasonal breeders (Bourgarel et al., 2002; Fairall, 1983; Van Rooyen, 1993).

Sexually mature impala males are at optimum body condition prior to commencement of the breeding season in April/May. Thereafter, their condition and live weight declines due to reduced feed intake and high energy expenditure caused by fighting between males for a mating opportunity with female impala (Anderson, 1965; Bourgarel et al., 2002; Brooks, 1978; Dunham & Murray, 1982; Furstenburg, 2005; Oliver, 2002; Robbel & Child, 1970; Van Rooyen, 1993). A similar decline in body condition has also been found to occur in bachelor impala males that are prevented from taking active part in the breeding season. While these impala do not have the same energy expenditure as males that are actively breeding, the similar decline in both condition and live weight is most likely the result of the decline in nutritional quality of vegetation in the dry winter season by

means of higher lignin and lower protein content of the pasture (Van Rooyen, 1993). These fluctuations in the condition and live weight of impala males between seasons is accompanied by fluctuations in testes weight and kidney fat weight (Anderson, 1965; Hanks et al., 1976; Skinner, 1971).

Seasonal reproductive status also influences the body condition and fat reserves of adult female impala, with both parameters usually peaking during gestation and then declining to a minimum during the initial months of lactation from November/December to February (Dunham & Murray, 1982; Furstenburg, 2005; Van Rooyen, 1993). The dressed carcass weights of impala are also affected by seasonal changes, with lower weights recorded for all impala in years with low rainfall and heavier weights recorded for adult male impala in cool dry seasons (Bourgarel et al., 2002). Male impala were found to be affected more by changes in nutritional resources than female impala, with the latter showing no differences in carcass weights between two habitats in the Omay Communal Area within the Nyaminyami District in Zimbabwe (Bourgarel et al., 2002). The influence of season on the carcass weights of impala is also dependent on the environmental conditions that are specific to production regions, such as rainfall, natural vegetation occurring in the area, parasites and feeding management. Thus, season is an important factor to consider when culling impala for meat production, to ensure optimal carcass yields.

Production region and farm location substantially influences live weights and dressed carcass weights primarily due to the quantity and quality of the natural vegetation, and consequently the available nutrients (Von La Chevallerie, 1970). The undressed carcass weights of impala of different ages have been determined at a variety of farm locations in several different production regions across South Africa, Uganda, Zimbabwe and Kenya. A compilation of the adult undressed carcass weights of both male and female impala as obtained in different research studies is presented in Table 2.3. The adult undressed carcass weights vary widely between different regions, with the mean adult undressed carcass weights of male impala ranging from 44.2 kg at the Nyala Game Ranch in KwaZulu-Natal (Anderson, 1982) to 77.2 kg at Mara Research Station in Limpopo (Theobald, 2002). The adult undressed carcass weights of female impala ranged from a mean of 38.3 kg in the Kruger National Park to 73.0 kg in the Ndzalama Wildlife Reserve in Limpopo (Theobald, 2002). The large differences in undressed carcass weights between broad age classes reiterate the importance of accurate age determination (in months or years) and defining the age range of the classification used for the purpose of comparisons between different studies.

For adult impala (3-5 years), a general trend appears when comparing production regions. In two separate studies comparing the carcass yields of impala from Mara Research Station with that of impala from Messina/Musina Experimental Farm, both studies found that both male and female impala have significantly heavier undressed carcass weights at Mara than at Messina/Musina (Du Plessis et al., 2006; Hoffman et al., 2005b). While both locations are situated in the Savanna Biome of the Limpopo Province of South Africa, the vegetation and climate of the two locations differ. Mara Research Station has an Arid Sweet Bushveld vegetation type, while Messina/Musina Experimental Farm is located in the Mopani veld (Hoffman et al., 2005b; Mucina & Rutherford, 2006). Impala

occur naturally at Mara Research Station, which is considered to be the ideal habitat for impala with high nutritional quality and increased energy availability for growth. This is speculated to be the primary reason for the higher carcass weights of impala from Mara Research Station compared to impala from Messina/Mucina (Table 2.3), while external and internal parasites and seasonal variation in grazing quality were speculated to have also made a contribution (Du Plessis et al., 2006; Hoffman et al., 2005b).

Table 2.3 Mean undressed carcass weights (kg) ± standard error (where supplied) of adult/mature male and female impala obtained at different localities.

Location	Male	Female	Author
Kruger National Park, RSA*	49.2 ± 1.02	38.3 ± 1.79	Fairall & Braack (1976)
	49.4	-	Fairall (1983)
Mabula District, Limpopo, RSA	58.2 ± 2.50	43.8 ± 3.30	Hoffman, Mostert, Kidd & Laubscher (2009)
Mara Research Station, Limpopo, RSA	55.5 ± 1.10	46.4 ± 1.10	Van den Berg (2009)
	61.8 ± 3.13	46.9 ± 0.64	Hoffman, Kritzinger & Ferreira (2005)
	61.8 ± 1.00	48.4 ± 0.80	Du Plessis et al (2006)
	77.2 ± 3.70	-	Theobald (2002)
Messina/Musina Experimental Farm, Limpopo, RSA	52.9 ± 0.50	41.2 ± 0.40	Du Plessis et al (2006)
	58.3 ± 3.74	42.1 ± 2.06	Hoffman, Kritzinger & Ferreira (2005)
Ndzalama Wildlife Reserve, Limpopo, RSA	74.0 ± 4.10	73.0 ± 5.10	Theobald (2002)
Northern Transvaal, RSA	57.2 ± 2.83	-	Monro & Skinner (1979)
Nyala Game Ranch, KwaZulu-Natal, RSA	44.2 ± 2.16	40.5 ± 1.50	Anderson (1982)
Overberg Test Range (Denel), Western Cape, RSA	-	42.6 ± 1.8	Van Zyl & Ferreira (2004)
S.A. Lombard Reserve, North West Province, RSA	63.3 ± 2.2	-	Skinner (1971)
Selati Game Reserve, RSA	60.0 ± 3.1	58.0 ± 3.2	Theobald (2002)
Serengeti National Park, RSA	56.9	42.1	Sachs (1967)
Lake Mburo region, Uganda	53.5	-	Averbeck (2002)
Maneze Wildlife Conservancy, Zimbabwe	59.1	44.1	Hoffman (2000)
Ranch near Lake Elmenteita, Kenyan Rift Valley, Kenya	63.5 ± 1.7	-	Bramley & Neaves (1972)

*Abbreviations: RSA = Republic of South Africa.

In another study comparing Mara Research Station to other production regions, Theobald (2002) also found impala from Mara to have the highest undressed carcass weights in both the juvenile and adult age classes of both sexes when compared to impala from Ndzalama Wildlife Reserve and

Selati Game Reserve. The nutritional quality of the browsing material of each location and the internal parasite loads of the impala were compared, and it was found that the browsing material and soil samples at Mara had significantly higher phosphorus (P) concentrations than the other two locations, as well as higher selenium (Se) and copper (Cu) concentrations in the livers of impala. The lower undressed carcass weights of the impala at Selati Game Reserve were attributed to parasitic infection with Bankrupt worm in the livers and intestines of impala in this production region, as the parasites render nutrients in the diets of these animals unavailable, which in turn impairs growth (Theobald, 2002). Parasitic infection is a factor that may have a detrimental effect on the carcass weights of impala and was thought to be the causal factor for the comparatively low mean carcass weight of adult male impala (44.2 kg) recorded at Nyala Game Ranch (Anderson, 1982).

It has been recorded that external parasites such as ticks may negatively impact carcass weights of ungulates by means of loss in weight gain. In cattle, tick infestation can cause a loss of up to 3.1 kilograms in live weight gain per tick per year in developing calves, depending on the species of tick (Mooring, Mckenzie, & Hart, 1996a; Norval, Sutherst, Jorgensen, Gibson, & Kerr, 1989; Norval, Sutherst, Kurki, Gibson, & Kerr, 1988). This loss in weight gain is caused by reduction in energy and nutritional resources due to the extraction of blood by ticks, to which infant ungulates such as impala lambs are particularly vulnerable (Hart, 1990; Mooring & Hart, 1997b). Due to their selective feeding behaviour and consequent close contact with vegetation, impala are exposed to higher ectoparasite loads than bulk grazing animals that primarily feed in the open plains (McKenzie, 1990; Oliver, 2002). To combat this, impala naturally practice a unique form of parasite control by means of reciprocal allogrooming, which facilitates the removal of external parasites (or ectoparasites) such as ticks from one another by means of mutual oral grooming (Hart & Hart, 1992; Mooring & Hart, 1997a; Mooring et al., 1996a). Oral grooming is conducted with upward raking/scraping actions using the lower incisor-canine teeth (Mooring & Hart, 1997a). It has been found that the rate of both self-grooming and allogrooming in impala increases with an increased exposure to ticks, particularly during the warm, wet season when adult ticks are abundant (Mooring & Hart, 1997b; Mooring et al., 1996a). This increase of grooming in tick-dense environments may be caused by tick-bite stimuli in the form of local histamine production or systemic tick saliva absorption (Mooring & Hart, 1997b). When prevented from grooming, the load of ticks present on an impala is substantially higher than on impala allowed to groom freely (Mooring et al., 1996a).

Whilst the natural allogrooming behaviour of impala assists in preventing excessive losses in carcass weights from external parasitic infection, impala are still vulnerable to losses from internal parasitic infections. Anderson (1982) found that impala raised on a relatively small (444 ha) game ranch in KwaZulu-Natal had lower undressed carcass weights than impala raised in large game reserves. The difference in carcass weights between farming locations were speculated to be the result of higher parasite loads found on smaller game farms where the stocking density is high. Higher stocking densities prevent impala from following their natural seasonal movement patterns, consequently decreasing the condition of grazing material and thus resulting in a higher rate of internal parasitic infections (Anderson, 1982). Internal parasites have been found in the rumen and reticulum (*Paramphistomum cotylophorum*), abomasum (*Haemonchus bedfordi,*

Longistrongylus sabie, Trichostrongylus axei, T. colubriformis), small intestine (*Cooperia fuelleborni, Cooperioides hamiltoni, Impalaia tuberculata*, *Strongyloides papillosus, T. colubriformis, T. falculatus*), lungs (*Pneumostrongylus calcaratus*), liver (*Cooperioides hepaticae, Stilesia hepatica, Fasciola gigantica*), caecum and colon (*Gaigeria pachyscelis, Oesophagostomum columbianum, Trichuris globulosa*) of impala in South Africa (Anderson, 1983). The prevalence of parasites in impala was found to be the highest in young animals, followed by a decrease as animals get older and often increased again in very old impala (Anderson, 1983). The prevalence of parasites also differs between production regions: Theobald (2002) found that impala that had limited or no parasitic infections at Mara Research Station had significantly higher undressed carcass weights than impala at Ndzalama Wildlife Reserve or Selati Game Reserve (Table 2.3), with the lower undressed carcass weights of impala from the latter two locations attributed to severe parasitic infections found in the animals.

An analysis of the correlation between parasitic infection rate of impala and game reserve characteristics confirmed that confinement in small fenced areas may amplify rates of parasite cross-transmission due to increased vulnerability of impala to infection caused by increased stress conditions, such as restricted movement and disruption of social structure (Ezenwa, 2004). Infection at a young age may be the cause of consistently lower live weights of impala throughout their lifetimes, regardless of the state of infection at a later stage in life (Anderson, 1982). Furthermore, impala and domestic livestock may be affected by the same parasites and serve as communal sources of infestation (Anderson, 1983). In cattle, infection with liver fluke (*Fasciola hepatica*) results in decreased weight gain caused by decreased feed intake and reduced feed conversion efficiency (Hope Cawdery, Strickland, Conway, & Crowe, 1977). While liver fluke infection only had a detrimental effect on cattle performance during the first six months of infection, no compensatory weight gain was recorded thereafter, thus resulting in lower mean undressed carcass weights than uninfected cattle at the same age (Hope Cawdery et al., 1977). Treatment of low-level liver fluke infections after six months would therefore not present substantial economic benefit in terms of increased production per animal. This loss in weight gain may also be prevalent in impala that are exposed to similar parasites. Conversely, these production losses can only be avoided by preventing initial infection, rather than attempting treatment (Hope Cawdery et al., 1977).

Therefore, it has been recommended that impala in South Africa should be separated from domestic livestock through effective fencing, as the latter is usually more vulnerable to diseases resulting from parasitic infestation (Anderson, 1983). However, a study comparing a game-only production system and a mixed game and livestock system in the same area near Lake Mburo found that the faecal parasite egg counts of impala did not differ between the two systems (Ocaido, Siefert, & Baranga, 1999). Although seasonal changes caused overall fluctuations in the faecal egg counts of impala in both systems, with a peak in the rainy summer season, the population densities of the two systems did not differ and may account for the lack of differences in impala faecal parasite egg counts between systems. This is in agreement with previous findings that increased parasite loads are related to higher population densities and higher rainfall (Anderson, 1982; Ocaido et al., 1999), while impala are increasingly vulnerable to infectious diseases and

parasitic infections as the size of the camps decreases and the intensity of camp systems increases (Furstenburg, 2016).

For treatment of a variety of internal parasites in impala, it is recommended that non-toxic, soluble anti-helmintics (e.g. fenbendazole or albendazole) could be provided in the form of medical mineral licks or added to watering points. To monitor the infection status of animals, faeces should be collected and analyzed for parasite load, particularly for animals that are newly transported to the game ranch. These animals should be kept under quarantine until treatment has effectively reduced parasitic infections (Anderson, 1983). Rotational grazing can also be practiced as an effective treatment and preventative measure by improving the condition of pasture and reducing parasitic contamination thereof as a result, thereby circumventing the complications that ensue from the high stocking densities that often occur on game farms (Anderson, 1983; Furstenburg, 2016; Hope Cawdery et al., 1977).

2.3.2.3 Dressing percentages and offal yields

The dressing percentage of an animal is obtained by expressing the dressed carcass weight as a percentage of the live weight (also known as undressed carcass weight or body weight). While higher dressing percentages are more desirable as they are indicative of a lower offal and higher meat yield, dressing percentages can vary significantly between different animal species due to differences in internal and external offal yield (Van Zyl & Ferreira, 2004). Dressing percentages may also vary substantially within the same species due to intrinsic and extrinsic factors, as was found when comparing the dressing percentages of impala obtained by various authors. The lowest mean dressing percentage was obtained for nine-month-old male impala in the Kruger National Park (53.1 %; Fairall, 1983), while the highest mean dressing percentages were recorded for 54-month-old male impala from Mara Research Station (65.6 %; Hoffman et al., 2005b) and for 36-month-old female impala from the Overberg Test Range (Denel) near Bredasdorp (66.3 %; Van Zyl & Ferreira, 2004).

Differences in the dressing percentages of animals from the same species may be due to a variety of factors. One factor that has a substantial influence is differences in the methodology used to obtain or calculate the dressing percentages between authors. These differences also complicate the comparison of game animal dressing percentages to those of domestic livestock, which often have restricted feed intake prior to culling and consequently decreased intestinal content at time of slaughter. The dressed weights of game animals also often include the weight of the skin, as carcasses are generally transported with the skin on. This influences the undressed carcass weights of livestock and as a result, the dressing percentages (Hoffman, 2000b). Nonetheless, the information on carcass yields (weights) of game species such as the impala is of value to the industry and researchers as it gives a better indication of the weight of carcasses from this species when predictions are made on how much meat various wild animals can provide. Furthermore, the methodology used for calculating the dressing percentages of impala has largely been standardized in most studies on impala carcass yields (Du Plessis et al., 2006; Fairall, 1983; Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009; Van den Berg, 2009), and comparisons can be made

between factors that may influence the dressing percentage of this species.

No significant differences have been found between male and female impala for dressing percentages despite the significantly heavier carcass weights of males compared to that of females (Hoffman, 2000b; Hoffman et al., 2005b). The lack of sexual dimorphism for the dressing percentages of impala may be attributed to the higher amounts of intramuscular fat, kidney fat and subcutaneous fat that were observed for female impala. Furthermore, the presence of horns in male impala causes the weight of their heads to contribute a larger percentage to the external offal than the heads of females. Male impala were also found to have heavier mean visceral weights (Hoffman, 2000b; Hoffman et al., 2005b).

The dressing percentages of impala have been found to differ significantly between production regions. Both male and female impala obtained from Mara Research Station were found to have significantly higher mean dressing percentages (61.0-63.2 %) than impala from Musina Experimental Farm (55-60.3 %) when comparing the same 30-42-month-old age groups (Hoffman et al., 2005b). These differences were attributed to the unusually visible subcutaneous fat layer of the impala from Mara Research Station, with the exceptionally good body condition of these animals caused by high quality grazing for two seasons in a row due to favourable rainfall conditions (Hoffman et al., 2005b). While Musina Experimental Farm and Mara Research Station are both situated in the Limpopo Province of South Africa, the Arid Sweet Bushveld vegetation of the latter region (Mucina & Rutherford, 2006) was better suited to the natural habitat of impala and provided grazing material of higher nutritional quality. Consequently, more energy was available for the development and growth of impala in this region, resulting in higher carcass weights, improved physical condition and higher dressing percentages (Hoffman et al., 2005b). These findings reiterate the importance of diet and feeding management across different production regions and within production systems for the meat production potential of impala. Due to the lack of research on different production systems (intensive, semi-extensive and extensive), this area would require further investigation.

A mean pooled dressing percentage of 59.4 % was calculated for all impala from the dressing percentages obtained by previous authors (Addendum I). The dressing percentages obtained for impala in various research studies were consistently higher than the dressing percentages recorded for domestic livestock, which has been reported to range from 50.3 to 53.8 % for cattle (Nguni, Bonsmara, Angus; Muchenje, Dzama, Chimonyo, Raats, & Strydom, 2008) and 41.5 to 44.2 % for sheep (South African Mutton Merino and Dormer sheep; Cloete et al., 2004). Furthermore, impala generally have little to no subcutaneous fat layers (Fairall, 1983; Hoffman, 2000b), unlike the thick layer of subcutaneous fat often found in domestic livestock. Therefore, in addition to the higher mean dressing percentages of impala, this game species also produces a higher lean meat yield than domestic livestock.

The slaughter of game animals for meat production produces edible by-products in the form of internal and external offal. External offal of game animals typically consists of the un-skinned head (containing horns and tongue) and feet, the skin, and in some cases, the skinned tail (Ledger, 1963). The internal offal is comprised of the heart, lungs and trachea, liver, kidneys, oesophagus,

stomachs (rumen, reticulum, omasum and abomasum), and intestines (Ledger, 1963). In the red meat industry, the cleaned edible internal offal of domestic livestock is utilized as a food source by low-income consumers (McCrindle et al., 2013). However, there is a lack of literature on similar utilization of offal from game species in South Africa. When considering that impala have a pooled mean dressing percentage of 59.4 %, the uncleaned offal yield forms 40.6 % of the undressed carcass weight. Furthermore, when expressed as a percentage of the body weight without the stomach and intestinal contents, the internal offal of impala comprised 20.6 ± 2.0 % and the external offal comprised 13.1 ± 0.5 % (Van Zyl & Ferreira, 2004). McCrindle et al. (2013) found that every impala culled yielded approximately three kilograms of edible offal, comprised of selected internal organs, cleaned intestines and meat from the feet and heads. In addition, Van Zyl & Ferreira (2004) recorded a proportional crude protein content of 19.3 ± 4.0 % for the internal offal of impala, which is similar to that obtained for sheep (16.5-23.5 %). Considering the high proportional protein content and the relatively large yield of offal, the edible offal produced by impala has the potential to contribute to the food security of low-income South African communities. However, to effectively utilize the edible offal of impala, food safety inspection practices will have to be implemented and marketing channels for the edible offal will have to be developed (McCrindle et al., 2013).

2.3.2 Impala meat quality

Meat quality generally refers to the inherent characteristics of meat which determine the suitability of meat for consumption, additional processing and storage that includes retail display (Andersen, Oksbjerg, Young, & Therkildsen, 2005). The primary attributes determining the quality of meat from both domestic livestock and game species can be divided into physical (pH, water-holding capacity, surface colour, tenderness), chemical (nutritional composition comprised of moisture, protein, intramuscular fat and ash content) and sensory (aroma, flavour, and texture) meat quality attributes (Andersen et al., 2005; Hoffman, 2000b; Issanchou, 1996). Meat quality is influenced by a variety of *ante-* and *post-mortem* factors, including species, age, sex, environmental and nutritional conditions, slaughter conditions and *post-mortem* processing of meat and meat products (Hocquette et al., 2010; Listrat et al., 2016). These factors also affect the composition and structure of various skeletal muscle types, which in turn influences meat quality and may largely involve direct relationships between intramuscular biological characteristics and meat quality traits (Listrat et al., 2016). To improve market competition with traditional meat types and the overall meat quality of meat from game animals, such as the impala, it is important to determine all aspects of the physical, chemical and sensory meat quality of this species (Hoffman, 2000b; Kohn et al., 2005).

2.3.2.1 Physical meat quality

The physical meat quality of domestic livestock and game animals can be evaluated in terms of acidity (pH), meat surface colour, water-holding capacity (WHC), and tenderness using the standardized methodologies as published by Honikel (1998). These methodologies can be used as a quality assurance tool and an assessment of treatment effectiveness for international comparisons of the meat quality of animals from different countries or species, as well as for comparisons between

different slaughter ages, sexes, diets, and production systems within the same species (Honikel, 1998). The influence of different treatments on the physical meat quality attributes of impala has been investigated by previous researchers (Hoffman, 2000a; Hoffman & Laubser, 2009; Hoffman et al., 2009; Kritzinger et al., 2003; Van den Berg, 2009), and a compilation of their results is presented in Table 2.4 and 2.5.

The acidity of meat is determined by measuring the pH at predetermined times after slaughter. The pH_{45} value of meat (measured at 45 minutes *post-mortem*) provides a more accurate indication of the pH of the muscle at the point of slaughter and can be used to estimate the rate of pH decline (Hoffman, 2000a). The ultimate pH (pH_u) value of meat (measured ± 24 hours *post-mortem*) is a direct result of the muscle glycogen (energy) levels at slaughter and provides information on the physical quality of meat as pertaining to colour, water-holding capacity, shelf-life and tenderness (Wiklund, Manley, & Littlejohn, 2004). The ideal ultimate pH range of meat is 5.5-5.7, which is the result of sufficient glycogen content of the muscles of animals in good physical condition (Wiklund, Johansson, & Malmfors, 2003). However, final pH ranges of 5.4-6.0 have been reported for non-stressed animals, with variation depending on the concentration of muscle glycogen and type of muscle (Honikel, 2004), while the normal pH_u range for beef is considered to be 5.5-5.8 (Immonen, Ruusunen, & Puolanne, 2000). In addition to the pH_u values, the rate of pH decline is also important for physical meat quality, with moderate rates of pH fall associated with more tender *Longissimus thoracis et lumborum* (LTL) steaks, whereas tough meat is often a consequence of a rapid pH fall (Marsh, Lochner, Takahashi, & Kragness, 1981).

The rate of pH decline in impala meat has been shown to be significantly influenced by the culling method (day culling vs. night culling) by two separate studies. Day culling is a conventional method of hunting game animals on foot during daylight hours, whereas night culling is the hunting of animals from a vehicle with the use of spotlights during the night (Hoffman & Laubser, 2009; Kritzinger et al., 2003). Both studies found that conventional day hunting resulted in significantly increased rates of pH decline compared to night culling. This is attributed to the increased physical activity and *ante-mortem* stress experienced by impala during the day, resulting in an increased duration of high glycolytic enzyme activity and consequently a more rapid pH fall (Hoffman & Laubser, 2009; Kritzinger et al., 2003). In contrast, night culling is considered to be a more efficient hunting method in terms of reducing *ante-mortem* stress for animals during culling (Lewis, Pinchin, & Kestin, 1997).

Ante-mortem stress and unaccustomed exercise may cause the depletion of glycogen and lower lactic acid production in muscles, with consequently high pH_u values (> 6.06) that may result in the production of meat that is dark, firm, and dry (DFD) (Honikel, 2004; Shange, Gouws, & Hoffman, 2019; Viljoen, de Kock, & Webb, 2002). In addition to the culling method, Von La Chevallerie & Van Zyl (1971) found that *ante-mortem* stress is also related to shot placement in impala. While neck and head shots cause animals to drop instantly, shots placed in the shoulders, rib or back of antelopes may cause them to run for considerable distances and experience substantial *ante-mortem* stress, which in turn may negatively impact meat quality (Von La Chevallerie & Van Zyl, 1971). These findings were confirmed in a later study, where a wounded impala was found to

have a rapid pH decline and an abnormally high pH_u (> 6.0), which resulted in DFD characteristics including an undesirable dark surface colour and a high water-binding capacity (Hoffman, 2000a). Therefore, correct culling methods will prevent the reduction in meat quality that is caused by excessive *ante-mortem* stress, imprecise shot placement, inadequate exsanguination, and insufficient reduction of carcass temperatures post-slaughter (Hoffman, 2003, as cited by Hoffman et al., 2004).

Hoffman (2000a) found sex to have a significant effect on both the pH_{45min} and the pH_u values of impala meat, with higher mean values recorded for males than for females (Table 2.4). These differences were ascribed to the overall more active response to disturbances shown by male impala compared to that of females (Lewis et al., 1997), as well as to the heightened state of excitement observed in male impala that had reached the end of their rutting season just prior to slaughter (Hoffman, 2000a). The heightened physical activity of males will deplete more glycogen, resulting in reduced lactic acid production and a consequently higher pH_u. While a similarly higher pH_u was found in male impala than females for the *triceps brachii* (TB) muscle by Van den Berg (2009), no significant differences were found between sexes for the pH_u of the *semitendinosus* (ST), *longissimus dorsi* (LD), *semimembranosus* (SM) or *biceps femoris* (BF) muscles. However, the male impala were found to have higher mean pH values than females at 0.75, 3, 6, and 12 hours *post-mortem* when all measurements were pooled (Van den Berg, 2009). Even so, the inherent physical meat quality properties of the different muscles of male and female impala have yet to be established, and the pH_u values of other commercially important muscles are yet to be determined.

The water-holding capacity of meat is the ability of meat to retain water. The majority of water present in meat is maintained in the space between thick and thin muscle filaments (Offer et al., 1989). Water-holding capacity is an important aspect of physical meat quality that is related to pH_u, with the minimum point of water binding capacity reached at the iso-electric point (at pH 5.4 to 5.5) of meat. The pH_u of meat is generally reduced to approximately 5.4-5.5 due to post-slaughter glycolysis in the muscles, and therefore the loss of some moisture is unavoidable due to the loss of water-holding capacity of meat (Lawrie & Ledward, 2006). High rates of pH fall and low pH_u are tied to the development of low water-holding capacity in meat and consequently an undesirably high moisture loss (Huff-Lonergan & Lonergan, 2005). Large amounts of moisture loss in the form of drip loss (which can be observed as bloody liquid in the packaging) is perceived negatively by consumers, and therefore an important aspect of meat production is striving to minimize the moisture loss in meat (Troy & Kerry, 2010). Another form of moisture loss in meat can occur as cooking loss, which is moisture lost when meat is cooked. During the cooking of meat, the heating process alters the chemical and physical properties of the meat and consequently results in fluid loss (Hamm & Deatherrage, 1960). Low cooking loss percentages are associated with improved meat quality and greater juiciness in cooked meat due to higher amounts of moisture being retained in the meat (Sebsibe, 2008).

An inverse relationship exists between the water-holding capacity and the pH_u of meat, with a decreased amount of moisture loss often found in meat with a higher pH_u (Lawrie & Ledward, 2006; Shange et al., 2019). Hoffman et al. (2009) recorded a significant negative correlation (r = -

0.277; P = 0.023) between the pH_u and cooking loss percentage of the LD of both impala and kudu. While a similar tendency was found between pH_u and drip loss percentage (*r* = -0.227; P = 0.071), the correlation was not significant (Hoffman et al., 2009). While no correlations were calculated, the lowest cooking loss percentages (23.5-24.5 %) can be observed in impala with the highest pH_u (5.7-5.8; Hoffman, 2000a), indicating that there was also an inverse relationship between moisture loss and pH_u for impala meat in the latter study (Table 2.4). However, Hoffman & Laubser (2009) found no significant correlations between pH_u and the cooking loss or drip loss percentages of impala LD muscles. With these correlations tested in only two of the research studies on impala meat quality (Hoffman & Laubser, 2009; Hoffman et al., 2009), further research is required to establish if inverse relationships between pH and moisture loss exist for all impala meat, or if such correlations differ depending on *ante-mortem* factors that may influence impala meat quality.

The drip loss percentages of impala meat were only found to be affected by the culling method at Mara Research Station (Kritzinger et al., 2003), where night culling resulted in a significantly lower mean drip loss percentage than day culling (Table 2.4). This phenomenon was be attributed to the higher pH_{45} values found in night-culled impala and increased *ante-mortem* stress experienced by day-culled impala, with differences in pH persisting even after standardization of temperature differences between treatments to negate the influence of differences in cooling rate (Kritzinger et al., 2003). Van den Berg (2009) found a significant difference between sexes for the cooking loss percentage of impala, which was observed to be higher in males than in females at Mara Research Station. However, no similar differences were recorded between sexes at Maneze Wildlife Conservancy, nor between different culling methods or levels of electrical stimulation (Table 2.4). The disparities between research findings may be attributed to several factors known to influence the physical meat quality of game animals, particularly age at slaughter and production system, both factors which were not standardized across research studies. It would be recommended that the moisture loss of male and female impala should be determined for animals at the same slaughter age and raised in the same production system to rule out the effect of all intrinsic and extrinsic factors except the influence of sex.

Overall, the moisture loss of impala LTL meat ranged from 1.2-4.8 % (mean of 3.5 %) for drip loss and 23.5-33.0 % (mean of 29.2 %) for cooking loss across all treatments in previous research (Table 2.4). It should be noted that all values obtained for drip loss (4.3-4.8 %) by Van den Berg (2009) are higher than the 2.5-2.9 % drip loss range found in previous research studies (Table 2.4), except for the very low 1.2 % obtained for impala in the Mabula district of Limpopo (Hoffman et al., 2009). The high drip loss values obtained by Van den Berg (2009) are similar to the 4.2 ± 2.34 % obtained for day-culled animals from the same location at Mara Research Station (Kritzinger et al., 2003). Since the same daytime culling method was utilized for both studies at Mara and for the 3.7 ± 0.54 % drip loss obtained for day-culled impala at Leeukop Game Ranch (Table 2.4), it would indicate that culling method has a significant effect on the drip loss percentage of impala meat overall. The higher drip loss percentage (3.7-4.8 %) of all day-culled impala also indicate that the meat produced by means of this culling method would be less juicy than the meat of night-culled impala (2.5-2.9 %; Table 2.4). The drip loss percentages of night-culled impala also

compare favourably to the values reported for pork (2.4-2.6 %; Fisher, Mellett, & Hoffman, 2000) and are lower than those recorded for beef cattle (4-6 %) by Hornick et al. (1998). While no clear trend was apparent for cooking loss, the 29.2 % pooled mean cooking loss percentage of impala meat is relatively similar to the 22-27 % of beef (Hornick et al., 1998) and the 27 % of pigs (Fisher et al., 2000). It can therefore be concluded that the meat from this game species is no less juicy than traditional red meat.

The tenderness of meat is one of the most important parameters of meat quality for consumers, as it is related to the palatability of meat and thus influences consumer experience and acceptance (Troy & Kerry, 2010; Von La Chevallerie, 1972). Meat tenderness is influenced by variation in *ante-mortem* treatment, species and sex of animals, as well as the extent of proteolysis (primarily by calpains) on structural proteins, collagen content and degree of muscle fibre shortening in the meat *post-mortem*, all which influence meat pH_u and consequently meat tenderness (Dransfield, 1993; Offer et al., 1989; Troy & Kerry, 2010). The tenderness of meat is determined by measuring the Warner-Bratzler shear force (WBSF) values of cooked meat, with lower shear force values representing increased meat tenderness. The shear force values of meat tend to increase as the meat pH_u increases from 5.5 to 6.1, after which the shear force values decrease with an additional rise in pH_u of up to 7.0 (Purchas & Aungsupakorn, 1993). While the exact cause of the curvilinear relationship between pH_u and meat tenderness has yet to be determined, it has been speculated that the activity of proteolytic enzymes is reduced between a pH_u of 5.8-6.3, whereas the activity of calpains peak from a pH_u of six to seven (Purchas & Aungsupakorn, 1993). The influence of pH_u on tenderness is apparent in impala meat, as was found by the strong positive correlation (r = 0.75; P = 0.008) calculated between the pH_u and shear force values of impala meat across all treatments, based on the values obtained by previous researchers (Table 2.4). This correlation means that an increase in the pH_u will be accompanied by an increase in the shear force values, and consequently a decrease in the tenderness of impala meat. This can be observed with the lowest shear force values (1.6-2.3 kg/1.27 cm Φ) and thus most tender meat found in impala with the lowest pH_u values (5.39-5.55) in Table 2.4. However, the pH_u values of impala meat obtained from previous research only reached a maximum of 5.8 (Table 2.4; Hoffman, 2000a) and thus the response of impala meat tenderness to higher pH_u values has yet to be established.

Contrasting results were found for the tenderness of impala meat in two studies comparing culling methods (night vs. day). Kritzinger et al. (2003) found a significantly higher mean shear force value in day-culled impala, while Hoffman & Laubser (2009) found night-culled impala to have a higher mean shear force value than day-culled impala (Table 2.4). In both studies, the causal factor for higher tenderness was speculated to be the slower rate of pH decline in night-culled impala. However, Kritzinger et al. (2003) stated that the slower pH decline caused the meat of night-culled impala to be tenderer, while Hoffman & Laubser (2009) stated that the slower rate of decline resulted in reduced tenderness in night-culled impala. In the latter study, no differences were found between culling methods for the pH_{45} or the pH_u, but a significant negative correlation (r = -0.66; P = 0.004) was found between the rate of pH decline and tenderness (Hoffman & Laubser, 2009). While no such correlation was recorded for the former study, the pH_u values were significantly

higher in day-culled impala (Kritzinger et al., 2003). In addition, the rates of pH decline for night- and day culling were relatively similar (day-culled = -0.58; night-culled = -0.45; Kritzinger et al., 2003) when adjusted for temperature, whereas the temperature-adjusted rates of pH decline obtained by Hoffman & Laubser (2009) differed by a much larger margin (day-culled = -0.385; night-culled = -0.184). Therefore, it may be speculated that the significantly higher shear force values of day-culled impala in the study by Kritzinger et al. (2003) may be caused by the positive correlation to the pH_u value, whereas the differences in shear force found by Hoffman & Laubser (2009) are due to the strong negative correlation found between the rate of pH decline and meat tenderness. These results demonstrate the importance of both the pH_u and rate of pH decline in the tenderness of impala meat. Furthermore, it is necessary to adjust for temperature differences when comparing the rate of pH decline, as the latter is correlated with the rate of temperature decline (or cooling), and the cooling rate of carcasses is generally faster during the night than during the day (Kritzinger et al., 2003). The cooling rate of a carcass has an influence on the degree of cold-shortening during the onset of *rigor mortis* and may affect the rate of meat tenderization due to its influence on the activation of proteolytic enzymes (Bailey, 1972; North, 2014).

While the tenderness of impala meat did not differ significantly between sexes, age groups or between electrically stimulated and non-electrically stimulated LTL muscles (Table 2.4), tenderness was significantly influenced by muscle (Mostert, 2007). In a comparison of five different muscles (LD, BF, SM, ST, and SS) of impala to that of kudu, Mostert (2007) found a significant species-muscle interaction for meat tenderness. The more tender muscle was the SS muscle from the forequarter, followed by the ST from the hindquarter, the LD from the back, and then the BF and SM muscles from the hindquarter in impala (Mostert, 2007). The comparative tenderness of selected impala muscles differed from that of kudu meat, in which tenderness was found to be the highest in the SS, followed by the BF, ST, LD and SS (Mostert, 2007), whereas springbok meat was the most tender in the LL (*Longissimus et lumborum*), followed by the RF (*Rectus femoris*), BF, ST and SS (Du Buisson, 2006). These differences show that species may have a substantial influence on muscle tenderness, and that tenderness differs significantly between muscles within a species. The grain and texture of skeletal muscles are largely influenced by the size of the muscle fibre bundle and the muscle fibre type, with the properties of the latter depending on the myosin heavy chain (MHC) isoforms that are expressed (Kohn et al., 2005; Lawrie & Ledward, 2006). In a study on the characteristics of four impala muscles (*Psoas major*/PM, *deltoideus*/D, LL and SM), Kohn et al. (2005) found that the muscles express different proportions of MHC isoforms, which are influenced by slaughter age, live weight and potentially by farming practices, which in turn has an influence on meat quality. However, the influence of different farming practices and production systems on the meat quality of impala has yet to be determined and should therefore be investigated. Additionally, while the shear force values of the IS muscle of impala has yet to be determined, this muscle was found to be the most tender in both eland and blue wildebeest (Laubser, 2018; Van Heerden, 2018) and therefore merits further research for the comparison of all six muscles in impala.

Overall, the Warner-Bratzler shear force values of impala LTL muscles ranged from 1.6-4.7 kg/1.27 cm Φ (Table 2.4). In comparison to the tenderness of other game species, impala meat

was found to be less tender than the LTL of blue wildebeest (4.9 ± 0.27 kg/1.27 cm Φ; Van Heerden, 2018), and comparable to the LTL muscle of kudu (4.1 ± 0.15 kg/1.27 cm Φ; Hoffman et al., 2009), mountain reedbuck (3.0 kg/1.27 cm Φ; Hoffman et al., 2008) and springbok (1.7-2.7 kg/1.27 cm Φ; Hoffman, Kroucamp, & Manley, 2007). The shear force values of impala LTL muscles are also similar to that of pigs (3.0 kg/1.27 cm Φ; Fisher et al., 2000) and beef (3.4 kg/1.27 cm Φ; Belew, Brooks, McKenna, & Savell, 2003). These values indicate that the tenderness of impala meat is equivalent to that of domestic livestock and thus do not have the Warner-Bratzler shear force values that would be expected for meat that is tough. Tough meat has been classified as meat with shear force values higher than 4.9 kg/1.27 cm Φ, which is considered undesirable by consumers and has been shown to lower the retail value of the meat (Miller, Carr, Ramsey, Crockett, & Hoover, 2001).

While the tenderness of impala meat compares favourably to that of domestic livestock, the shear force value range obtained for impala meat by previous authors (1.6-4.7 kg/1.27 cm Φ; Table 2.4) is still relatively wide, with the highest values close to the 4.9 kg/1.27 cm Φ threshold that is considered undesirably tough to consumers (Miller et al., 2001). One method that may improve tenderness and decrease the variation in Warner-Bratzler shear force values of impala meat may be the utilization of *post-mortem* ageing, which is the process of ageing refrigerated meat to achieve optimum tenderness (Dransfield, 1993). *Post-mortem* ageing improves the tenderness of meat by causing loss of tissue integrity due to numerous changes in the micro- and ultrastructure of muscle fibres caused by the degeneration of proteins by endogenous proteinases (Nowak, 2011). *Post-mortem* ageing has long been proven to increase the tenderness of meat from traditional livestock species such as beef (Monsón, Sañudo, & Sierra, 2005), and has recently been shown to have a similar effect on game meat from species such as eland (Laubser, 2018), springbok (North & Hoffman, 2015) and blue wildebeest (Van Heerden, 2018). In addition to improving tenderness, ageing can also influence other meat quality attributes such as juiciness, aroma and flavour (Monsón et al., 2005). However, the effect of *post-mortem* ageing has not yet been investigated for the meat of impala, and thus highlights an area to be researched.

Table 2.4 Mean values for the physical meat quality parameters of impala (*Aepyceros melampus*).

Location	Age	Muscle	Sex	n	Treatment	pH_{45}	pH_u	Drip loss (%)	Cooking loss (%)	WBSF[a] (kg/1.27cmΦ)	Reference
Maneze Wildlife Conservancy, Zimbabwe	8-48+ months	LT[b]	Male	8	Sex	7.3 ± 0.06*	5.8 ± 0.13*	2.5 ± 1.36	24.5 ± 1.39	4.1 ± 0.51	#1
			Female	8	Sex	7.1 ± 0.11*	5.7 ± 0.07*	2.7 ± 1.10	23.5 ± 1.45	3.2 ± 0.24	
Mabula District, Limpopo, RSA	Adult & sub-adult	LD[d]	Both	16	Compared to kudu	-	5.6 ± 0.03	1.2 ± 0.13	31.0 ± 0.46	4.1 ± 0.15	#2
Mara Research Station, RSA	Random	LL[c]	Both	24	Night-culled	6.7 ± 0.11	5.4 ± 0.08	2.9 ± 1.60	33.0 ± 5.11	1.9 ± 0.57	#3
				12	Day-culled	6.6 ± 0.24	5.5 ± 0.11	4.2 ± 2.34	32.9 ± 4.10	2.3 ± 0.81	
Leeukop Game Ranch, RSA	8-20 months	LD	Both	9	Night-culled	6.4 ± 0.13	5.7 ± 0.06	2.8 ± 0.50	27.4 ± 0.51	4.7 ± 0.20	#4
			Both	9	Day-culled	6.4 ± 0.13	5.7 ± 0.06	3.7 ± 0.54	28.0 ± 0.55	4.3 ± 0.17	
Mara Research Station, RSA	-	LDL[e]	Both	20	ES[f]	-	5.5 ± 0.02	4.5 ± 0.30	30.1 ± 0.70	1.6 ± 0.08	#5
			Both	20	NES[g]		5.5 ± 0.03	4.6 ± 0.30	30.5 ± 0.50	1.8 ± 0.09	
			Male	20	Sex (ES + NES)		5.6 ± 0.02	4.3 ± 0.30	31.2 ± 0.50	1.7 ± 0.09	
			Female	20	Sex (ES + NES)		5.5 ± 0.03	4.8 ± 0.30	29.4 ± 0.60	1.7 ± 0.09	

[#1]Hoffman, 2000a; [#2]Hoffman et al., 2009 [#3]Kritzinger et al., 2003; [#4]Hoffman & Laubser, 2009; [#5]Van den Berg, 2009.

Abbreviations: [a]WBSF = Warner-Bratzler shear force; [b]LT = *Longissimus thoracis*; [c]LL = *Longissimus Lumborum*; [d]LD = *Longissimus dorsi*; [e]LDL = *Longissimus dorsi et lumborum*; [f]ES = Electrical stimulation; [g]NES = Non-electrical stimulation.

*pH_{45} and pH_u measured in the *Semitendinosus* (ST) muscle of the hindquarters in the study by Hoffman (2000a).

The surface colour of meat is an intrinsic quality cue that plays an important role in consumer acceptance, as it is often used as an indication of "freshness" of the meat (Issanchou, 1996; Mancini & Hunt, 2005; Troy & Kerry, 2010). Consumers prefer a bright, cherry-red colour in red meat types, while a brownish discolouration is considered unacceptable (Mancini & Hunt, 2005; Neethling, Suman, Sigge, Hoffman, & Hunt, 2017). With the increasing global demand for fresh meat from various game species, fresh meat from species such as the impala has considerable market potential (Hoffman & Cawthorn, 2013; Hoffman & Wiklund, 2006). However, a common misconception among consumers is that meat from South African game animals generally have a dark, unattractive red colour, similar to beef with DFD-like (Dark, firm, dry) characteristics and thus equate game meat with similar eating quality to DFD beef (Hoffman, Muller, Schutte, Calitz, & Crafford, 2005; Hoffman et al., 2004; Scanga, Belk, Tatum, Grandin, & Smith, 1998). This misperception is most likely the result of the limited information available on the surface colour attributes of game meat, which creates the necessity to determine these characteristics and the factors that influence them for the establishment of baseline data on game species of interest (Neethling et al., 2017).

The colour measurements of impala meat have been investigated (Table 2.5). The measurements were taken in accordance with the CIE Lab colour system, which reported values according to lightness (CIE L*), red-green spectrum (CIE a*) and blue-yellow spectrum (CIE b*). No significant differences were found between sexes for any of the colour measurements, nor between culling methods for the L* values, b* values and hue-angle values, or between slaughter age and the a* values and b* values (Table 2.5). However, the sub-adult impala were found to have a significantly lighter meat colour than adults (Mostert, 2007), with similar findings recorded for the LTL muscles of other game species such as kudu (Mostert, 2007) and blue wildebeest (Van Heerden, 2018). The darker colour of meat in adult animals may be caused by changes in the extent of protein denaturation and muscle structure with muscle development as animals become older, which in turn influences the scattering of light. A further explanation may be the increase in the myoglobin (MB) concentration of meat as the animal ages (Cho, Kang, Seong, Park, & Kang, 2015; Humada, Sañudo, & Serrano, 2014). The concentration of MB influences the perceived surface colour of meat, and as a consequence, older animals will have meat that appears darker (higher L* values) due to increased MB concentrations (Kranen et al., 1999; Warriss, Brown, Adams, & Lowe, 1990). This effect of slaughter age may also be observed with the L* values of impala across different studies (Table 2.5), with higher values found in younger impala at eight to 20 months old, whereas impala with a higher mean age (range of eight months to > 4 years) produced meat with lower L* values. Day-culled impala were reported to produce significantly redder meat than night-culled impala by Hoffman & Laubser (2009), whereas Kritzinger et al. (2003) found no significant differences between culling methods for the a* values of impala (Table 6.5). The significant differences in a* values found by Hoffman & Laubser (2009) were attributed to the higher (although not significant) L* values of day-culled impala. However, the small sample size (n = 17; Table 2.5) may have an influence on the significance of the results, whereas a larger sample size will be more likely to provide a more accurate representation of the influence of the different treatments.

The lack of differences between sexes for all surface colour parameters in impala LTL muscles is in accordance with findings on other game species, with no significant differences in LTL colour measurements found between sexes in kudu (Hoffman et al., 2009), mountain reedbuck (Hoffman et

al., 2008), roe deer (Daszkiewicz et al., 2012), or eland (Laubser, 2018). It was speculated that the lack of differences in the surface colour of these game species may be due to a lack of differences in myoglobin concentration and daily physical activity between the male and female animals within each species (Hoffman et al., 2009). The higher mean values obtained for impala LTL muscles at Mara Research Station for both the b* values and a* values (Kritzinger et al., 2003) than for impala at other farm locations (Table 2.5) may be the result of the lower pH_u values (5.4-5.5; Table 2.4) recorded for impala at Mara. The surface colour of meat is influenced by both the pH_u and the rate of pH decline after slaughter, with high pH_u values generally resulting in darker meat, whereas a lower pH_u leads to meat with a lighter, redder colour (Lawrie & Ledward, 2006; Neethling et al., 2017; Shange, Gouws, & Hoffman, 2019). The inverse relationship between pH_u and the surface colour of meat was observed by Hoffman et al. (2009), whom found significant negative correlations between the pH_u and the L* values (r = -0.368; P = 0.002), the a* values (r = -0.433; P < 0.001) and the b* values (r = -0.441; P < 0.001) for the LD muscle of both impala and kudu.

In a study comparing the physical meat quality of impala and kudu culled during the same period on the same farm, Mostert (2007) found a significant interaction between species and muscle (LD, BF, SM, ST, and SS) for the L* values. The LD and SM muscles of impala had significantly higher L* values than that of kudu, while the BF, ST and SS did not differ significantly between species (Mostert, 2007). While no further species-muscle interactions were recorded for the other surface colour measurements, significant differences were found between the selected muscles for the pooled results of impala and kudu. The SS was found to be the reddest muscle (a* = 13.7 ± 0.18), while the ST had the highest b* values (b* = 10.1 ± 0.15), with the highest chroma values (16.4-16.7) observed in both the SS and ST muscles (Mostert, 2007). These differences may be the results of the different inherent properties of the muscles, as the SS is known as a “red muscle” due to the high content of oxidative muscle fibres, high concentration of connective tissue and low protein content associated with this muscle (Lawrie & Ledward, 2006). However, the surface colour measurements of the IS muscle of both male and female impala has yet to be investigated.

An important factor that may influence the physical colour measurements of impala is production system. The colour and colour stability of meat can be influenced by intensive (concentrate/feedlot/grain) or extensive (forage/grass/pasture) production systems by means of feeding strategy (Neethling et al., 2017). This may also be applicable to production region, where different regions are characterized by different natural vegetation and consequently different dietary regimes for impala raised in each region (Hoffman et al., 2005b). In addition, the recent intensification of production systems for game species from extensive (natural vegetation only) to semi-extensive or intensive production systems is often associated with the provision of supplementary feed, or in some cases, complete replacement of pasture in favour of specially formulated diets to improve animal productivity (Taylor et al., 2016). Diet can have a significant influence on the surface colour of meat due to its influence on the pH of muscles. It has been reported that pasture-raised beef cattle may have increased meat pH_u values as a consequence of inadequate energy intake, a phenomenon that may also be the cause of differences between production systems (Daly, Young, Graafhuis, Moorhead, & Easton, 1999; Neethling et al., 2017). Furthermore, animals raised in extensive systems have reduced contact with humans and may thus be more vulnerable to *ante-mortem* stress (Daly et al., 1999). The low glycogen

content and resulting decreased lactic acid production in muscles caused by *ante-mortem* stress results in a high (> 6.0) pH_u, which in turn significantly influences the surface colour of meat due to greater water-holding capacity and reduced light reflection (Neethling et al., 2017; Shange et al., 2019). The influence of production system on meat surface colour has recently been observed in blue wildebeest meat, for which significant interactions were recorded between production system (extensive vs. semi-extensive) for the a*, chroma and hue-angle colour parameters (Van Heerden, 2018), and thus merits similar research in impala, which are often managed in intensive and semi-extensive breeding systems.

Overall, impala meat had the following range for surface colour measurements across various studies: L* = 28.3-32.8; a* = 10.4-13.2; b* = 7.1-9.4; hue = 33.7-36.4°; chroma = 12.8-16.0 (Table 2.5; Hoffman & Laubser, 2009; Mostert, 2007). These values are comparable to the measurements obtained for the LTL muscles of other game species, such as kudu (L* = 30.3-33.2; a* = 11.0-11.9; b* = 8.5-8.7; Mostert, 2007), eland (L* = 32.3-37.5; a* = 12.0-15.5; b* = 10.6-12.9; Laubser, 2018), blue wildebeest (L* = 30.6-33.8; a* = 10.9-15.1; b* = 7.3-9.7; Van Heerden, 2018), and black wildebeest with a normal pH range (L* = 33.1; a* = 13.6; b* = 10.3; Shange et al., 2019). In comparison to domestic livestock, impala meat is darker and less red than lamb (L* = 34.2-36.0; a* = 16.4-17.6; b* = 5.6-6.1; Warner et al., 2005) and beef (L* = 41.0, a* = 12.9; b* = 12.6; Bartoň, Bureš, Kotrba, & Sales, 2014). The overall darker colour of impala meat compared to that of traditional livestock may be the result of a higher myoglobin content in the meat of impala (7.3-7.5 mg/g) than in that of beef (5.8 mg/g) or chicken (2.5 mg/g) (Hoffman et al., 2005a). Game animals generally have higher levels of daily activity than traditional livestock, resulting in increased muscle myoglobin content to increase oxygen carrying capacity, which in turn leads to a darker surface colour of the meat (Hoffman et al., 2005a).

While the overall surface colour of impala LTL muscles is darker and less red than that of domestic livestock, it is still lighter and redder than the colour measurements that would be expected for dark, firm and dry (DFD) meat. The latter is a persistent meat quality fault that negatively impacts the water-holding capacity, colour and tenderness of meat and consequently shortens shelf life, particularly in meat that is vacuum-packed (Honikel, 2004; Lawrie & Ledward, 2006; Shange et al., 2019). Hoffman (2000a) observed that a wounded male impala that ran for four minutes prior to culling produced meat with a high pH_u (6.1), high water-holding capacity (0.0 % drip loss) and a darker, less red surface colour (L* = 25.4; a* = 9.1; b* = 4.9) than that of non-stressed impala. The physical meat quality measurements of meat from the wounded impala are characteristic of dark, firm, and dry (DFD) meat, which was caused by *ante-mortem* stress. Similar results were obtained with a study on black wildebeest meat, where animals with high pH_u values (> 6.06) produced darker, less red meat (L* = 27.2; a* = 11.1; b* = 7.0; Shange et al., 2019) than black wildebeest with normal pH_u values (< 6.06). In comparison, the surface colour of the wounded impala was much darker, less red and less yellow, indicating that the surface colour measurements of DFD meat may be species specific, although this would require further investigation with a larger sample size in impala. Ultimately, the CIE Lab values obtained for impala LTL muscles across a variety of different treatments (Table 2.5) do not conform to the values expected for DFD meat and therefore falls within the range considered acceptable for game meat.

Table 2.5 Mean values (± standard error) for the meat surface colour measurements of impala (*Aepyceros melampus*).

Location	Age	Muscle	Sex	n	Treatment	L*	a*	b*	Reference
Maneze Wildlife Conservancy, Zimbabwe	8-48+ months	LT[a]	Male	8	Sex	28.8 ± 1.99	11.1 ± 1.88	7.1 ± 1.3	#1
			Female	8	Sex	29.7 ± 2.75	11.4 ± 0.96	7.6 ± 0.76	
Mabula District, Limpopo, RSA	Adult & sub-adult	LD[c]	Male	17	Sex	29.9 ± 0.45	10.8 ± 0.33	7.6 ± 0.37	#2
			Female	15	Sex	28.4 ± 0.46	10.4 ± 0.34	7.7 ± 0.38	
	Adult		Both	18	Age	28.3 ± 0.45	10.6 ± 0.33	7.5 ± 0.38	
	Sub-adult		Both	14	Age	29.9 ± 0.48	10.7 ± 0.34	7.8 ± 0.40	
Mara Research Station, RSA	Random	LL[b]	Both	24	Night-culled	30.1 ± 1.30	13.2 ± 1.48	9.4 ± 1.78	#3
			Both	12	Day-culled	30.5 ± 2.76	12.5 ±1.36	8.8 ± 1.42	
Leeukop Game Ranch, RSA	8-20 months	LD	Both	9	Night-culled	32.1 ± 0.36	10.6 ± 0.23	7.1 ± 0.32	#4
			Both	9	Day-culled	32.8 ± 0.39	11.4 ± 0.25	7.7 ± 0.34	

[#1]Hoffman, 2000a; [#2]Mostert, 2007 [#3]Kritzinger et al., 2003; [#4]Hoffman & Laubser, 2009.

Abbreviations: [a]LT =*Longissimus thoracis*; [b]LL = *Longissimus Lumborum*; [c]LD = *Longissimus dorsi* muscles

2.3.3.2 Chemical meat quality

When considering non-traditional species, such as the impala, for meat production and contribution to food security, it is necessary to investigate the nutritive value and quality of the meat to improve productivity and to produce meat products with consistent quality (Cawthorn & Hoffman, 2014). The nutritional value of meat must fulfil the health requirements of consumers in a suitable manner, particularly with regards to obesity issues and cardiovascular disease related to diet (Schack, Bergh, & Du Toit, 2016). The nutritional value and chemical meat quality of meat is principally characterized by its basic biochemical composition, which is generally comprised of approximately 75 g/100 g moisture, 20 g/100 g protein, 1-10 g/100 g intramuscular fat (IMF) and 1g/100 g carbohydrates, vitamins and minerals (with the latter usually analyzed as ash) in lean skeletal muscles (Ang, Young, & Wilson, 1984; Huff-Lonergan & Lonergan, 2005; Listrat et al., 2016). The total of these constituents is commonly referred to as the proximate composition of meat, which can vary depending on the species, slaughter age, and sex of animals, as well as between different muscles in a carcass (Hocquette et al., 2010; Hoffman et al., 2005b; Sebranek, 2014).

The proximate composition of impala meat has been analyzed by several authors, and a summary of their findings are presented in Table 2.6. The moisture content of impala meat ranged from 70.2-75.7 g/100 g for all studies, with no significant differences recorded between sexes, slaughter ages or production regions (Table 2.6). The moisture content of impala meat is comparable to that of other game species, such as fallow deer (73.4-76.6 g/100 g; Fitzhenry, 2016), kudu (75.7-75.8 g/100 g; Hoffman et al., 2009), and blesbok (73.9-76.1 g/100 g; Neethling et al., 2014). However, the moisture content recorded for impala meat was higher than that of the LTL of domestic livestock such as White Dorper lambs (62.4-63.2 g/100 g; De Brito et al., 2016) and pigs (70.44-73.03 g/100 g; Tomović et al., 2016). The negative correlation (r = -0.525; $P \leq 0.05$; Hoffman et al., 2009) found between moisture and IMF content for impala meat may explain the higher moisture content of impala meat compared to that of domestic livestock as a consequence of the very low IMF content found in this game species.

The protein content of impala meat from the respective studies did not differ between sexes or age groups (Table 2.6). However, Hoffman et al. (2005b) found a significantly higher protein content in impala of both sexes from Musina Experimental Farm than impala from Mara Research Station (Table 2.6), which was speculated to be the result of nutritional differences between production regions. Similar differences in protein content were also observed between springbok from four different production regions (Hoffman, Kroucamp, & Manley, 2007b), while a significantly higher protein content was found in blue wildebeest reared in semi-extensive production systems compared to extensive production systems (Van Heerden, 2018). These findings indicate that a combination of diet and production environment in different production systems have an influence on the proximate composition of game meat. While the effect of different production systems on chemical meat quality has been demonstrated in beef cattle (Keane & Allen, 1998) and pigs (Olsson & Pickova, 2005), it has yet to be established in the impala. Determining the influence of different production systems on the proximate composition of impala meat is an important potential area of research due to the increased utilization of more intensive production systems for increased productivity of game species, and the effect thereof on meat production should thus be investigated. The high protein content of impala meat (22.6-24.9 g/100 g;

Table 2.6) compares favourably to that of traditional livestock species such as Aberdeen Angus cattle (21.4 g/100 g; Bureš et al., 2015) and spent dairy cattle (20.1 ± 0.85 g/100 g; Paleari et al., 1998).

The IMF content of meat is an important characteristic of meat quality due to its relation to the juiciness, tenderness and flavour of meat (Geldenhuys, Hoffman, & Muller, 2014; Hoffman, Mostert, & Laubscher, 2009). Consumers use the amount of visible fat (inter- and intramuscular) as an indication of the health quality of meat (Issanchou, 1996). Impala have no subcutaneous fat layers (Hoffman, 2000b) and produce lean meat with barely any visible fat (Fairall, 1983). While no differences were between production regions or age groups for the IMF content of impala meat (Table 2.6), it was found that female impala tend to have a significantly higher IMF content than males in approximately the same age groups (Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009), and is thus another example of sexual dimorphism in this species. The lower IMF content of male impala may be caused by seasonal changes in body condition, with a loss in condition resulting from the strenuous activities related to the rutting season in sexually mature males (Anderson, 1965; Hoffman, 2000b). Reproduction status may also influence the IMF content of female impala, as demonstrated by the exceptionally high IMF content (> 7.0 g/100 g) of one female impala from Musina that did not lamb in the season prior to slaughter and thus maintained her lipid deposits and also had a visible subcutaneous fat layer (Hoffman et al., 2005b). Differences in sample types may also affect IMF content, as indicated by the higher IMF content recorded for females from the Overberg Test Range (4.3 ± 0.8 g/100 g; Van Zyl & Ferreira, 2004) and from the Maneze Wildlife Conservancy (3.4 ± 0.17 g/100 g; Hoffman, 2000b) in comparison to the values obtained in other studies (Table 2.6). The 9th-10th-11th rib cut was used in the former two studies, with the entire cut grounded prior to analysis by Van Zyl & Ferreira (2004). The inclusion of subcutaneous fat and bone in the latter cut may result in higher IMF and ash contents than in research based on samples consisting only of muscle tissue. When excluding research based on the 9th-10th-11th rib cuts, the IMF content of both sexes of impala ranged from 1.4-2.4 g/100 g for the LTL muscle, which is consistent with the typical low IMF content values of less than three g/100 g expected for game meat (Schack et al., 2016). The low IMF content of impala LTL meat is an indication of the leanness of meat from this species, which makes it an appealing offer for health conscious consumers.

It should be noted that the findings in Table 2.6 were based primarily on sections of the LTL muscle, which is frequently utilized as the indicator muscle for the meat quality of the entire carcass due to the large size and accessibility of the muscle (Warner, Kauffman, & Russel, 1993). However, the proximate composition of meat has been found to vary between different muscles due differences in muscle structure, function and anatomical location in the carcass (Hocquette et al., 2010). While Mostert (2007) found significant differences between the proximate composition of five different muscles (LD, BF, SM, ST, and SS) of impala, the IS muscle was not investigated. Significant differences have been found between the six different muscles for all chemical components in blue wildebeest (Van Heerden, 2018) and eland meat (Laubser, 2018), while sex-muscle interactions were found for the moisture content of blesbok (Neethling et al., 2014). This highlights the necessity to determine the proximate composition of the six main muscles of impala, as well as the influence of sex on this aspect of meat quality for each of the different muscles.

Table 2.6 Means (± standard error) of the proximate composition (g/100 g of meat) of impala (*Aepyceros melampus*) meat.

Location	Treatment	Muscle	Age	Sex	n	Moisture	Protein	IMF	Ash	Reference
S.A. Lombard Nature Reserve, RSA*	Species comparison	*Longissimus dorsi*	Adult	Male	18	75.7	-	1.4	-	#1
Maneze Wildlife Conservancy, Zimbabwe	Night-culled/Sex comparison	9th-10th-11th rib cut	8-10 months to 4+ years	Male Female	8 8	72.8 ± 0.49 72.0 ± 0.48	24.1 ± 0.32 23.6 ± 0.17	2.5 ± 0.32 3.4 ± 0.17	2.1 ± 0.10 2.2 ± 0.16	#2
Overberg Test Range (Denel), RSA	Species comparison (impala, springbok, blesbok)	9th-10th-11th rib cut	18 months 36 months	Male Female	2 6	74.0 ± 0.8 70.2 ± 1.3	18.9 ± 0.1 20.0 ± 1.1	1.2 ± 0.1 4.3 ± 0.8	4.6 ± 0.6 4.4 ± 1.0	#3
Musina Experimental Farm, RSA	Sex and region comparison	*Longissimus lumborum*	Pooled (sub-adult + adult)	Male Female	15 13	72.5 ± 1.05 72.5 ± 1.59	24.9 ± 1.19 24.9 ± 1.59	1.4 ± 0.51 2.0 ± 0.64	1.2 ± 0.33 1.2 ± 0.13	#4
Mara Research Station, RSA				Male Female	24 16	73.1 ± 1.79 71.9 ± 3.83	23.8 ± 0.80 23.9 ± 0.92	1.4 ± 0.24 1.9 ± 0.73	1.2 ± 0.09 1.2 ± 0.17	
Mabula District, Limpopo, RSA	Sex and age comparison	*Longissimus dorsi*	Sub-adult Sub-adult Adult Adult	Male Female Male Female	6 8 11 7	74.7 ± 0.33 74.3 ± 0.29 75.0 ± 0.24 74.0 ± 0.31	23.4 ± 0.27 23.0 ± 0.32 22.6 ± 0.27 23.1 ± 0.34	2.0 ± 0.22 2.4 ± 0.19 2.1 ± 0.16 2.4 ± 0.20	1.2 ± 0.06 1.3 ± 0.06 1.2 ± 0.05 1.2 ± 0.06	#5

#1Von La Chevallerie, 1972; #2Hoffman, 2000b; #3Van Zyl & Ferreira, 2004; #4Hoffman et al., 2005b; #5Hoffman et al., 2009.
*Abbreviation: RSA = Republic of South Africa.

2.3.3.3 Sensory meat quality

The sensory characteristics of meat are considered to be the most important attributes of meat quality, as the sensory quality of meat is essential for the satisfaction of consumers (Hoffman et al., 2004; Listrat et al., 2016; Oltra et al., 2015). The sensory quality of meat is comprised of visual, retronasal and aroma, flavour, juiciness and textural characteristics, which may be affected by the sex, species and dietary regime (feeding management) of the animals (Calkins & Hodgen, 2007; Melton, 1990; Neethling, 2016). Natural variations in meat quality affects the consistency of sensory attributes, which in turn negatively impacts the reliability of the product quality as perceived by consumers (Issanchou, 1996). Hoffman & Wiklund (2006) found that consumers evaluate the sensory quality of game meat using the same quality criteria as that used to evaluate meat obtained from domesticated species. However, there is a lack of product uniformity and established quality standards in game meat. This is further complicated by the fact that game meat is usually only marked under the generic category of "venison", with no specification regarding game species, sex or production system, leading to high variability between products (Hoffman et al., 2004; Neethling, 2016).

In a study comparing the sensory meat quality of six different South African game species (blesbok; gemsbok, *Oryx gazella*; impala; kudu; red hartebeest, *Alcelaphus buselaphus caama*; and springbok), Neethling (2016) found that the sensory profiles of game meat differ between species, with a species-specific sex effect also recorded for the sensory meat characteristics of impala, kudu and red hartebeest. When comparing the aforementioned six game species in a descriptive sensory analysis (DSA), impala meat was found to have the highest Warner-Bratzler shear force values (62.5 ± 2.91 N) and sour-associated aroma (together with blesbok), while the highest cooking loss percentages were found in the impala (31.6 ± 1.08 %), gemsbok (31.9 ± 1.16 %) and kudu (30.5 ± 1.41 %). Impala meat scored on a 100-point scale) the highest for residue (9.0 ± 1.35) and the lowest for sensory tenderness (57.5 ± 1.80), with a negative correlation recorded between the latter two traits (Neethling, 2016). Despite having the highest sensory rating for residue, the value is still very low and it is debatable whether it will have an impact on consumer acceptability.

In an earlier study comparing the sensory meat quality of kudu and impala, no differences were found between species for the sensory tenderness, sustained juiciness or residue scores (Hoffman et al., 2009). However, impala scored higher than kudu for the intensity of game aroma and flavour (Hoffman et al., 2009). These findings where confirmed by Neethling (2016), whom recorded that impala meat scored higher for gamey aroma intensity than kudu, red hartebeest and gemsbok, but had a less intense gamey aroma than springbok. Impala meat had the lowest intensity gamey flavour together with gemsbok, red hartebeest and kudu, while the gamey flavour was more pronounced in springbok and blesbok meat (Neethling, 2016). Impala meat also had a more pronounced beef-like flavour than springbok and blesbok, but scored lower for this favourable sensory characteristic than gemsbok meat. The flavour of meat is related to the aromas which are released inside the mouth upon consumption of the meat or meat product (Listrat et al., 2016). Differences in the flavour of meat derived from different species may be caused by intramuscular lipids in the meat, which release specific flavours upon degradation during the cooking process (Melton, 1990; Mottram, 1998). Strong positive correlations (r = 0.412, $P < 0.05$; and r = 0.645, $P < 0.001$, respectively) were found between game

flavour and the IMF content in both descriptive sensory analyses performed on impala meat by previous authors (Hoffman et al., 2009; Neethling, 2016). Therefore, it can be deduced that the intensity of game flavour of impala meat will increase as the IMF content of the meat increases.

In addition, the flavour of game meat can vary substantially due to seasonal variation in natural vegetation, different *ante-mortem* management practices and supplementary feeding with commercial feed combinations (Wiklund et al., 2003). Variation in the dietary regime of ruminants such as impala can affect the flavour and/or aroma of meat due to the influence of diet on the fatty acid content and volatile compound profile of meat (Calkins & Hodgen, 2007; Melton, 1990; Neethling, 2016). Differences in the polyunsaturated fatty acid (PUFA) to saturated fatty acid (SFA) ratios were speculated to be the cause of flavour differences between impala (0.73 ± 0.07) and kudu (1.22 ± 0.07), with the differences in multiple fatty acids between the two species attributed to differences in dietary regimes (Hoffman et al., 2009). Diet was found to have a significant influence on both the fatty acid profile and sensory meat quality of reindeer (*Rangifer tarandus tarandus*) that were either fed with a commercial feed mixture or grazed on natural pasture (Wiklund et al., 2001, 2003). However, similar research on the influence of different dietary regimes, feeding management and production system on the sensory meat quality of impala has yet to be conducted. As impala are mixed-feeders, their diet is highly variable depending on the season and natural vegetation of the environment (Chapter 2.2.1) and may be substantially influenced by the supplementary feeding and/or complete replacement of natural grazing with supplied feed that is often associated with more intensive production systems. These factors may influence the fatty acid content, volatile profile and sensory meat quality of impala (Hoffman et al., 2009; Neethling, 2016), and thus require further investigation.

For impala meat, the highest percentage of the total fatty acids (40 %) consisted of two saturated fatty acids, namely C18:0 (stearic acid; 22.7 %) and C16:0 (palmitic acid; 16.7 %). However, no correlations were recorded between any fatty acids and game meat flavour, and only arachidic acid and myristic acid were found to have weak correlations ($P < 0.10$) to sensory aroma (Hoffman et al., 2009). Despite the lack of strong correlations between the fatty acid profile and the flavour and aroma characteristics of impala meat, the fatty acid profile may still have an influence on the sensory characteristics of game meat by means of its influence on the volatile compound profile of meat (Neethling, 2016; Nuernberg et al., 2005). In addition, due to the influence of dietary regime and seasonal variation in vegetation quality, the fatty acid profile may have an influence on the sensory characteristics of meat from impala on different diets and in different production regions.

When comparing male and female impala, significantly higher linoleic acid (C18:2n6c) contents were found in meat from female impala compared to that of males in two separate studies (Hoffman et al., 2005a; Neethling, 2016). However, Hoffman et al. (2005a) found significant differences between the sexes for the total PUFA and SFA contents, while Neethling (2016) found no differences between male and female impala for the aforementioned fatty acid contents. The magnitude of the influence of sex on the sensory quality of game meat has also been speculated to be affected by dietary regime, which may account for the differences between studies (Neethling, 2016). While differences were found between male and female impala for the sour taste, fish-like flavour and mealiness sensory characteristics, the differences between sexes for the mean ratings of these attributes were numerically small and may be considered negligible in terms of influence on consumer perception (Neethling, 2016).

Hoffman et al. (2009) also found that sex had no significant effect on the sensory meat quality of impala. Therefore, based on sensory meat quality analysis, the sex of impala does not have to be taken into account for the marketing of impala meat, although none of these studies evaluated male meat during the rut. However, it is recommended that the influence of farm location and production systems on the sensory meat quality of impala should be investigated.

2.4 CONCLUSION

The impala is a species that has been the focus of a vast number of research studies concerning its growth, feeding behaviour and reproduction. Due to their abundance, high fecundity and ability to utilize a wide variety of habitats across southern Africa, the potential of this species for meat production has recently gained attention. Impala were found to have high carcass yields and tender meat with a high protein and low intramuscular fat content. While impala meat was found to have the darker, less red surface colour commonly associated with game meat, neither the colour nor other physical meat quality attributes have qualities that are usually associated with DFD-like meat. In terms of flavour and aroma, research on the sensory meat quality of impala thus far is limited.

It is clear that there are various aspects potentially influencing the meat production potential of impala that have yet to be investigated. Most past studies on the physical and chemical meat quality of impala have been limited to the *Longissimus thoracis et lumborum* (LTL) muscle, since this muscle has been regarded as representative of the entire carcass in terms of meat quality. However, due to differences found in the quality and composition of the limited different muscles that were investigated, it would be recommended that the physical meat quality and chemical composition of more important muscles (e.g. LTL, BF, SM, ST, IS, and SS) of impala be investigated for both male and female impala. Furthermore, with the significant differences found between production regions for the carcass yields and meat quality of impala, it is necessary to investigate the influence of different production systems (intensive, semi-extensive and extensive) on these parameters. Despite the increasingly larger role of different production systems in the breeding and management of impala, the impact of the different feeding and management strategies on the physical, chemical and sensory meat quality of impala within these systems has yet to be investigated. In addition, no research studies have been conducted on the influence of *post-mortem* ageing on the improvement of tenderness and product uniformity of impala meat.

Based on the available literature, the production of meat from game species such as the impala is beneficial due to the increased adaptability and ectoparasite resistance of this species, as well as utilization of areas that are less suitable for cattle and other livestock species, in addition to the production of meat with nutritional quality that compares favourably to that of traditional red meat types. Overall, the impala is a species that may be ideally suited to meat production in South Africa and other southern African countries where it occurs. However, it is important to determine the influence of all *ante-* and *post-mortem* factors such as sex, muscle, production system and *post-mortem* ageing that may influence the meat quality of impala in order to compete with traditional red meat types and produce meat products with consistent quality for the consumer market.

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CHAPTER 3

THE EFFECT OF SEX AND PRODUCTION SYSTEM ON IMPALA (*AEPYCEROS MELAMPUS*) CARCASS YIELDS

ABSTRACT

This study determined the influence of sex and production system on the carcass yield of sub-adult impala to provide baseline data for the South African game industry. A total of 58 impala were culled, of which 22 were allocated to the sex comparison trial and 36 were allocated to the production system trial. For the sex comparison, 11 male and 11 female impala from the same semi-extensive production system were culled in the Modimolle region of Limpopo. While no sexual dimorphism was recorded for carcass weights (36.4 ± 1.30 kg males, 37.8 ± 1.30 kg females), male impala had a higher (P = 0.004) mean dressing percentage than females (59.1 ± 0.76 % vs. 55.6 ± 0.76 %). For the production system comparison, 12 sub-adult (±15-18 months old) male impala were culled per production system (intensive, semi-extensive and extensive; n = 36). The proportional yields of sub-adult male impala did not differ between production systems for dressing percentage (57.9 ± 0.58 % pooled mean) or total offal yields (39.7 ± 0.48 % pooled mean). Carcass and total offal weights were significantly heavier in extensive system impala (46.5 ± 1.12 kg undressed carcass weight) than in intensive (37.9 ± 0.92 kg undressed carcass weight) or semi-extensive system impala (36.4 ± 0.96 kg undressed carcass weight), while the latter two systems did not differ significantly from each other. The overall high dressing percentages and proportional offal yields recorded for impala in this study confirm the high meat production potential of this species as an alternative protein source to traditional livestock in South Africa.

Keywords: Game animals, Dressing percentages, Offal yields

3.1 INTRODUCTION

South Africa is challenged by a growing protein shortage due to its ever-expanding population and simultaneous status as net importer of beef, lamb, pork and chicken (Meissner, Scholtz, & Palmer, 2013; Oberem & Oberem, 2016). Meat production is challenged by the fact that livestock numbers have remained relatively constant, or declined, despite the more than twofold increase in the South African population from 25 million to over 55 million in the last 35 years (DAFF, 2017). Further challenges to domestic livestock production are present in the form of stock theft, overgrazing and desertification resulting from climate change, to which beef production is particularly vulnerable (Otieno & Muchapondwa, 2016). A practical solution to these challenges is presented through game farming, an economically sustainable enterprise that has the potential to contribute to the food security of South Africa (Bothma, Sartorius Von Bach, & Cloete, 2016; Hoffman & Cawthorn, 2012).

There has been a substantial shift in land-use allocation from traditional domestic livestock farming to the farming of indigenous game animals in an effort to combat the above-highlighted challenges faced by the livestock industry and as a result of the financial and ecological advantages presented by game farming (Child, Musengezi, Parent, & Child, 2012). Indigenous game species have evolved over millennia to be well-adapted to the arid South African environments, with improved utilization of low-quality vegetation, lower susceptibility to overgrazing and better parasite and disease resistance than traditional domestic livestock (Oberem & Oberem, 2016). Additionally, game animals are less susceptible to stock theft as a result of the more stringent fencing requirements, larger camps and overall less domesticated nature than their domestic counterparts (Snijders, 2012). Game animals have also been found to generate higher net farm profit margins than livestock (Berry, 1986; Child et al., 2012) and the game farming industry has made a significant contribution to the expansion in wildlife conservation, economic growth and job creation (Bothma, Sartorius Von Bach, et al., 2016; Taylor, Lindsey, & Davies-Mostert, 2016).

Increasing knowledge of the economic and ecological sustainability of game farming, combined with increasing financial incentives above that of traditional livestock farming has resulted in a vast expansion in the South African game industry (Taylor et al., 2016). This expansion is accompanied by utilization of various different production systems to optimize animal production according to farming area, environment and financial resources available. The different production systems are described according to farming intensity and categorized as either intensive, semi-extensive or extensive. Intensive production systems have been defined by Taylor et al. (2016) as small to moderate predator-controlled camps that require high human intervention through provision of the majority (or all) of the animal's feed, water and healthcare requirements. Semi-extensive game production systems are defined as environments large enough for the maintenance of self-sustaining game populations, regardless of fencing or lack thereof, but moderate human intervention is necessary in terms of feed supplementation, water and healthcare provision and/or parasite and predator control (Oberem & Oberem, 2016). Extensive production systems are defined as natural habitats large enough to maintain and manage free-running game populations with minimal human intervention in terms of medical care, feed and water supplementation (excluding drought intervention) and predator or parasite control. These extensive systems are not required to be fenced, but must be able to provide the physical and

nutritional requirements of the game populations inhabiting the area with minimum human intervention (Oberem & Oberem, 2016). The different production systems can be applied in different camps on the same game farm or in combination with livestock farming. While extensive production systems are less labour-intensive, the practice of selective breeding has caused an increase in the utilization of intensive and semi-extensive production systems on game farms that aim to produce superior animals with higher sale values, such as rare colour variants or animals with exceptional horn characteristics (Bothma, Sartorius Von Bach, et al., 2016). The consequent intensification of production systems and expansion in breeding of colour variants has resulted in a surplus of split animals (recessive gene carriers of colour variant genes) and colour variants with inferior genetics. These animals are generally not sold live, but are culled for meat (Hoffman, 2007).

When culling for meat, carcass yield becomes important as game animals are sold per kilogram (Hoffman & Wiklund, 2006; Oberem & Oberem, 2016). Game species produce higher lean meat yields than their domestic counterparts (Huntley, 1971), and may have a superior meat production potential than domestic livestock in relation to dressing percentages and lean meat production (Van Zyl & Ferreira, 2004). While higher dressing percentages are more desirable as they are indicative of a lower offal and higher meat yield, dressing percentages can vary significantly between game species due to differences in internal and external offal yield (Van Zyl & Ferreira, 2004).

The impala, a southern African antelope, is an excellent candidate for meat production due to the rapid population growth and high fecundity associated with this species (Fairall, 1983). The growth, development and reproduction of the impala has been the focus of previous research studies in Africa, although the majority of studies focused only on impala from one research location or farm in eastern or southern Africa. Recently, the potential of impala for meat production has motivated research to expand toward factors influencing impala carcass yield (Du Plessis et al., 2006; Hoffman, 2000b; Hoffman, Kritzinger, & Ferreira, 2005b; Van Zyl & Ferreira, 2004), muscle characteristics (Kohn, Kritzinger, Hoffman, & Myburgh, 2005) and meat quality (Hoffman, Mostert, Kidd, & Laubscher, 2009; Hoffman, Mostert, & Laubscher, 2009; Van den Berg, 2009). Several of these studies have compared impala from different farming locations (Anderson, 1982; Du Plessis et al., 2006; Hoffman et al., 2005b; Theobald, 2002) and both sexes (Anderson, 1982; Du Plessis et al., 2006; Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009; Van Zyl & Ferreira, 2004). Impala meat is also a popular choice for game meat export, with a contribution of approximately 20 858 kg exported in 2008 (McCrindle, Siegmund-Schultze, Heeb, Zárate, & Ramrajh, 2013) and have been found to improve the production potential of farms when combined with cattle farming (Skinner, Monro, & Zimmermann, 1984). Impala have a wide distribution, rapid reproductive rate and relative abundance as a species that make them ideal for sustainable culling regimes (Hoffman, Kritzinger, & Ferreira, 2005a; Selier, Hoffman, & Castley, 2016).

Previous studies have found that production system influences the carcass yields of other game species (Sampels, Pickova, & Wiklund, 2005; Van Heerden, 2018) and it has been stated than the impala is well-adapted to surviving in different production systems (Bothma & Van Rooyen, 2005). However, despite the suitability of impala for sustainable culling and the expansion of the market for game meat, the effect of production system on the carcass yield and meat quality of this species has not yet been quantified. In addition, previous studies focusing on the effect of sex have been limited to

growth and body measurements (Anderson, 1982; Fairall & Braack, 1976), and were limited by small or unequal sample sizes for the same age group or location (Hoffman et al., 2005a; Van Zyl & Ferreira, 2004) and have not compared individual muscle yields of the commercially important muscles. The aim of this research chapter is firstly, to compare the effect of sex on the carcass yields of impala from the same farm and production system (Trial 1), and secondly, to compare the effect of three different production systems (intensive, semi-extensive and extensive) on the carcass yield of male sub-adult (±15-18 months) impala (Trial 2) to establish baseline data for the game industry and determine their meat production potential.

3.2 MATERIALS AND METHODS

3.2.1 Experimental location and animals

For this study, a total of 58 impala were obtained from two experimental locations in March of 2017, namely Castle de Wildt near Modimolle in the Limpopo province and a farm near Bredasdorp in the Western Cape province of South Africa. Castle de Wildt (24°45'42.9"S 28°27'16.2"E) is located in a summer rainfall area in the Central Sandy Bushveld bioregion of the Savanna biome. This area is a subtropical thermal region with elevations ranging from 850 m to 1450 m above sea level. The mean annual rainfall is 500 mm to 700 mm with a distinct dry season in the winter months of June, July and August. The vegetation in this area varies with the landscape and includes *Acacia*, *Euclea* and *Ziziphus* species, with *Burkea Africana* and *Terminalia sericea* as prominent deciduous woodland species and *Panicum maximum* as a dominant grass species (Mucina & Rutherford, 2006).

The farm in the Western Cape is within a winter rainfall area in the Central Rûens Shale Renosterveld vegetation unit of the Fynbos biome. This region has sloping hills and plains at altitudes of 20 m to 340 m above sea level. The mean annual rainfall ranges from 300 mm to 480 mm, with 49% of rainfall occurring in the late autumn and winter months from May to August. The vegetation is primarily grassy shrublands dominated by renosterbos (*Elytropappus rhinocerotis*) and includes shrubs of the *Aspalathus*, *Athanasia* and *Rhus* species (Mucina & Rutherford, 2006).

Of the 58 impala in the study, 11 male and 11 female impala from the same semi-extensive production system at Castle de Wildt were culled for the sex comparison trial (Trial 1). While these 22 impala were harvested from the same system and location as the semi-extensive system impala from the production system trial (described below), they do not form part of the production system comparison. The impala obtained from Castle de Wildt for both the sex and production system trials were animals that carry recessive genes for colour variation and are referred to as "split" animals. The aim for both trials was to cull only sub-adult animals at approximately 15-18 months of age for experimental uniformity, with age estimated by horn size in impala males. However, like many other antelope species, female impala are hornless, and the age of female impala is estimated by body size in the field. Using only body size as ageing criteria is challenging, especially during culling operations where time is limited.

For the production system comparison (Trial 2), 12 sub-adult impala males (±15-18 months old) were culled per production system (intensive, semi-extensive and extensive, n = 36). The intensive production system was a 0.25 ha boma system located at Castle de Wildt in the Modimolle region. This

system required a high management input, as the sole source of feed intake for impala in this system was through feed supplied *ad libitum* in troughs daily. The 12 impala males harvested for the production system trial were the only animals inhabiting the boma. These males were raised in the semi-extensive system until nine to 12 months of age, at which point they were relocated to the intensive boma system, where they remained for a period of six months prior to culling. Due to the high stocking density of impala in this system, all accessible natural browsing material has been eradicated from the camp by the time of culling, similar to the effect observed near watering points in overpopulated regions (Young, 1972). Samples of the feed supplied in the intensive system were collected for chemical analysis, where it was found to have a composition of 8.3 % moisture, 13.3 % crude protein, 91.7 % dry matter, 7.6 % ash, 27.9 % crude fibre, 47.7 % neutral detergent fibre (NDF) and 30.5 % acid detergent fibre (ADF). These nutritional values are within the recommended dietary requirements of less than 40 % crude fibre and high protein content (8 % in winter and 16 % in summer) for this species (Furstenburg, 2016).

The semi-extensive production system consisted of a 200 ha camp system at Castle de Wildt, and required moderate human intervention through supplementary feed (using the same feed as that supplied in the intensive system), although the primary feed intake of impala from this system was from grazing and browsing the natural vegetation in the Savanna biome. In addition to impala, the semi-extensive camps contained multiple different game species, including blue wildebeest, springbok, kudu and sable, as well as colour variants of several species. Impala could form natural herds, which included mixtures of black impala, common natural coloured impala and split animals. The male impala culled for the production system trial were obtained from bachelor groups and were primarily split animals. The semi-extensive system had a stocking density of approximately 250-300 animals in the 200 ha camp, with no apparent signs of overgrazing observed during culling.

The extensive system was located within the Central Rûens Shale Renosterveld region near Bredasdorp and consisted of a single 800 ha camp that was large enough for management of self-sustaining game populations in natural ecosystems. Therefore, minimal human intervention was required in the extensive system as the only source of feed intake for impala was the natural Fynbos vegetation. The extensive system was located on a mixed game and cattle farm, and animals had access to mineral licks and watering points. All impala in this system were natural common impala, and no breeding of colour variants occurred on the farm in the Bredasdorp region. Impala from both the extensive and semi-extensive production systems were raised in their respective systems from birth until culling at approximately 15-18 months of age.

3.2.2 Culling, carcass processing and sampling

All impala were culled during the day (ethical clearance number 10NP_HOF02) using suppressor-equipped light calibre rifles (.22 or .243), which are less likely to cause a herd to become stressed and flee during hunting than heavier calibre rifles (Hoffman, 2000a). Animals were shot in the head, which has been shown to have the least detrimental effects to meat quality when compared to shoulder or rib shots (Van Schalkwyk & Hoffman, 2016; Von La Chevallerie & Van Zyl, 1971). After shooting, the impala were bled out in the field, tagged and transported to the on-farm slaughter facility on the back of a secure culling vehicle.

At the slaughter facility, a hanging scale was used to record the undressed carcass weight of the exsanguinated impala carcasses. Thereafter, the impala were skinned, eviscerated and dressed according to the guidelines stipulated by Van Schalkwyk & Hoffman (2016). The external offal, consisting of the head, feet and skin, were removed and weighed first, followed by measurement of the horns. The internal offal was removed, and organ weights were recorded, with hearts and kidneys weighed after removal of the surrounding fat layers. Testes of male impala were weighed without the skin. After dressing, the warm carcasses were weighed. Dressing percentages were calculated using warm carcass weights (WCW) as a percentage of the undressed carcass weights. The horns of all male impala were measured with a flexible measuring tape according to the method described by Schwabland & Barnhart (2016). The measurements taken for this study are illustrated in Figure 3.1, with measurements taken for both the left and right horns. Figure 3.1 also illustrates the characteristic horn shape and short tip-to-tip distance of sub-adult impala males (at ±15-18 months) which was used to estimate age in the field. The tip-to-tip measurement determines the distance between the tips of the horns (Sachs, 1967). The horn length was measured on both horns from the front of the base to the tip, following the curvature of the horns. At this age, it is expected that male impala will have 4-6 grooves on their horns and an average horn length of 32-40 cm (Furstenburg, 2016).

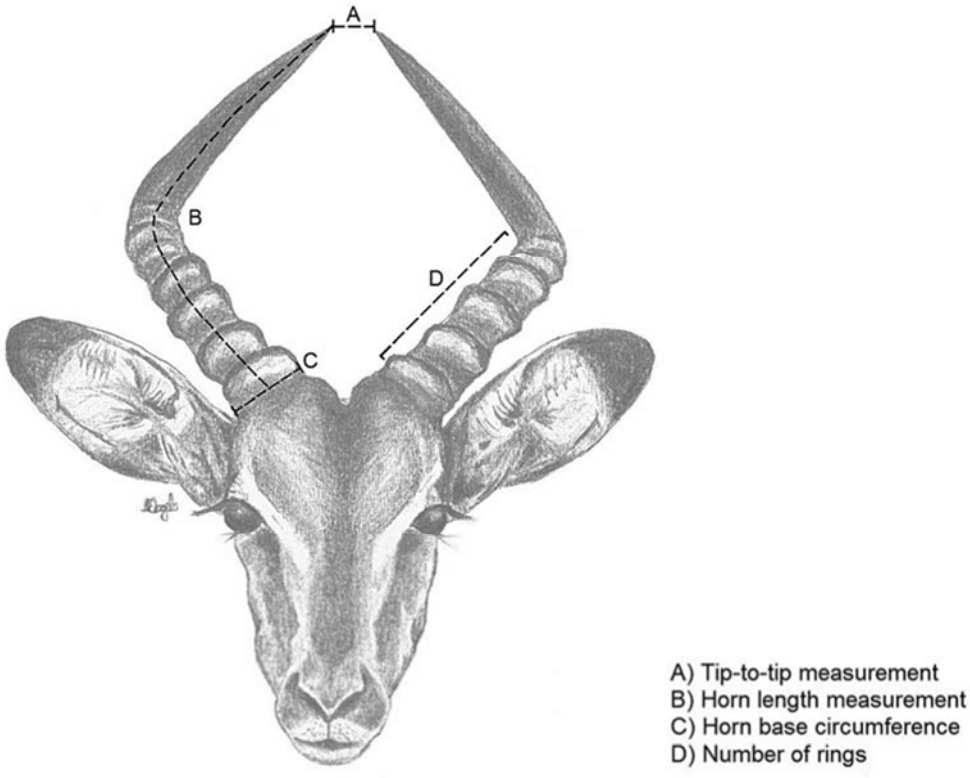

Figure 3.1. Illustration of sub-adult (±18 months) male impala horn measurements (Artist: R.A. Engels).

After dressing, carcasses were hung by the Achilles tendons of both hind legs in a chiller set to 4 ± 1°C to undergo *rigor mortis*. After ±24 hours, the cold dressed carcasses were weighed (CCW) and ultimate pH was recorded. Cold carcass dressing percentage was calculated using the CCW as a percentage of the undressed carcass weight. The carcasses were deboned, and the six commercially important

muscles were removed from the hindquarters and the forequarters of the carcasses. The muscles from the hindquarter consisted of the LTL (*Longissimus thoracis et lumborum*) (Kauffman, Habel, Smulders, Hartman, & Bergstrom, 1990), BF (*Biceps femoris*), SM (*Semimembranosus*) and ST (*Semitendinosus*), and the muscles from the forequarter included the IS (*Infraspinatus*) and SS (*Supraspinatus*) muscles. All six of these muscles were removed from both the right and left sides of the carcasses and weighed for the 11 male and 11 female impala for the sex comparison. The LTL muscles were removed and weighed for the 36 impala from the three different production systems, after which the rest of the carcasses were processed. The abovementioned muscle samples were subjected to further analysis, to be described in Chapters 4-7.

The carcass yield was recorded to determine the meat production potential of impala as affected by sex and production system, respectively. To give a complete representation of carcass yields in terms of weights and dressing percentages, dressing percentages were calculated using warm dressed carcass weight as a percentage of undressed carcass weight (referred to as warm dressing percentage) and using cold dressed carcass weight as a percentage of undressed carcass weight (referred to as warm dressing percentage), respectively, in order to be more comparable to previous studies.

3.2.3 Statistical Analysis

A completely random experimental design was used for the sex comparison trial (Trial 1), with sex as the main effect and animals as the experimental units. It was observed that four of the female impala in the sex comparison were lactating at time of culling; however, these animals were still included in the statistical analysis due to having similar undressed carcass weights to the mean of the female group and were deemed to be young females having had their first lambs. These lambs were close to weaning (±3-4 months old) and were able to adapt without their mothers due to the crèche system used by impala (Furstenburg, 2005).

The production system trial (Trial 2) was also a completely random experimental design, with production system as the main effect and sub-adult impala males as the random replications. Outlier animals were removed from the production system trial due to being at least 12 months older (four impala males from the extensive system treatment group) and in one case, six months younger (one male from the semi-extensive system) than the 15-18 months age class required. A further outlier animal (52.5 kg undressed carcass weight, 53.4 cm horn length, 15 horn rings) was identified in the extensive group but was kept for statistical analysis as the outlier animal closest to the required age group to ensure sufficient sample size.

The sex comparison (Trial 1) therefore included data of 11 male impala (n = 11) and 11 female impala (n = 11), while the production system comparison (Trial 2) included 12 intensive system impala (n = 12), 11 semi-extensive system impala (n = 11) and eight extensive system impala (n = 8) males. Data was analyzed 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 from the model to test for deviation from normality (Shapiro & Wilk, 1965). In instances when an observation's standardized residual diverged with more than three standard deviations from the model value and thus deviated

significantly from normality, this outlier's values were removed. Fisher's least significant difference was calculated at a significance level of 5 % to compare sex or production system means (Lyman Ott & Longnecker, 2010).

For the sex comparison, differences between the sexes were tested with the null hypothesis H_0: $\mu_A = \mu_B$ and the alternative hypothesis H_a: $\mu_A \neq \mu_B$ by means of contrast analyses and estimated least square means (± standard error). The production system comparison tested the null hypothesis H_0: $\mu_A = \mu_B = \mu_C$ and the alternative hypothesis (H_a) that at least one of the treatment means (μ_i) is different from the others. A probability level of 5 % was considered significant for all significance tests, below which ($P \leq 0.05$) differences between the variables are deemed to be significant for sex and production system, respectively.

3.3 RESULTS

3.3.1 Sex Comparison (Trial 1)

3.3.1.1 Carcass and offal yields

The effect of sex on the carcass and offal yields of impala are presented in Table 3.1. The various yields are presented both as weights and expressed as a percentage of undressed carcass weights in order to give a complete comparison between treatments. Impala carcass weights were reduced after 24 hours in the cold room, with mean cold dressed carcass weights lower than warm carcass weights by 0.7 kg in males and 0.5 kg in females. No differences ($P > 0.05$) were observed between male and female impala for mean undressed or dressed carcass weights (warm or cold), with mean undressed carcass weight recorded as 36.4 ± 1.30 kg in males and 37.8 ± 1.30 kg in females. However, males had significantly higher mean dressing percentages (59.1 ± 0.76 % warm and 57.4 ± 0.75 % cold) than ewes (55.6 ± 0.76 % warm and 54.3 ± 0.75 % cold).

While the total offal yield (comprised of the combined total internal and external offal) did not differ ($P = 0.069$) between sexes in weight, female impala had a higher ($P = 0.050$) total offal yield contribution to undressed carcass weight at 41.6 ± 0.84 % than male impala (39.2 ± 0.84 %). The mean pooled total offal yield amounted to 15.0 ± 0.42 kg for both sexes. The total external offal was heavier ($P = 0.007$) in male impala (5.4 ± 0.17 kg) than in females (4.7 ± 0.17 kg). Male impala also had significantly higher mean weights for their heads (weighed with tongues and horns if present) and feet than females. No differences ($P > 0.05$) were observed between sexes for the mean yields of the skin, heart, lungs and trachea, liver or kidneys in terms of weight or as proportional contribution to undressed carcass weight. Significant differences were noted between the mean yields of the spleen, GIT (gastro-intestinal tract with full stomach and intestines) and total internal offal of male and female impala. The GIT had the highest proportional contribution to the total offal yield for both sexes and was heavier ($P = 0.050$) in females (9.2 ± 0.42 kg, 24.3 ± 0.82 %) than in males (6.8 ± 0.42 kg, 18.9 ± 0.82 %).
The four female impala that were lactating at the time of slaughter had a mean udder weight of 362.5 ± 23.94 g, with a 0.9 ± 0.05 % mean contribution to undressed carcass weight. As expected, the testicles were very light (19.9 ± 2.90 g) and hardly contributed to the total live weight (0.045 ± 0.003 %).

Table 3.1 LSMeans (± standard error) of impala carcass yields in kg and percentage (expressed as percentage of undressed carcass weight) as influenced by sex.

Carcass parameter		Sex		P-value
		Female (n = 11)	Male (n = 11)	
Undressed carcass	kg	37.8 ± 1.30	36.4 ± 1.30	0.451
Dressed carcass - warm	kg	21.0 ± 0.82	21.6 ± 0.82	0.639
Dressing percentage - warm	%[1]	55.6 ± 0.76	59.1 ± 0.76	0.004
Dressed carcass - cold	kg	20.5 ± 0.82	20.9 ± 0.82	0.727
Dressing percentage - cold	%	54.3 ± 0.75	57.4 ± 0.75	0.009
Head	kg	1.9 ± 0.07	2.4 ± 0.07	< 0.001
	%	5.1 ± 0.12	6.5 ± 0.12	< 0.001
Feet	kg	1.1 ± 0.03	1.2 ± 0.03	0.008
	%	2.8 ± 0.08	3.3 ± 0.08	< 0.001
Skin	kg	1.7 ± 0.09	1.8 ± 0.09	0.428
	%	4.6 ± 0.20	5.0 ± 0.20	0.192
Total external offal	kg	4.7 ± 0.17	5.4 ± 0.17	0.007
	%	12.5 ± 0.28	14.8 ± 0.28	< 0.001
Heart	g	259.8 ± 9.79	260.9 ± 9.79	0.938
	%	0.7 ± 0.01	0.7 ± 0.01	0.139
Lungs & trachea	g	731.8 ± 62.62	769.3 ± 62.62	0.677
	%	1.9 ± 0.15	2.1 ± 0.15	0.312
Liver	g	601.5 ± 26.58	599.1 ± 26.58	0.949
	%	1.6 ± 0.05	1.6 ± 0.05	0.451
Kidneys	g	106.7 ± 5.32	110.1 ± 5.32	0.660
	%	0.3 ± 0.01	0.3 ± 0.01	0.072
Spleen	g	153.3 ± 17.64	216.5 ± 17.64	0.020
	%	0.4 ± 0.04	0.5 ± 0.04	0.018
GIT[2]	kg	9.2 ± 0.42	6.8 ± 0.42	< 0.001
	%	24.3 ± 0.82	18.9 ± 0.82	< 0.001
Total internal offal	kg	11.1 ± 0.49	8.8 ± 0.49	0.004
	%	29.1 ± 0.88	24.3 ± 0.88	< 0.001
Testes	g		19.9 ± 2.90	
	%		0.045 ± 0.003	
Udder (n = 4)	g	362.5 ± 23.94		
	%	0.9 ± 0.05		
Total offal	kg	15.8 ± 0.57	14.2 ± 0.57	0.069
	%	41.6 ± 0.84	39.2 ± 0.84	0.050

[1]Parameter % = percentage of the undressed carcass weight. [2]GIT: gastro-intestinal tract (includes full stomach & intestines)

3.3.1.2 Muscle weights

There were no significant differences between the right and left sides of the carcasses in terms of muscle weight, therefore the mean muscle weights per sex are represented in Table 3.2. None of the muscle weights differed significantly between male and female impala at the 5% level. The heaviest muscles for impala from both sexes originated from the hindquarter and includes the LTL (± 852.8 g), SM (± 641.5 g) and BF (± 606.5 g) muscles.

Table 3.2 LSMeans (± standard error) of muscle weight (g) as influenced by sex.

Muscle	Sex		P-value
	Female (n = 11)	Male (n = 11)	
LTL[1]	855.4 ± 34.41	850.1 ± 34.41	0.916
BF[2]	610.8 ± 27.38	602.2 ± 27.38	0.826
SM[3]	638.9 ± 30.20	644.0 ± 31.68	0.910
ST[4]	182.1 ± 7.28	183.0 ± 7.28	0.937
IS[5]	164.6 ± 7.73	178.4 ± 7.73	0.222
SS[6]	139.8 ± 6.78	154.0 ± 6.78	0.155

Abbreviations: [1]LTL = *Longissimus thoracis et lumborum*, [2]BF= *biceps femoris*, [3]SM = *semimembranosus*, [4]ST = *semitendinosus*, [5]IS = *infraspinatus*, [6]SS = *supraspinatus.*

3.3.2 Production System Comparison (Trial 2)

3.3.2.1 Horn measurements

The mean horn measurements did not differ significantly between the left and right horns for the impala males of each production system, therefore the pooled mean horn measurements (left and right) for each production system are presented in Table 3.3. No differences (P = 0.946) were observed between the different production systems for impala horn base circumference, with an average base circumference of 14.1 ± 0.23 cm for sub-adult impala for all three production systems. The extensive production system had higher (P ≤ 0.05) horn length and tip-to-tip measurements than the other two systems, while the latter two systems did not differ from each other. The impala from the extensive system also had a significantly higher number of horn rings (6.8 ± 0.78) than the impala from the semi-extensive system (4.5 ± 0.66), while the impala from the intensive system (5.6 ± 0.63) did not differ from those within either of the other two systems regarding horn ring numbers.

Table 3.3 LSMeans (± standard error) of impala horn measurements from different production systems

Horn measurements	Production system			P-value
	Intensive (n = 12)	Semi-extensive (n = 11)	Extensive (n = 8)	
Tip-to-tip measurement (cm)	7.0^{b} ± 1.55	5.7^{b} ± 1.62	13.2^{a} ± 1.82	0.011
Horn length (cm)	31.0^{b} ± 1.22	32.0^{b} ± 1.27	37.9^{a} ± 1.49	0.003
Horn base circumference (cm)	14.1 ± 0.21	14.0 ± 0.22	14.1 ± 0.25	0.946
Number of rings	5.6^{ab} ± 0.63	4.5^{b} ± 0.66	6.8^{a} ± 0.78	0.085

[a,b,c]Means with different superscripts in the same row differ significantly from each other (P ≤ 0.05).

3.3.2.2 Carcass and offal yields

The effect of production system on sub-adult male impala carcass yields are presented in Table 3.4. The extensive production system produced impala with a heavier (P < 0.001) mean undressed carcass weight (46.5 ± 1.12 kg) than the intensive (37.9 ± 0.92 kg) and semi-extensive systems (36.4 ± 0.96 kg), with no significant differences noted between the latter. Relatedly, impala from the extensive system also had significantly heavier dressed carcass weights (warm and cold) than the other two systems. However, dressing percentages did not differ (P = 0.364) between the three systems, thus the pooled mean warm dressing percentage for sub-adult impala males from all three production systems (n = 31) was 57.9 ± 0.58 % and the mean cold dressing percentage was 56.0 ± 0.58 %, with a mean chilling loss of 1.9 % in carcass weight after 24 hours in the cold room.

While the total offal yield in terms of weight was heavier (P < 0.0001) in extensive system impala than impala from the other two systems, the proportional total offal yield of impala males did not differ (P = 0.1937) between the three production systems when expressed as a percentage of the undressed carcass weight, with a pooled total mean of 39.7 ± 0.48 %. Impala from the extensive system also had significantly heavier mean head, skin, total external offal, liver, GIT, testes, and total internal offal weights than the intensive or semi-extensive impala, while those weights did not differ between impala from the latter two systems. Proportionally, no significant differences were observed between the three systems' impala for the contribution to undressed carcass weights of the skin (mean 4.8 ± 0.19 %), heart (mean 0.7 ± 0.02 %), GIT (mean 20.2 ± 0.52 %) and total internal offal (mean 25.2 ± 0.43 %). The GIT of impala from all systems had the highest proportional contribution to the total offal yield of all internal and external offal parameters measured.

The semi-extensive system impala had a higher (P < 0.001) proportional total external offal yield (14.7 ± 0.25 %) than the extensive system impala (14.0 ± 0.29 %), while intensive system impala did not differ from either of the other two systems. The mean percentage yield of the head was the highest in the intensive system impala (6.6 ± 0.10 %) and the lowest in extensive system impala (6.3 ± 0.12 %), while the semi-extensive system impala did not differ from either of the former systems. No differences were noted between the three systems for the mean lungs and trachea weights (P = 0.245) or spleen weights (P = 0.657). However, the proportional yield of the semi-extensive system impala was higher (P = 0.038) for the lungs and trachea (2.1 ± 0.12 %) and lower (P = 0.012) for the kidneys (0.27 ± 0.01 %) than the yields obtained from the intensive and semi-extensive system impala, while the latter two systems' impala did not differ significantly from each other for the proportional contribution of the kidneys or lungs and trachea. The proportional contribution of the liver to the undressed carcass weight was the highest in extensive system impala (1.7 ± 0.14 %) and the lowest in intensive system impala (1.4 ± 0.05 %), while the semi-extensive system impala did not differ significantly from either of the other two systems.

When combining the proportional contributions of the warm carcasses and total offal of all the impala for this study, a small percentage of the undressed carcass weight is unaccounted for (±2.7 % in intensive system impala, 1.2 % in semi-extensive system impala, 3.7 % in extensive system impala). This may be explained by the loss of small amounts of faecal matter, urine, milk (from females with udders), and residual blood during the slaughter proces

Table 3.4 LSMeans (± standard error) of sub-adult male impala carcass yields in kg and percentage (expressed as percentage of undressed carcass weight) as influenced by production system.

Carcass parameter		Production system			P-value
		Intensive (n = 12)	Semi-extensive (n = 11)	Extensive (n = 8)	
Undressed carcass	kg	$37.9^{b} \pm 0.92$	$36.4^{b} \pm 0.96$	$46.5^{a} \pm 1.12$	< 0.001
Dressed carcass - warm	kg	$21.9^{b} \pm 0.65$	$21.3^{b} \pm 0.68$	$26.6^{a} \pm 0.79$	< 0.001
Dressing percentage - warm	%[1]	57.9 ± 0.53	58.4 ± 0.55	57.1 ± 0.65	0.364
Dressed carcass - cold	kg	$20.9^{b} \pm 0.64$	$20.7^{b} \pm 0.669$	$26.1^{a} \pm 0.78$	< 0.001
Dressing percentage - cold	%	55.2 ± 0.53	56.7 ± 0.56	56.1 ± 0.65	0.155
Head	kg	$2.5^{b} \pm 0.07$	$2.4^{b} \pm 0.07$	$2.9^{a} \pm 0.08$	< 0.001
	%	$6.64^{a} \pm 0.10$	$6.56^{ab} \pm 0.10$	$6.28^{b} \pm 0.12$	0.071
Feet	kg	$1.2^{ab} \pm 0.04$	$1.2^{b} \pm 0.04$	$1.3^{a} \pm 0.05$	0.113
	%	$3.3^{a} \pm 0.11$	$3.2^{a} \pm 0.12$	$2.9^{b} \pm 0.14$	0.043
Skin	kg	$1.8^{b} \pm 0.08$	$1.8^{b} \pm 0.08$	$2.2^{a} \pm 0.10$	0.001
	%	4.6 ± 0.18	4.9 ± 0.18	4.8 ± 0.21	0.551
Total external offal	kg	$5.5^{b} \pm 0.14$	$5.4^{b} \pm 0.15$	$6.5^{a} \pm 0.17$	< 0.001
	%	$14.6^{ab} \pm 0.24$	$14.7^{a} \pm 0.25$	$14.0^{b} \pm 0.29$	0.122
Heart	g	$265.5^{b} \pm 8.68$	$237.0^{c} \pm 9.07$	$310.8^{a} \pm 10.63$	< 0.001
	%	0.7 ± 0.02	0.7 ± 0.02	0.7 ± 0.02	0.378
Lungs and trachea	g	666.7 ± 54.37	786.4 ± 56.79	785.9 ± 66.59	0.245
	%	$1.8^{b} \pm 0.11$	$2.1^{a} \pm 0.12$	$1.7^{b} \pm 0.14$	0.038
Liver	g	$541.0^{b} \pm 24.05$	$569.8^{b} \pm 25.12$	$779.4^{a} \pm 29.46$	< 0.001
	%	$1.4^{b} \pm 0.05$	$1.6^{ab} \pm 0.06$	$1.7^{a} \pm 0.06$	0.024
Kidneys	g	$115.3^{b} \pm 4.21$	$97.5^{c} \pm 4.39$	$144.1^{a} \pm 5.15$	< 0.001
	%	$0.31^{a} \pm 0.01$	$0.27^{b} \pm 0.01$	$0.31^{a} \pm 0.01$	0.012
Spleen	g	178.7 ± 10.01	192.0 ± 10.46	183.9 ± 12.27	0.657
	%	$0.47^{ab} \pm 0.02$	$0.53^{a} \pm 0.03$	$0.40^{b} \pm 0.03$	0.013
GIT[2]	kg	$7.5^{b} \pm 0.22$	$7.4^{b} \pm 0.23$	$9.3^{a} \pm 0.26$	< 0.001
	%	19.9 ± 0.48	20.5 ± 0.50	20.2 ± 0.58	0.719
Total internal offal	kg	$9.4^{b} \pm 0.23$	$9.3^{b} \pm 0.24$	$11.7^{a} \pm 0.28$	< 0.001
	%	24.9 ± 0.40	25.6 ± 0.41	25.2 ± 0.48	0.392
Testes	g	$20.3^{b} \pm 2.97$	$25.5^{b} \pm 3.10$	$55.6^{a} \pm 3.64$	< 0.001
	%	$0.05^{c} \pm 0.004$	$0.06^{b} \pm 0.004$	$0.12^{a} \pm 0.005$	< 0.001
Total offal	kg	$14.9^{b} \pm 0.34$	$14.7^{b} \pm 0.33$	$18.2^{a} \pm 0.39$	< 0.001
	%	39.4 ± 0.44	40.4 ± 0.46	39.2 ± 0.54	0.194

[a,b,c]Means with different superscripts in the same row differ significantly from each other ($P \leq 0.05$). [1]Parameter % = percentage of the undressed carcass weight. [2]GIT: gastro-intestinal tract (includes full stomach & intestines)

3.4 DISCUSSION

This study aimed to quantify the respective effects of sex and three different production systems on the carcass yield and meat production potential of impala in South Africa. With the expansion of the market for game meat and limited information available in literature on the influence of production system on meat production of game species, the contribution of this study may establish baseline data for the game industry. This may assist in future marketing of game meat and potential contribution of impala meat to the food security of South Africa.

3.4.1 Sex Comparison (Trial 1)

Once sexual maturity has been reached at 13-16 months, it would be expected that male impala would have heavier live weights than females at the same age (Furstenburg, 2005). However, no significant differences were found between the mean undressed or dressed carcass weights of male and female impala (Table 3.1), with mean undressed weights of 36.4 kg for males versus 37.8 kg for females. This is in contrast to the study by Hoffman (2000b), who observed that older, mature male impala had a significantly heavier mean undressed carcass weights than females (49.4 kg for males versus 33.5 kg for females). The heavier undressed carcass weights of male impala above that of females at the same age has also been noted in several other studies (Anderson, 1982; Du Plessis et al., 2006; Fairall & Braack, 1976; Hoffman et al., 2005b; Sachs, 1967; Theobald, 2002; Van den Berg, 2009) with the exception of very young impala at six months of age, where no differences in carcass weights between sexes were observed (Fairall & Braack, 1976). In relation, heavier dressed carcass weights for males have also been recorded in previous studies for warm (Hoffman, 2000b; Hoffman et al., 2005a; Van den Berg, 2009) and cold (Du Plessis et al., 2006; Hoffman, 2000b; Van den Berg, 2009) carcass weights. In contrast, studies by Van Zyl & Ferreira (2004) and Hoffman et al. (2009) found female impala to be heavier than males. In the study by Van Zyl & Ferreira (2004), age differences between sample animals were found as the cause for significant differences between the sexes, with much lighter live and dressed carcass weights recorded in the male impala (±18 months old, n = 2) than in the females (±36 months old, n = 6) in animals cropped in the Overberg Test Range near Bredasdorp in the Western Cape of South Africa.

Similar differences between the ages of male and female impala may also be a causal factor in differences between the sexes of impala from the present study. The presence of milk within the udders in four of the female impala in this study indicates that they had lambs at the time of culling. Female impala are approximately 18 months old at the first mating, with gestation lasting 185-205 days (Furstenburg, 2005; Oberem & Oberem, 2016). Therefore, these four ewes were at least 24 months old, assuming conception occurred at first mating. When undressed carcass weight is also considered, most of the female impala were estimated to be approximately 24-36 months old at culling, with a mean undressed carcass weight of 37.8 ± 1.30 kg. Only two of the 11 females culled had lighter undressed carcass weights (27.8 kg and 29.4 kg, respectively) than the 36.4 ± 0.91 kg mean weight of the male impala. The undressed carcass weights of these two females are similar to the weights recorded by Fairall & Braack (1976) for impala ewes at 12 months. Upon exclusion of the two younger females, the nine remaining female impala have a mean undressed carcass weight of 39.8 ± 1.01 kg, which is

significantly (P = 0.0204) heavier than the undressed carcass weights for the male impala. This is in accordance with the undressed carcass weight range of 38.3 kg to 40.5 kg recorded for adult female impala at 36 months or older in previous studies by Anderson (1982) and Fairall & Braack (1976). The female impala were therefore significantly older than the stipulated aim of 15-18 months old for the study, which reinforces the difficulty of female impala age estimation in the field due to overlapping body size between age groups and dense vegetation obscuring characteristics such as udders. In contrast, age estimation using horn size in the field proved to be accurate for the impala males, which were determined to be within the stipulated sub-adult age group (±15-18 months) according to their mean undressed carcass weights (mean of 36.4 kg) and horn shape and size, with a mean horn length of 29.3 cm and a mean of 5.8 rings per horn. The lack of sexual differences between undressed or dressed carcass weights may therefore be attributed to the age difference between the male and female impala in this study; with the males not having reached breeding age yet.

While impala males reach sexual maturity at 16 months of age, breeding with females only commences once males are three and a half years old. Impala are strictly seasonal breeders in southern Africa, with breeding season peaking in May (Fairall, 1983). Impala males usually gain weight prior to this season, during which competition with other males for a breeding opportunity with females will result in energy stores in the body being depleted and thus a consequential weight loss (Bourgarel, Fritz, Gaillard, De Garine-Wichatitsky, & Maudet, 2002; Furstenburg, 2005). The impala for this study were harvested in March, during which the males should be in optimum condition and heavier than females of the same age. However, at 15-18 months, the male impala would be too young to actively partake in breeding and would not gain the same condition as mature males that go into rut.

At 57.4 % (warm) and 55.9 % (cold), the mean pooled dressing percentages of male and female impala from the present study are higher than the dressing percentages of domestic livestock, which has been reported to range from 50.3 to 53.8 % for cattle (Nguni, Bonsmara, Angus) (Muchenje, Dzama, Chimonyo, Raats, & Strydom, 2008) and 41.5 to 44.2 % for sheep (South African mutton merino and dormer sheep) (Cloete, Hoffman, Cloete, & Fourie, 2004). In combination with the lack of visible subcutaneous fat in impala, these high dressing percentages are indicative of superior lean meat production potential in impala (Hoffman, 2000a). Comparing the effect of sex, the significantly higher dressing percentages of male impala compared to females in the present study (Table 3.1) are in contrast to the findings of Hoffman (2000a), Du Plessis *et al.* (2006) and Van den Berg (2009), whom found no significant differences between the sexes for dressing percentage of impala. Nonetheless, most dressing percentages recorded in previous research were similar to those of the present study. One study (Van Zyl & Ferreira, 2004) reported significantly higher dressing percentages in female impala (66.3 %) than in males (63.5 %) although this may also be attributed to the previously mentioned age difference between the animals in that study.

The high dressing percentages noted in the findings of Van Zyl & Ferreira (2004) and other authors (Du Plessis et al., 2006; Hoffman et al., 2005b) of up to 65.6 % may be explained by differences in the method of calculation for dressing percentage between studies (e.g. calculating dressing percentage using warm vs. cold carcass weight as percentage of live vs. whole empty body weight). This is demonstrated in the present study, where a decrease of 1.3-2.7 % in dressing percentage was recorded when warm carcass weight was substituted for cold carcass weight as percentage of

exsanguinated undressed carcass weight in the calculation. This is the result of a loss in dressed carcass weight in the chiller, as caused by shrinkage due to moisture loss from the carcass (Savell, Mueller, & Baird, 2005; Smith & Carpenter, 1973). Previous researchers have also noted problems resulting from variations in the calculation of the dressing percentages used to express carcass yield in literature, with dressing percentages calculated before vs. after exsanguination and with full vs. empty stomach and intestines (Ledger, 1963, 1967; Von La Chevallerie, 1970; as referenced by Hoffman, 2000a). These methodological variations in dressing percentage calculation complicates the comparison of game animal dressing percentages to those of domestic livestock. Typically, livestock have restricted feed intake prior to culling and therefore decreased intestinal content at time of slaughter, thus influencing their undressed carcass weights and consequent dressing percentages (Hoffman, 2000b). Nonetheless, the information on yield (weight) is of value to the industry and researchers as it gives a better indication of the weight of carcasses from this species when predictions are made on how much meat various wild animals can provide (as estimated for example by Taylor et al., 2016).

Variation in gut fill could also have influenced the results of the present study, where differences in dressing percentages may be influenced by the differences in offal yields between male and female impala. Female impala were found to have higher internal offal yields (11.1 ± 0.49 kg for females versus 8.8 ± 0.49 kg for males), mostly due to their heavier gastro-intestinal tract (GIT) weights. The heavier GIT, consisting of stomach and intestines, of female impala over that of males from the same farm location recorded in this study is in accordance with the findings of Hoffman (2000b) and Hoffman et al. (2005b), although those results were obtained by comparing empty, washed GITs, whereas the GITs from the present study were weighed with full contents. Differences in gut fill due to *ante-mortem* feeding cause variation in stomach and intestine weights, which may in turn affect dressing yields (Hoffman et al., 2009). Because of their higher internal offal yield, female impala had a significantly higher mean total offal yield (41.6 ± 0.84 %) than males, despite the higher total external offal yield (comprised of head, skin and feet yields) presented by male impala (Table 3.1). The heavier head weights of the male impala can be explained by the lack of horns in the female impala, with similar findings reported in previous studies (Hoffman, 2000b; Hoffman et al., 2005b; Sachs, 1967). The heavier feet yields of male impala found in this study is also in accordance with the results of Hoffman et al. (2005b). The differences between sexes for the head and feet yields are indicative of sexual dimorphism that is present regardless of age differences between male and female impala.

The six main commercially important muscles did not differ in weight between the left and right side of carcasses, nor between sexes for the impala in this study (Table 3.4). The lack of sexual dimorphism between muscles is in contrast with the results of Hoffman (2000b), whom observed heavier carcass cuts for male impala. This may also be explained by the age differences between sexes of the impala in this study as well as the young age of these impala, with the lack of difference between sexes for undressed and dressed carcass weights causing a similar lack of sexual dimorphism between individual muscle yields. The LTL muscle was the heaviest of all impala muscles, which is beneficial for meat production, as this muscle is considered to be a valuable cut in livestock species such as beef and lamb due to its high tenderness and low intramuscular fat content. Additionally, the heavier muscles from the hindquarter are popular for the processing of biltong (Jones, Arnaud, Gouws, & Hoffman,

2017).

3.4.2 Production system comparison (Trial 2)

Significant differences were observed between the three different production systems with regards to the horn measurements. However, one of the eight extensive system impala that were included in the statistical analysis was significantly older than the rest (52.5 kg undressed carcass weight, 53.4 cm horn length, 15 horn rings), estimated at 30 months old according to horn size. The inclusion of this impala had a significant influence on the results of the horn measurement group, leading to an increase in the mean tip-to-tip measurement, horn length, base circumference and number of rings of the extensive production system. When this outlier is removed, the mean horn measurements of the remaining extensive system impala (n = 7) are as follows: 10.6 ± 1.27 cm for tip-to-tip distance, 35.7 ± 0.77 cm for horn length, 14.0 ± 0.22 cm for base circumference and 5.4 ± 0.41 for the number of rings, all which are within the expected range for impala within the 18-month age group. Therefore, there was no apparent mean age difference between the different treatment groups for the production system comparison. Except for the horn measurements, inclusion of the single older impala in the extensive system group did not significantly influence mean carcass yields of the extensive system in the production system comparison.

When comparing impala from different production systems, it would be expected that impala finished in an intensive system (similar to a feedlot in livestock production) should have higher carcass yields than those of animals raised in semi-extensive or extensive systems at the same age. However, significantly higher undressed carcass weights were obtained from the extensively produced impala from the Bredasdorp region of the Western Cape, compared with both the intensive and semi-extensive system impala from the Modimolle region of the Limpopo Province of South Africa (Table 3.4). This contrasts with the results reported in other studies where intensive production systems produced higher carcass weights than conventional or extensive systems for beef (Keane & Allen, 1998) and where a semi-extensive system produced higher carcass weights than an extensive system for blue wildebeest (Van Heerden, 2018). Sampels, Pickova & Wiklund (2005) found that production system influenced the carcass weights of reindeer, with significantly heavier carcasses produced by reindeer that were fed grain-based pellet feeds, although production system in this study was characterized by diet rather than farming intensity.

In the present study, the significant difference in undressed carcass weights between sub-adult male impala of the extensive system from that of impala from the other two systems may be caused by regional and nutritional differences between the two farming locations, rather than differences between production systems *per se*. Previous research has shown varying results for the carcass yields of impala from different farm locations in different farming regions, even within the same biome (Anderson, 1982; Du Plessis et al., 2006; Hoffman et al., 2005b). While each farming region is unique in terms of natural vegetation and climate, individual farm locations within these regions may vary greatly in terms of management practices, camp sizes, production systems and nutritional content of the natural vegetation and supplied feed. However, most of these factors are often not specified in previous research studies, and the present study is the first to compare the influence of different production systems on impala. Therefore, comparisons must be made on basis of farm location and region with

the limited knowledge available.

The undressed carcass weights of the sub-adult male impala from different production systems obtained in this study are similar to the weights obtained in previous research (Du Plessis et al., 2006; Hoffman et al., 2005b; Hoffman et al., 2009). At 37.9 kg (intensive, n = 12) and 36.4 kg (semi-extensive, n = 11), the mean undressed carcass weights for impala from the intensive and semi-extensive production systems at Castle de Wildt, Limpopo, were within the range of previously obtained mean undressed carcass weights (33.0-38.1 kg) of sub-adult impala in similar production regions of the same province (Du Plessis et al., 2006; Hoffman et al., 2005b; Hoffman et al., 2009). The higher mean undressed carcass weight of extensive system impala (46.5 kg, n = 8) in the Bredasdorp region of the Western Cape was similar to those of sub-adult impala from Mara Research Station in Limpopo (46.9-48.3 kg), where impala occur naturally on a farm that focuses primarily on extensive cattle production (Du Plessis et al., 2006; Hoffman et al., 2005b). Relatedly, the dressed carcass weights of intensive and semi-extensive production systems were in accordance with the findings of earlier researchers for warm carcass weight (Van Zyl & Ferreira, 2004) and cold carcass weight (Du Plessis et al., 2006; Hoffman et al., 2009) for sub-adult male impala at ±18 months. Dressed carcass weights for the extensive system impala also were similar to previous findings for both warm carcass weight (Hoffman et al., 2005b) and cold carcass weight (Du Plessis et al., 2006).

When comparing the findings of this study with previous research, it was observed that impala carcass weights vary significantly both between and within the provinces of South Africa. In the Limpopo province, mean male impala carcass weights are significantly higher at the Mara Research Station than at the Messina/Musina Experimental Farm (Du Plessis et al., 2006; Hoffman et al., 2005b), the Mabula District (Hoffman et al., 2009) and Castle de Wildt (present study), all of which are located within the Savanna biome. Similarly, the impala from the Western Cape farm in this study were substantially heavier than impala from the Overberg Test Range (Van Zyl & Ferreira, 2004), with both farms located near Bredasdorp in the Western Cape, within the Fynbos biome. However, due to the limited sample size (n = 2) of the male impala for the Overberg study (Van Zyl & Ferreira, 2004), results may not be representative of all impala from that age group and location.

In earlier studies on impala from different farming regions and ages, dressing percentages recorded for male impala ranged from 53 % for young animals at 9 months (Fairall, 1983) to ± 66 % for older animals at 54 months during the mating season (Hoffman et al., 2005b), with the majority ranging from 56-61 % for male impala of all ages (Du Plessis et al., 2006; Fairall, 1983; Hoffman, 2000b; Hoffman et al., 2005b; Hoffman et al., 2009; Van den Berg, 2009). Despite the significantly heavier carcass weights of extensive system impala, the present study found no differences between the dressing percentages of sub-adult male impala for either production system (intensive, semi-extensive or extensive) or farm location (near Modimolle vs. near Bredasdorp), with dressing yields ranging from 57.1 to 58.4 % for warm carcasses and from 55.2 to 56.7 % for cold carcasses. These dressing percentages are similar to those previously recorded for sub-adult male impala culled in a mixed game camp at Musina/Messina Experimental Farm (57.0-59.2 %) but are lower than the ± 61% dressing percentage recorded at Mara Research Station (Du Plessis et al., 2006; Hoffman et al., 2005b) where impala occur naturally on a farm that focuses primarily on extensive cattle production.

The high carcass weights and dressing percentages recorded in impala from Mara Research

Station in previous studies may be due to the nutritional environment. Mara is located in Arid Sweet Bushveld, which is considered to be the optimum habitat for impala with a high variety of superior quality grazing material (Acocks, 1988, as cited by Kritzinger, 2002). Increased dietary nutrient availability results in higher availability of energy for growth and consequent size and weight increases (Kritzinger, 2002). Mature impala in the Lowveld of eastern South Africa have up to 13 % lower body weights than impala from north-western Limpopo and north-eastern North West provinces (Bothma, Van Rooyen, & Du Toit, 2016). In natural circumstances, the intermediate feeding behaviour of impala allows them to select browsing material with higher nutritional quality (Rodgers, 1976), and higher variety of selection allows for an increased carcass weights. This is observed with the high carcass weights in impala from the Arid Sweet Bushveld Mara region, whereas lower carcass weights were observed in the Mopani veld region of Musina Experimental Farm (Hoffman et al., 2005b), a monoculture region with high fibre content and lower digestibility. While the Central Rûens Shale Renosterveld region near Bredasdorp is not considered part of the historically natural range of impala, the present carcass yield results of these sub-adult male impala from the extensive system are similar to results obtained in the optimal nutritional habitat for impala at Mara Research Station (Du Plessis et al., 2006; Hoffman et al., 2005b). This suggests that the natural Fynbos vegetation in the Bredasdorp region of the Western Cape could have high nutritional quality, which possibly contributed to the increased carcass weights of the extensive system impala. In addition, the increased variety in vegetation in the Shale Renosterveld region may allow for increased dietary selection and higher carcass weights in extensive system impala than the Central Sandy Bushveld Modimolle region in the 200 ha camp of the semi-extensive system, or the lack of variety in the supplied feed of the 0.25 ha intensive system. However, the main aim of this study was to compare different production systems rather than diet, therefore the nutritional quality of the natural vegetation of the different production systems was not determined and highlights an area for further research.

In a comparison of impala of different ages from the 444 ha Nyala Game Ranch to impala from the much larger Kruger National Park (Fairall & Braack, 1976) and Serengeti National Park (Sachs, 1967), Anderson (1982) concluded that male impala from smaller game farms had lower live weights than impala from larger farms. Higher live weights of game animals from large game reserves with more natural populations are thought to be the result of elimination of smaller, weaker animals by predators. In contrast, the lighter live weights of animals from smaller game farms may be caused by animals with superior horn and body size to be sold for trophy hunting or reserved for the breeding herd, although consistently lower undressed carcass weights at one location for impala at all ages is indicative of growth being hampered by amongst others, parasitic infection of animals from a young age (Anderson, 1982). The presence of internal parasites may also have influenced the carcass yields of impala from different production systems and locations in the present study. During evisceration, liver flukes (*Fasciola* spp.) were observed in the livers of two of the 11 sub-adult males and one of the 11 females from the sex comparison, as well as in two of the 12 sub-adult males in the intensive boma system inthe production system comparison, all originating from the Modimolle region in the Limpopo province. The observed liver flukes recorded in this study were only those visible to the naked eye upon removal of the liver from the carcasses without further in-depth examination to determine whether additional animals may have been affected. The extensively produced impala from the Bredasdorp region did not

present with any visible signs of internal parasites. These findings are consistent with those of Ezenwa (2004), whom determined that the rate of parasitic infections increase when game species are held in smaller enclosures with increased stocking rates, such as intensive boma systems, whereas larger, more natural populations with lower stocking densities and consequent improved pasture quality have lower parasite loads (Anderson, 1982). Additionally, parasites are more prevalent in animals from environments with a higher rainfall (Van Wyk & Boomker, 2011), which explains the apparent lack of parasites in impala in the low rainfall areas of the Bredasdorp region (300-480 mm per year) and Mara Research Station (452 mm per year) (Hoffman et al., 2005b). While the livers of most impala from the Modimolle region appeared to be free of internal parasites in this study, no further examination of their intestines was conducted to determine the actual parasite load. Such an examination was conducted by Van Wyk & Boomker (2011), whom found that impala from similar environments in the Limpopo province are highly susceptible to several species of internal parasites due to their mixed feeding behaviour and the climatic environment.

Internal parasites may result in a nutritional deficiency and consequent decreased live weight of impala (Theobald, 2002). Even though supplied feed was the only source of feed intake for the impala from the intensive system in this study, these impala were raised in the same environment as semi-extensive impala until 9-12 months of age before they were moved to the boma system six months prior to culling. The intensive boma system consisted of a camp of only 0.25 ha in size, which is below the recommended minimum of 25 ha for 12 impala (Furstenburg, 2016). Due to the overgrazing, the impala from the intensive production system were prohibited from engaging in their natural feeding behaviour due to a lack of natural vegetation. Despite the *ad libitum* supply of feed, the high stocking density in such a small camp may be a disadvantage to growth in the intensive system impala, as confined areas subject game animals to unnatural conditions that expose them to stress factors (Anderson, 1983). While neither chronic nor acute stress was quantified for the impala in the present study, stress factors associated with confinement may increase vulnerability to detrimental environmental factors such as parasites. Anderson (1982) reported that parasitic infections at a young age may limit growth and consequent live weights of impala consistently throughout their lifetime. Combined with nutritional quality differences between regions, parasitic infection from a young age may explain the lack of significant carcass yield advantage for impala finished in the intensive system above that of semi-extensively raised impala in this study, as well as the lower undressed carcass weights for both the intensive and semi-extensive production systems in the Modimolle region than that recorded for the extensive system impala from the Bredasdorp region. While treatment of parasites may not rectify the loss in weight gain caused by infection at a young age, rotational grazing may be an effective preventative measure by improving pasture condition and consequently reducing parasitic contamination of the pasture itself, thereby circumventing the complications that ensue from high stocking densities. A variety of parasites in impala may be treated with non-toxic, soluble anti-helmintics (e.g. fenbendazole or albendazole) provided in the form of mineral licks or added to watering points, thereby reducing infection rates (Anderson, 1983). However, the safety of anti-helmintics will have to be determined for the meat production of impala, particularly concerning the duration that residues may remain in the meat and internal and external offal. Even so, research performed concerning these factors on other ruminants may be used as a guideline.

The internal and external offal (including the heart, liver, kidneys, stomach, intestines, head and feet) of impala is considered to be an edible by-product of meat production and may provide a wholesome and cost-efficient alternative protein source that may contribute to South African food security, with one impala yielding as much as three kilograms of edible offal (McCrindle et al., 2013). Impala from the extensive system had significantly higher total external and internal offal weights than impala from the other two systems. However, no significant differences were observed between the three production systems when these weights are calculated as a proportion of the mean undressed carcass weight for the impala of each production system. The pooled means of sub-adult male impala from all three production systems were calculated to have a proportional yield of 39.7 % total offal, which is comprised of 25.2 % internal offal and 14.5 % external offal. The lack of significant differences between the total proportional distributions for impala offal of all three production systems from both production regions are in accordance with the lack of significant difference between the dressing percentages of the production systems. In contrast, Hoffman et al. (2005b) found differences between production regions for proportional carcass yield, with the proportion of external and internal offal lower in male impala from the Mara Research Station than impala from the Musina Experimental Farm, while the dressing percentage was higher at Mara. However, Hoffman et al. (2005b) determined the proportional offal yield for the empty GIT, which may be larger in impala from Musina due to the higher fibre content of the Mopani veld vegetation compared to vegetation with higher nutrient concentrations and thus reduced rumen size for impala at Mara. In the present study, the proportional yield was determined for the full GIT. The lack of significant proportional differences between the GIT and total internal offal of impala from all three production systems indicates that the selected dietary fibre content of all three production systems was similarly high enough to prevent the reduction in GIT volume associated with low fibre intake (Hofmann, 1989), whereas large differences in dietary fibre intake would have resulted in different proportional yields between production systems. In addition, the proportional yield of the GIT and total internal offal would be expected to be similar for impala of the same sex at the same age, as the GIT increases in constant proportion to increasing live weight as the animal moves through different stages of the growth curve (Demment & Van Soest, 1985). The proportional similarity of carcass and total offal yields between all three production systems is in accordance with expectation for male impala at the same age and in the same stage in the growth curve.

3.5 CONCLUSION

The results of this study demonstrate that the overall mean carcass weights and dressing percentages (warm or cold dressed carcass weights expressed as percentage of undressed carcass weight) of the impala in this study are similar to the values obtained by previous researchers. The high mean dressing percentages of 56-58 % for all impala in this study (Trial 1 & 2) are superior to those of domestic livestock, which is promising for overall meat production potential of impala. The internal offal of impala comprises a substantial proportion of the undressed carcass weight and should be fully utilized as an edible by-product of meat production. The lack of significant sexual dimorphism between male and female impala in this study is the result of significant age difference between the sexes with the males still being young and reiterates the difficulty of age estimation for female impala in the field due to lack

of horns as criteria for age estimation.

The proportional total offal yields and dressing percentages did not differ significantly between production systems for sub-adult male impala, which indicates that undressed and dressed carcass weights will determine the meat production potential of impala from different production systems and production regions. Mean carcass weights were significantly heavier for impala from the extensive system in the Bredasdorp region than for impala from either the intensive or semi-extensive systems in the Modimolle region, which may be caused by variation in nutritional quality and selection variety, environmental conditions, and parasite loads between the two production regions. Contrary to expectation, the intensive system presented no substantial advantage in terms of carcass yields over that of the semi-extensive system when impala are harvested at 15-18 months of age in the same production region and after having received a feedlot diet for six months. Therefore, the increased management input and feed required for the intensive production system is not justified when impala are slaughtered at 18 months of age after only six months in the intensive system.

These research results may prove to be valuable as baseline data regarding the carcass performance of impala under different production management in the game industry. However, it is recommended that the influence of sex and production system on the meat quality of impala should be investigated for more accurate recommendations regarding the meat production potential of impala. Additionally, further research is required where diet and farming region is controlled or extensively quantified to better ascertain the influence of production system management practise on carcass performance and yield over a range of culling ages for both sexes of impala. It is also recommended that both chronic and acute stress as typically experienced during the feeding and culling process should be evaluated in further research studies to determine the effect of stress on the growth and carcass yield of impala.

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CHAPTER 4

PHYSICAL MEAT QUALITY ATTRIBUTES OF IMPALA (*AEPYCEROS MELAMPUS*) AS AFFECTED BY SEX, MUSCLE AND PRODUCTION SYSTEM

ABSTRACT

The aim of this study was to determine the influence of sex, muscle (*Longissimus thoracis et lumborum, biceps femoris, semimembranosus, semitendinosus, infraspinatus,* and *supraspinatus*), and three different production systems (intensive, semi-extensive and extensive) on the physical meat quality of impala. Sex-muscle interactions were found for the drip loss percentages, cooking loss percentages and CIE a* values. The pH_u of both sexes, all muscles and both intensive and semi-extensive production system impala fell within the acceptable normal range (5.6-5.9). However, the extensive system impala had an exceptionally high pH_u (6.2 ± 0.06) and produced meat with DFD-like characteristics, with the lowest drip loss (0.9 ± 0.14 %), cooking loss (28.1 ± 0.79 %) and darkest, least red and least saturated surface colour (L* = 26.8; a* = 10.0; b* = 5.2; chroma = 11.4). With the exception of extensive system impala, all impala meat had CIE colour measurements within the range of expectation for game meat (L* = 30.9-36.8; a* = 11.4-13.6; b* = 6.0-8.8). Overall, impala meat from both sexes, all muscles and all production systems produced meat with shear force values below 43 N (range of 19.2-39.3 N) and may thus be classified as tender. This study has shown that impala meat has desirable physical meat quality attributes that are comparable with those of other game species and traditional livestock, and the results may be useful for improvement of the marketing and sale of impala meat.

Keywords: Game meat, Impala, Surface colour, Tenderness

4.1 INTRODUCTION

The South African game industry is based on four pillars, namely hunting, ecotourism, breeding and meat production, by means of the utilization of a wide variety of indigenous game species (Oberem & Oberem, 2016; Van der Merwe, Saayman, & Krugell, 2004). Initial success of the industry was due to hunting and ecotourism, followed by expansion in breeding and live sales of high value game species and colour variants, such as the black impala and golden wildebeest (Bothma, Sartorius Von Bach, & Cloete, 2016; Oberem & Oberem, 2016). The expansion of the South African game industry has resulted in increased utilization of different production systems that enable optimum selective breeding and animal production to increase live sales (Taylor, Lindsey, & Davies-Mostert, 2016). This opportunity for the selective breeding of game colour variants has resulted in a surplus of "split" animals (F1 progeny that carry recessive genes for colour variation) and colour variants with inferior horn characteristics, which are culled for game meat production (Bothma et al., 2016).

The importance of meat production for the financial sustainability of game farming is increasing (Berry, 1986; Bothma et al., 2016; Hoffman, Kritzinger, & Ferreira, 2005b). In comparison to live sales, trophy hunting and recreational hunting, Berry (1986) found that game meat production generated the highest net revenue per biomass weight. Due to the low intramuscular fat and high protein content of game meat (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012; Hoffman, 2000b, 2007; Van Zyl & Ferreira, 2004; Von La Chevallerie, 1972), meat from indigenous South African game animals is considered a healthy alternative protein source to red meat obtained from domestic livestock (Bekker, Hoffman, & Jooste, 2011; Hoffman et al., 2005b; Hoffman, Van Schalkwyk, & Muller, 2008). In addition, the culling of game through hunting is also considered to be more humane than present traditional livestock operations at abattoirs (Cooper & Van der Merwe, 2014). In combination with the increased demand for game meat by health-conscious consumers, and the increase in game animals available for sustainable culling, the production and sale of South African game meat has the potential to expand significantly (Bekker, Hoffman, & Jooste, 2011; Bothma et al., 2016).

It is important to quantify all aspects of the physical quality of meat from game animals, such as the impala, to improve overall meat quality and market competition with traditional meat types and meat products (Kohn, Kritzinger, Hoffman, & Myburgh, 2005). The impala, a southern African antelope, is a popular choice for the breeding of colour variants that is also favoured for its meat (Furstenburg, 2005). Impala are widely distributed throughout South Africa due to the ability of this species to utilize a wide variety of habitats (Fairall, 1983; Mason, 1976), and is recorded as the most common herbivore species on South African game ranches, accounting for 24.1 % of all animals counted (Taylor et al., 2016). Combined with the gregarious behaviour, rapid reproduction rate and high carcass yield of this species, impala are considered to be ideal for continuous culling for the production of game meat (Chapter 3; Fairall, 1983; Féron, Tafira, Belemsobgo, Blomme, & De Garine-Wichatitsky, 1998; Hoffman, 2000b; Schenkel, 1966).

Game meat is subjected to evaluation by the same meat quality criteria as meat from traditional livestock, which includes the evaluation of muscle pH, water-holding capacity, tenderness and colour as physical parameters of meat quality (Hoffman, 2000b; Issanchou, 1996). The ultimate pH (pH_u) valueof meat (measured approximately 24 hours *post-mortem*) is a direct result of the muscle glycogen

(energy) levels at slaughter and provides information on the physical quality of meat pertaining to surface colour, water-holding characteristics, shelf-life and tenderness (Wiklund, Manley, & Littlejohn, 2004). Meat surface colour is an intrinsic quality que which plays an important role in consumer acceptance, as it is often equated to meat “freshness” (Mancini & Hunt, 2005; Troy & Kerry, 2010). The colour of meat is affected by the chemical composition and myoglobin content of meat, which in turn is influenced by the function and level of activity of the muscles in the animal (Neethling, Suman, Sigge, Hoffman, & Hunt, 2017). The tenderness of meat is related to the palatability of the meat and thus influences consumer eating experience and acceptance. Meat tenderness is influenced by variation in *ante-mortem* treatment, species and sex of animals, as well as the extent of proteolysis (primarily by calpains) on structural proteins, collagen content and degree of muscle fibre shortening in the meat *post-mortem* (Dransfield, 1993; Offer et al., 1989; Troy & Kerry, 2010).

The suitability of the impala for sustainable culling and the potential of this species for meat production has recently merited research that investigated the physical meat quality parameters of this species as influenced by sex and rifle calibre (Hoffman, 2000a), and culling method (Hoffman & Laubser, 2009; Kritzinger, Hoffman, & Ferreira, 2003). Previous research has also investigated the physical meat quality of impala in comparison to other game species such as the kudu (*Tragelaphus strepsiceros*) (Hoffman, Mostert, Kidd, & Laubscher, 2009; Mostert, 2007). However, the majority of previous studies on physical impala meat quality have been limited to only the *Longissimus thoracis et lumborum* (LTL) muscle, whilst the influence of sex on the physical meat quality of all six different commercially important muscles has not yet been investigated. In addition, the effect of different production systems on the physical meat quality of impala has not yet been determined. Therefore, the aim of this study was to collect data on the physical meat quality of six commercially important muscles from male and female impala and to investigate differences between sexes, muscles and production systems thereupon.

4.2 MATERIALS AND METHODS

4.2.1 Experimental location and animals

A total of 58 impala were obtained from two experimental locations in March of 2017, namely Castle de Wildt near Modimolle in the Central Sandy Bushveld bioregion of the Savanna biome in the Limpopo province (semi-extensive), and a farm near Bredasdorp in the Central Rûens Shale Renosterveld vegetation unit of the Western Cape province of South Africa (extensive). A 0.25 ha boma system located at Castle de Wildt in the Modimolle region was used to produce impala intensively. To compare the influence of sex and muscle, 22 (11 males and 11 females) of the 58 impala for this study were culled from the semi-extensive production system at Castle de Wildt (Trial 1). For the production system comparison (Trial 2), a further 12 sub-adult male impala were culled from the semi-extensive system, as well as 12 animals from each of the intensive and extensive systems (n = 36). The 12 male impala maintained in the intensive system received feed supplied *ad libitum* (8.3 % moisture, 13.3 % crude protein, 91.7 % dry matter, 7.6 % ash, 27.9 % crude fibre) in troughs as their sole source of daily feed intake for six months before culling. The semi-extensive production system consisted of a 200 ha camp at Castle de Wildt, where the primary source of feed intake for the impala consisted of the natural

Savanna vegetation, supplemented by feed with the same composition as that supplied to the intensive system impala. The extensive production system near Bredasdorp consisted of a single 800 ha camp that was large enough for the management of self-sustaining game populations in natural ecosystems. The sole source of feed intake for impala in this system was the natural Fynbos vegetation, and minimal human intervention was required through provision of watering points and mineral licks. All impala in the extensive system were natural common impala, with no selective breeding for colour variants practiced on the farm. Further information regarding the description of vegetation and production of the impala can be found in the Materials and Methods of Chapter 3.2.1.

4.2.2 Culling, carcass processing and sampling

All impala were culled during the day (ethical clearance number 10NP_HOF02) using suppressor-equipped light calibre rifles (.22 or .243) and exsanguinated, tagged and transported to the on-farm slaughter facilities as described in Chapter 3.2.2. At the slaughter facility, the impala carcasses were skinned, eviscerated and dressed according to the guidelines stipulated by Van Schalkwyk & Hoffman (2016), after which the dressed carcasses were hung in a chiller set to 4 ± 1°C to undergo *rigor mortis*. After ±24 hours in the chiller, all impala were deboned and selected muscles were excised for further analysis. For the sex and muscle comparison, six commercially important muscles were removed in their entirety from the back (*Longissimus thoracis et lumborum/LTL),* hindquarters (*Biceps femoris/BF, semimembranosus/SM* and *semitendinosus/ST*) and forequarters (*Infraspinatus/IS* and *supraspinatus/SS*) of both the left and right sides of the carcasses of the 11 male and 11 female impala of the sex comparison (n = 22) trial. For the production system comparison, only the LTL muscles were sampled for further analysis from both sides of the carcasses of the 36 impala from the three different production systems. All muscles were weighed individually, and sections of all muscles sampled from the right side of the carcasses were kept for physical analyses.

4.2.3 Physical analysis

4.2.3.1 Acidity (pH)

The ultimate pH (pH_u) of each impala muscle was measured at ±24 hours *post-mortem* with a two-point calibrated (using standard buffers of pH 4 and pH 7) Crison pH25 portable pH meter (Crison Instruments, Barcelona, Spain) with a glass electrode. Measurements were taken by inserting the electrode at an angle as close to the centre of each whole muscle as possible. Between each measurement, the electrode was cleaned by rinsing with distilled water and blotted dry with absorbent paper. After the pH_u was measured, three ±2.0 cm thick steaks were cut from the centre of each sampled muscle, at a right angle to the long axis of the muscle, for further physical analyses.

4.2.3.2 Colour

The surface colour of the fresh impala meat was measured on the three ±2.0 cm steaks that were cut for physical meat quality analyses, prior to the performance of the drip loss and cooking loss procedures. Colour measurements were taken with a calibrated Colour-guide 45°/0° colorimeter (BYK-Gardner GmbH, Gerestried, Germany) at five random positions on the surface of the meat after a

blooming period of ±30 minutes. Measurements were in accordance with the CIE Lab colour system, which reported values according to lightness (CIE L*), red-green spectrum (CIE a*) and blue-yellow spectrum (CIE b*). The recorded CIE a* and CIE b* values were used for the calculation of the hue-angle (colour definition) and chroma values (saturation/colour intensity). Calculations were performed according to the following equations:

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

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

4.2.3.3 Water-holding capacity (WHC)

The water-holding capacity of impala meat was determined by measuring the moisture loss of the meat. This was done by using the procedures as described by Honikel (1998) to determine the drip loss percentage of raw meat and the cooking loss percentage of cooked meat. For the determination of drip loss from the raw meat samples, one of the ±2.0 cm thick steaks cut after the pH_u measurement was weighed to record an initial weight for each sample. Samples were placed individually into inflated plastic bags and suspended after ensuring that the meat did not make contact with the interior of the bag. The samples were hung inside a chiller set to 4 ± 1°C for a duration of 24 hours. After this period, the samples were removed from the sealed plastic bags, blotted dry with absorbent paper to remove excess moisture, and weighed to determine the amount of moisture lost. The weight of each raw meat sample was expressed as a percentage of the initial weight to represent the drip loss (Honikel, 1998).

For the determination of cooking loss, one ±2.0 cm thick steak of each fresh meat sample was weighed to obtain an initial weight and placed inside a labelled thin plastic bag. The samples were subsequently placed into a preheated water bath set to a constant temperature of 80°C for a period of 60 minutes. Each meat sample was fully submerged for the duration of the cooking period. After 60 minutes, the cooked samples were removed from the water bath and excess water in the cooking bag drained. The samples were kept in their individual bags and placed inside a chiller at 4 ± 1°C for six hours until cooled. Thereafter, the samples were blotted dry with absorbent paper and weighed to record the final cooked weight of each sample for the determination of moisture lost through cooking. Cooking loss was determined by expressing the final weight of the cooked meat sample as a percentage of the initial weight of the fresh meat sample prior to cooking in the water bath (Honikel, 1998).

4.2.3.4 Warner-Bratzler shear force (WBSF)

The tenderness of impala meat was measured by determining the Warner-Bratzler shear force (WBSF) of the cooked meat samples used for determination of cooking loss. After the measurement of cooking loss, six cylindrical cores (with a diameter of 1.27 cm) were removed from the centre of each sample, ensuring that visible collagen tissue was excluded from the sampled cores. Each core was sheared at a right angle to the longitudinal axis of the muscle fibres with a Warner-Bratzler blade at a speed of 3.33 mm/s. The blade was fitted to an electronic scale that measured the peak force required to cut through the sample. Measurements were recorded in kg/1.27cm Φ diameter. The tenderness of each muscle was obtained by calculating the mean of the six measurements taken per sample, with lower shear

force values associated with more tender meat (Honikel, 1998). In order to allow the values obtained in this study to be more comparable with previous research and to maintain consistency throughout the thesis, the calculated measurements in kg/1.27cm Φ diameter were converted into Newton (N). Conversion was performed with the following calculation:

$$\text{Warner-Bratzler shear force (N)} = (\text{kg/1.27cm } \Phi * 9.81) /$$

$$\text{Area Where area} = \pi (1.27/2)^2$$

4.2.4 Statistical analysis

The experimental design of the sex and muscle comparison trial (Trial 1) was a completely random split plot design with 11 impala culled at random for each sex (male and female; n = 22). Sex served as the main plot factor and muscle (LTL, BF, SM, ST, IS and SS) served as the subplot factor. The production system trial (Trial 2) was a completely random experimental design with twelve male impala culled at random for each production system (intensive, semi-extensive and extensive; n = 36). Animals that were determined to be outside the stipulated 15-18 months age class were removed from statistical analysis. Statistical analysis for the production system comparison was consequently performed on the LTL muscles of the remaining 31 sub-adult impala from the intensive (n = 12), semi-extensive (n = 11) and extensive (n = 8) production systems. Data obtained for the physical meat quality attributes (pH_u, drip loss, cooking loss, shear force and colour) of impala from both trials was analyzed 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 from the model to test for deviation from normality (Shapiro & Wilk, 1965). However, it was not required to remove any further outlier values after removal of the abovementioned outlier animals. Fisher's least significant difference was used to compare sex, muscle or production system means (Lyman Ott & Longnecker, 2010). A probability level of 5 % was used, below which ($P \leq 0.05$) differences between the variables are deemed to be significant.

4.3 RESULTS

4.3.1 Sex and muscle comparison (Trial 1)

Interactions were observed between the effects of sex and muscle for drip loss percentage ($P < 0.001$), cooking loss percentage ($P = 0.012$) and the CIE a* values ($P = 0.017$) of impala meat (Figure 4.1). The drip loss percentage was significantly higher in female impala for the LTL, BF, SM and ST muscles and lower in the IS muscles than in male impala, while drip loss percentage did not differ between sexes for the SS muscle (Figure 4.1.a). The cooking loss percentage was also higher ($P \leq 0.05$) in female impala for the LTL, BF, SM, IS and SS muscles than in male impala, while the sexes did not differ significantly for the cooking loss percentage of the ST muscle (Figure 4.1.b). The a* values were lower ($P \leq 0.05$) in male impala for the LTL, BF, ST, and IS muscles than in females, while no significant differences were recorded between sexes for the a* values of the SM muscle (Figure 4.1.c).

No further interactions were observed between sex and muscle for the remaining meat quality parameters of the impala. Thus, the main effects of sex and muscle were interpreted individually for

the remainder of the parameters measured, reported within Table 4.1 and 4.2, respectively. Despite the interactions recorded between sex and muscle for the drip loss percentage, cooking loss percentage and a* values, the parameters are presented in Table 4.1 and 4.2 as affected by sex and muscle, respectively, to provide a more thorough representation of the meat quality of impala.

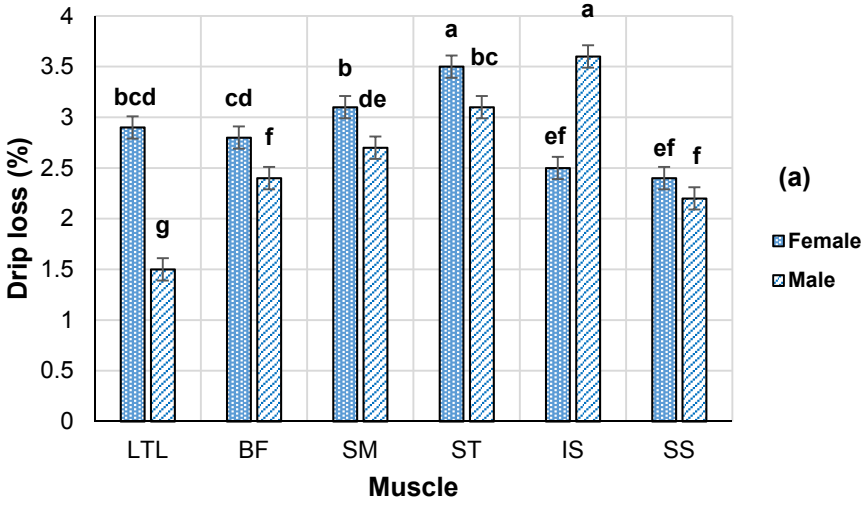
When comparing the influence of sex on the physical meat quality parameters of impala (Table 4.1), differences ($P \leq 0.05$) between sexes were found for all parameters except the L* values ($P = 0.247$), b* values ($P = 0.280$) and the hue ($P = 0.965$). The ultimate pH was higher ($P = 0.021$) in male impala (5.8 ± 0.05) than in females (5.6 ± 0.05) but female impala produced meat with higher ($P = 0.002$) shear force values (3.7 ± 0.14 kg/1.27cm Φ; 28.8 ± 1.08 N) than male impala. The chroma values were also significantly higher in meat from female impala than males.

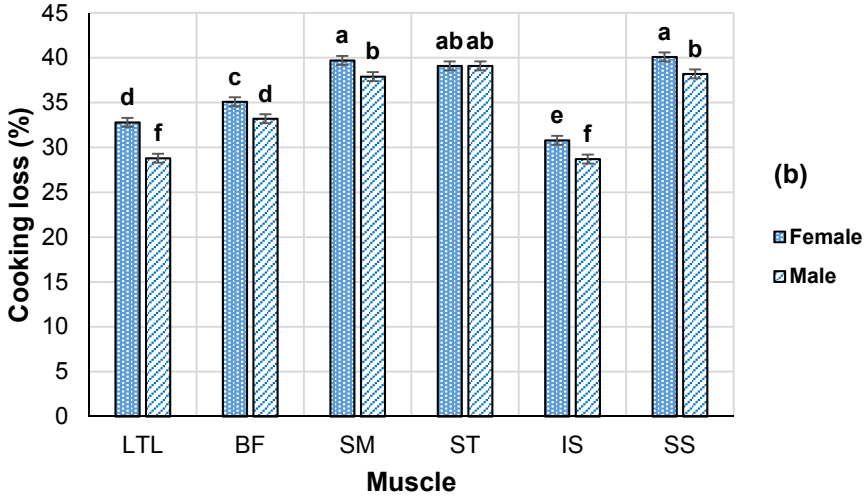
Table 4.1 LSMeans (± standard error) of impala physical meat quality parameters as influenced by sex.

Parameter	Sex		P-value
	Female (n = 11)	Male (n = 11)	
pH_u	5.6 ± 0.05	5.8 ± 0.05	0.021
#Drip loss (%)	2.9 ± 0.08	2.6 ± 0.08	0.013
#Cooking loss (%)	36.3 ± 0.57	34.3 ± 0.59	0.028
Shear force (kg/1.27cm Φ)	3.7 ± 0.14	3.0 ± 0.14	0.002
Shear force (N)	28.8 ± 1.08	23.2 ± 1.07	0.002
Colour			
L*	33.5 ± 0.77	34.8 ± 0.77	0.247
#a*	13.3 ± 0.27	12.2 ± 0.27	0.009
b*	8.4 ± 0.47	7.7 ± 0.47	0.280
Chroma	15.8 ± 0.45	14.5 ± 0.45	0.050
Hue-angle	32.1 ± 1.09	32.0 ± 1.10	0.965

#Interactions recorded between sex and muscle type for these parameters.

Muscle was found to have an influence ($P \leq 0.001$) on the physical quality parameters of impala meat of both sexes (Table 4.2). The pH_u ranged from 5.6-5.9 for all muscles of impala, with the highest pH_u recorded in the SS, followed by the IS, the LTL and then the three hindquarter muscles (BF, SM and ST), the latter four of which did not differ significantly from each other. Initial pH of individual muscles (taken 45 minutes *post-mortem*) could not be recorded in either Trial 1 or Trial 2 since deboning only commenced after 24 hours. The Warner-Bratzler shear force values of all impala muscles ranged from 2.5-4.1 kg/1.27cm Φ (19.2-31.7 N), with the highest shear force values observed in the SM and BF and the lowest values observed in the IS. For the surface colour parameters of impala meat, the ST and IS had the highest L* values, the IS had the highest a* value, and the ST had the highest b* value. Chroma values were the lowest in the BF and the highest in the ST, IS and SS muscles, and hue was the highest ($P \leq 0.001$) in both the SS and IS, while the remaining four muscles (LTL, BF, SM and SS) did not differ from one another (Table 4.2).





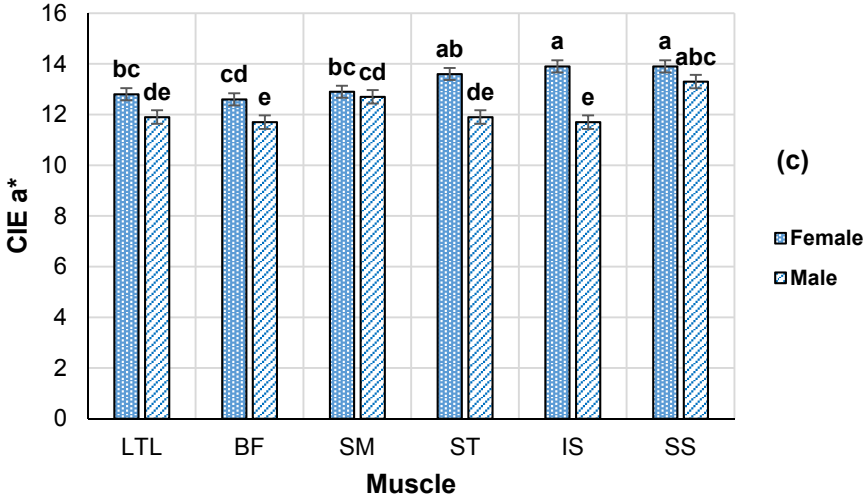


Figure 4.1 Interactions (LSMeans ± standard error) between sex and muscle for **(a)** drip loss percentage, **(b)** cooking loss percentage and **(c)** CIE a* colour value. Abbreviations: LTL = *longissimus thoracis et lumborum*; BF = *biceps femoris*; SM = *semimembranosus*; ST = *semitendinosus*; IS = *infraspinatus*; SS = *supraspinatus*. [a-f]Means (within a parameter) with different superscripts differ significantly from one another ($P \leq 0.05$).

Table 4.2 LSMeans (± standard error) of physical meat quality parameters of impala as influenced by muscle.

Parameter	Muscle						P-Value
	LTL[1]	BF[2]	SM[3]	ST[4]	IS[5]	SS[6]	
pH_u	$5.6^{c} \pm 0.03$	$5.7^{c} \pm 0.03$	$5.6^{c} \pm 0.03$	$5.7^{c} \pm 0.03$	$5.8^{b} \pm 0.03$	$5.9^{a} \pm 0.03$	< 0.001
[#]Drip loss (%)	$2.2^{d} \pm 0.08$	$2.6^{c} \pm 0.08$	$2.9^{b} \pm 0.08$	$3.3^{a} \pm 0.09$	$3.0^{b} \pm 0.08$	$2.3^{d} \pm 0.08$	< 0.001
[#]Cooking loss (%)	$30.8^{c} \pm 0.36$	$34.1^{b} \pm 0.35$	$38.8^{a} \pm 0.35$	$39.1^{a} \pm 0.36$	$29.8^{d} \pm 0.37$	$39.2^{a} \pm 0.35$	< 0.001
Shear force (kg/1.27cm Φ)	$3.3^{b} \pm 0.14$	$3.9^{a} \pm 0.14$	$4.1^{a} \pm 0.15$	$3.3^{b} \pm 0.14$	$2.5^{c} \pm 0.14$	$3.1^{b} \pm 0.14$	< 0.001
Shear force (N)	$25.5^{b} \pm 1.10$	$30.1^{a} \pm 1.10$	$31.7^{a} \pm 1.13$	$25.7^{b} \pm 1.10$	$19.2^{c} \pm 1.10$	$23.6^{b} \pm 1.10$	< 0.001
Colour							
L*	$31.4^{d} \pm 0.41$	$34.1^{b} \pm 0.41$	$32.8^{c} \pm 0.41$	$36.8^{a} \pm 0.41$	$36.1^{a} \pm 0.41$	$33.9^{bc} \pm 0.41$	< 0.001
[#]a*	$12.3^{bc} \pm 0.21$	$12.1^{c} \pm 0.20$	$12.8^{b} \pm 0.20$	$12.7^{b} \pm 0.20$	$12.8^{b} \pm 0.20$	$13.6^{a} \pm 0.20$	< 0.001
b*	$7.3^{d} \pm 0.28$	$7.6^{d} \pm 0.27$	$8.1^{bc} \pm 0.27$	$8.8^{a} \pm 0.27$	$8.6^{ab} \pm 0.27$	$8.1^{abc} \pm 0.27$	0.001
Chroma	$14.5^{bc} \pm 0.29$	$14.4^{c} \pm 0.28$	$15.2^{ab} \pm 0.28$	$15.6^{a} \pm 0.28$	$15.5^{a} \pm 0.28$	$15.9^{a} \pm 0.28$	0.001
Hue-angle	$29.6^{b} \pm 0.77$	$31.6^{b} \pm 0.75$	$31.7^{b} \pm 0.75$	$34.6^{a} \pm 0.75$	$33.8^{a} \pm 0.75$	$30.9^{b} \pm 0.75$	< 0.001

Abbreviations: [1]LTL = *Longissimus thoracis et lumborum*, [2]BF= *biceps femoris*, [3]SM = *semimembranosus*, [4]ST = *semitendinosus*, [5]IS = *infraspinatus*, [6]SS = *supraspinatus*.

[a,b,c]Means with different superscripts in the same row differ significantly from each other ($P \leq 0.05$). [#]Interactions recorded between sex and muscle type for these parameters.

4.3.2 Production system comparison (Trial 2)

Production system had a significant effect on the physical meat quality parameters of impala LTL muscles (Table 4.3). Impala from the extensive system had the highest ($P < 0.001$) ultimate pH (6.2 ± 0.06), followed by impala from the intensive system (5.8 ± 0.05), with the lowest pH_u measurement in impala from the semi-extensive system (5.6 ± 0.05). Drip loss percentage was the highest ($P < 0.001$) in the meat from intensive system impala (2.2 ± 0.12 %), followed by semi-extensive system impala (1.5 ± 0.12 %) and the lowest drip loss percentage was recorded for meat from the extensive system impala (0.9 ± 0.14 %). Intensive system impala also produced meat with the highest cooking loss percentage (36.8 ± 0.65 %), while the cooking loss percentage did not differ significantly between meat of impala from the semi-extensive and extensive production systems (29.5 ± 0.68 % and 28.1 ± 0.79 %, respectively). The most tender meat (inversely related to shear force values) was produced by semi-extensive system impala (2.9 ± 0.25 kg/1.27cm Φ; 22.4 ± 1.94 N), followed by extensive system impala (3.7 ± 0.29 kg/1.27 cm Φ; 29.0 ± 2.27 N) and the least tender meat was produced by intensive system impala, as observed by the highest shear force values recorded in meat from the latter at 5.1 ± 0.24 kg/1.27cm Φ (39.3 ± 1.85 N).

The colour of meat was significantly affected by production system at the 5 % level. The mean CIE L*, a* and chroma values were significantly lower in meat from extensive system impala than in meat from intensive or semi-extensive system impala, while the latter two systems did not differ significantly from each other for those parameters. The mean b* values were the lowest in extensive system impala meat and the highest in semi-extensive system impala meat, while intensive system impala did not differ significantly from either of the former two systems. The hue-angle did not differ ($P = 0.732$) between production systems, with the mean pooled hue for the LTL muscle of sub-adult male impala calculated to be 28.2 ± 1.80°.

Table 4.3 LSMeans (± standard error) of the *Longissimus thoracis et lumborum* (LTL) muscle's physical meat quality characteristics of impala from different production systems

Parameter	Production system			P-value
	Intensive (n = 12)	Semi-extensive (n = 11)	Extensive (n = 8)	
pH_u	5.8^{b} ± 0.05	5.6^{c} ± 0.05	6.2^{a} ± 0.06	< 0.001
Drip loss (%)	2.2^{a} ± 0.12	1.5^{b} ± 0.12	0.9^{c} ± 0.14	< 0.001
Cooking loss (%)	36.8^{a} ± 0.65	29.5^{b} ± 0.68	28.1^{b} ± 0.79	< 0.001
Shear force (kg/1.27cm Φ)	5.1^{a} ± 0.24	2.9^{c} ± 0.25	3.7^{b} ± 0.29	< 0.001
Shear force (N)	39.3^{a} ± 1.85	22.4^{c} ± 1.94	29.0^{b} ± 2.27	< 0.001
Colour				
L*	30.9^{a} ± 0.70	32.2^{a} ± 0.73	26.8^{b} ± 0.85	< 0.001
a*	11.4^{a} ± 0.34	12.2^{a} ± 0.35	10.0^{b} ± 0.41	0.002
b*	6.0^{ab} ± 0.51	7.1^{a} ± 0.53	5.2^{b} ± 0.62	0.075
Chroma	13.1^{a} ± 0.46	14.2^{a} ± 0.49	11.4^{b} ± 0.57	0.003
Hue-angle	27.8 ± 1.65	29.4 ± 1.73	27.5 ± 2.03	0.732

^{a,b,c}Means with different superscripts in the same row differ significantly from each other ($P \leq 0.05$).

4.4 DISCUSSION

The aim of this study was to investigate the effects of sex, muscle and production system on the physical meat quality of impala. When comparing the effects of sex and muscle, the ultimate pH (pH_u) of all sampled muscles was influenced by sex, while the pooled pH_u of both sexes differed between muscles. In addition, production system was found to have a significant influence on the pH_u of the LTL muscles from sub-adult (±15-18 months) male impala.

The higher pH_u of male impala (5.8 ± 0.05) than that of female impala (5.6 ± 0.05) in the sex comparison (Trial 1, Table 4.1) was in accordance with the findings of Hoffman (2000a), where the final mean pH values of males (5.8 ± 0.13) were also significantly higher than that of female impala (5.7 ± 0.07) at 24 hours *post-mortem*. The differences between sexes may be caused by the higher vigilance behaviour of male impala (Shorrocks & Cokayne, 2005) and consequently more dynamic reactions to any disturbance than that of female impala (Lewis, Pinchin, & Kestin, 1997). The pH_u of the different skeletal muscles ranged from 5.6-5.9 (Table 4.2), with differences between muscles most likely being the result of differences in function, activity levels and consequently the muscle glycogen content (Honikel, 2004). Glycogen is the primary substrate that is required for lactic acid formation in muscles and consequently for the normal decline in muscle pH after slaughter, with a pH_u of 5.5-5.8 classified as normal in beef (Immonen, Ruusunen, & Puolanne, 2000). The pH_u values of impala meat from both sexes and all muscles (Trial 1) fall within this range, with the exception of the SS, which had a slightly higher pH_u of 5.9 ± 0.03. However, the majority of the physical meat quality attributes of the SS did not differ significantly from the other muscles and the increased pH_u in this muscle may be the result of decreased glycogen storage of the small muscles of the forequarter, as indicated by the second highest pH_u found in the IS muscle at 5.8 ± 0.03.

When comparing the influence of production system on the pH_u of LTL muscles from sub-adult male impala (Trial 2, Table 4.2), the semi-extensive system (5.6 ± 0.05) was the only production system recorded to produce meat with a pH_u within the ideal range for meat produced from animals in a good physical condition, which is stated to range from 5.5-5.7 (Wiklund, Johansson, & Malmfors, 2003). The pH_u of meat from intensive system impala (5.8 ± 0.05) is at the high end of the normal (5.5-5.8) range for unstressed animals (Immonen et al., 2000). However, the pH_u of the meat from extensive system impala (6.2 ± 0.06; range of 6.0-6.5) exceeded the upper limit of the normal range. The high pH_u observed in the LTL muscles of impala from the extensive system is most probably the result of reduced lactic acid formation in the muscles due to depletion of muscle glycogen stores caused by pre-slaughter stress or exhaustive physical exercise (Honikel, 2004; Lawrie & Ledward, 2006). Meat quality is detrimentally affected when a normal pH decline does not occur *post-mortem*, as the resulting meat is often characterized by a higher water-holding capacity and firmer structure as a result of less pH-induced shrinkage, leading to an undesirable darker surface colour. This meat is referred to as dark, firm and dry (DFD) meat (Honikel, 2004; Viljoen, de Kock, & Webb, 2002).

The exceptionally high pH_u and resulting DFD-like characteristics of meat from the extensive system impala may be the result of a combination of the high levels of daily activity of the animals in the relatively large 800 ha camp and *ante-mortem* stress caused by the hunting procedure. While all the impala in this study were hunted during the day due to dense vegetation or environmental conditions

that made night culling impractical, the extensive system impala were particularly prone to fleeing when a vehicle approached, or a shot was heard. In contrast to night culling, when more than one impala can be shot per herd (Hoffman & Laubser, 2009), the impala culled during the day in the extensive system tended to flee as soon as a single animal fell, which indicates higher awareness of hunters, potentially due to decreased human exposure with extensive management. The relatively large camp size of the extensive system allowed the impala to cover significant distances after each shot, resulting in extended time spent tracking the herd until the next animal could be culled. Furthermore, multiple black wildebeest were hunted in the same camp for a duration of approximately four hours prior to the culling of impala, which resulted in substantial *ante-mortem* stress for the extensive system impala due to the extended fleeing period. The combination of stress and exhaustive physical activity may have resulted in a rapid depletion of glycogen in the muscles of these impala and the consequential high ultimate pH (Honikel, 2004). While the intensive system impala were also prone to fleeing from humans due to daily exposure to humans in close proximity during feeding, the small 0.25 ha boma allowed all animals to be culled within five minutes from the first shot. This short culling period would not result in the same extent of glycogen depletion as the extended hunting period for the extensive system impala and may thus explain the comparatively lower pH_u of 5.8 for the intensive system impala.

With the exception of the significantly higher pH_u of extensive system impala, the mean pH_u values of meat from all impala and muscles in the present study (Trial 1 & 2) were in accordance with previous findings, where pH_u ranges of 5.6-5.8 have also been recorded for impala (Hoffman, 2000a; Hoffman & Laubser, 2009; Hoffman et al., 2009). Lower pH_u values have been recorded by Kritzinger et al. (2003) for both day culled impala (5.5 ± 0.11) and night culled impala (5.4 ± 0.08). The latter values were most likely the result of a more rapid pH decline caused by increased glycolytic enzyme activity due to increased daily physical activity during the rutting period. In contrast, the male impala in the present study were sub-adults that were too young to partake in the rutting season, and would not experience a similar rapid pH fall in the carcasses *post-mortem*.

The water-holding capacity of impala meat was found to be influenced by sex, muscle and production system, with a significant interaction recorded between sex and muscle (Trial 1) for both drip loss and cooking loss percentage. Water-holding capacity is an important parameter of physical meat quality that is related to the ultimate pH value of the meat (Lawrie & Ledward, 2006). The lowest point of water binding is at the iso-electric point (at pH 5.4-5.5) to which meat usually declines due to *post-mortem* anaerobic glycolysis, and therefore some moisture loss is unavoidable (Lawrie & Ledward, 2006). However, high amounts of moisture loss in the form of drip loss (which can be observed as a large amount of bloody liquid in the packaging) is perceived negatively by consumers, and therefore an important aspect of meat production is striving to minimize the moisture loss of meat (Troy & Kerry, 2010). Low moisture loss in the form of cooking loss is associated with improved meat quality and greater juiciness in cooked meat due to higher amounts of moisture being retained in the meat (Sebsibe, 2008).

A higher pH_u of meat is related to a decreased amount of moisture loss from the meat (Lawrie & Ledward, 2006). This was observed with the lower amount of moisture lost by means of drip loss in the LTL, BF, SM and ST muscles of male impala compared to that of females (Trial 1, Figure 4.1.a), as a consequence of the higher pH_u recorded for male impala in these muscles. A similar trend was

recorded for the cooking loss percentages of the LTL, BF, SM, IS and SS muscles, which were also lower in male impala than in females (Figure 4.1.b). The decreased moisture loss in most of the muscles of male impala may be related to the influence of sex on the pH_u and consequently the water-holding capacity of muscles, with an overall higher pH_u recorded in males (Table 4.1). The influence of sex on water-holding capacity has also been observed in both cattle and pigs, where a higher pH_u of males above that of females or castrated males has resulted in an improved water-holding capacity and thus lower moisture loss in males compared to females or castrated males (Den Hertog-Meischke, Van Laack, & Smulders, 1997). The influence of pH_u on the cooking loss difference between sexes was also noted in a previous study on impala, where the LTL of female impala had a lower cooking loss percentage (26.4 ± 0.51 %) than that of males (29.0 ± 0.88 %) due to the slightly higher pH_u values of female impala above that of males (5.5 vs. 5.4) (Hoffman & Laubser, 2009). A similar trend was observed between individual muscles in the current study (Trial 1), where the lowest drip loss percentages were recorded for the SS muscle, which had the highest pH_u value for both male and female impala (5.8 for females and 6.0 for males). Similarly, the lowest cooking loss percentage was recorded for the IS muscle, which had the second highest pH_u value at 5.8 (Table 4.2) and may indicate that this muscle may produce the juiciest meat.

The effect of a high pH_u on the moisture loss of meat can also be observed with the high water-holding capacity of meat from extensive system impala (Trial 2), as indicated by the low drip loss (0.9 ± 0.14 %) and cooking loss percentages (28.1 ± 0.79 %). This is in accordance with previous research that found increased pH_u values to be related to increased water-holding capacity of impala meat, where a wounded male impala was recorded to have a zero percent drip loss related to DFD-meat (Hoffman, 2000a). Despite the moderately high pH_u of meat from intensive system impala, the impala from this system was found to have the highest drip loss and cooking loss percentages in comparison to impala from the other two production systems.

The drip loss percentages of male and female impala (2.7 ± 0.08 % pooled mean) and intensive system impala (2.2 ± 0.12 %) in the present study is similar to the 2.5 to 2.9 % range reported for night-culled impala in previous studies (Hoffman, 2000b; Hoffman & Laubser, 2009; Kritzinger et al., 2003) and lower than the 4.2 ± 2.34 % recorded for day-culled impala (Kritzinger et al., 2003), although the high values of the latter were speculated to be the result of *ante-mortem* stress caused by increased awareness of the hunters during the day. With the exception of the latter value for day-culled impala, the drip loss percentages recorded for impala in previous research and the present study (Trial 1 & 2) are similar to the percentages recorded for pork (2.4-2.6 %) by Fisher, Mellett, & Hoffman (2000), and lower than those recorded for beef cattle (4-6 %) by Hornick et al. (1998). While the drip loss percentage of the semi-extensive system impala (1.5 ± 0.12 %; Table 4.3) is lower than all the aforementioned values, it is similar to the 1.2 ± 0.13 % recorded for impala by Hoffman et al. (2009) and the 1.4-1.5 % recorded for sheep by Ekiz et al. (2012).

The cooking loss percentages of impala meat from both sexes, all muscles and all production systems (Trial 1 & 2) in this study (28.1-36.8 %) are similar to the values obtained for impala meat by most previous research, with previous cooking loss percentages ranging from 27.4 to 33.0 % (Hoffman & Laubser, 2009; Hoffman et al., 2009; Kritzinger et al., 2003; Van den Berg, 2009). This range

is higher than the 14.7-15.7 % cooking loss reported for lambs (Ekiz et al., 2012) and slightly higher than the 22-27 % for beef (Hornick et al., 1998) and the 27 % for pigs (Fisher et al., 2000). One study reported lower cooking loss percentages for night-culled impala (23.5-24.5 %) (Hoffman, 2000a). In a previous study comparing five of the six main muscles of impala to that of kudu (Mostert, 2007), the highest cooking loss percentages were found in the SM, ST and SS muscles of both species (range of 36.9-38.3 %), which concurs with the results of the present study (Trial 1) where a similar trend and range (38.8-39.2 %) was observed for these muscles. The high cooking losses reported for these muscles indicate that they will be perceived as less juicy (Sebsibe, 2008) than the LTL, BF and IS muscles, which have lower cooking loss percentages.

The tenderness of meat is determined by measuring the Warner-Bratzler shear force values of meat, with lower shear force values representing increased meat tenderness. When comparing the shear force values between sexes (Trial 1), female impala produced meat with significantly higher shear force values and thus less tender meat than male impala in the present study (Table 4.1). This is in contrast to previous research findings, where no differences were recorded between male and female impala for meat tenderness (Hoffman, 2000a; Hoffman et al., 2009; Van den Berg, 2009). The less tender meat of female impala compared to males in the present study may be explained by the age difference found between the sexes, where the female impala were determined to be substantially older (estimated 24 to 36 months old) than the male impala (±15-18 months old) of the sex comparison (female impala do not have horns and therefore it is difficult to judge their age from their body conformation only in the field; refer to Chapter 3.4.1 for more details). The age of an animal at the point of slaughter has been shown to influence the tenderness of the cooked meat (Purslow, 2005). Meat from older animals have been recorded to have higher shear force values and thus less tender meat than younger animals. This indicates a decrease in tenderness with increasing age at slaughter, which is most likely due to reduced collagen solubility in intramuscular connective tissue with age (Purslow, 2005). In addition, the size of individual muscle fibres increase as animals mature, therefore it would be expected that older animals such as the female impala in this study would have tougher meat than younger animals (Sebsibe, 2008), despite the difference in sex.

The grain and texture of meat is largely influenced by muscle fibre type and size of the muscle fibre bundle, which are in turn related to the role of the individual muscle in the animal and the intensity of muscle activity in the animal's body (Lawrie & Ledward, 2006). Small muscle fibre bundles are found in fine-grained muscles such as the ST, while large muscle fibre bundles comprise coarse-grained muscles such as the SM (Lawrie & Ledward, 2006). In addition, muscles that are frequently used for exercise become stronger and therefore tend to be less tender than muscles used for support (Sebsibe, 2008). The difference in skeletal muscle characteristics may explain the differences in tenderness between the muscles of impala (Trial 1), where muscles from the hindquarters and back (SM and BF, followed by the ST and LTL) of impala had the highest shear force values (range of 25.5-31.7 N) and the IS muscle from the forequarter had the lowest shear force values (19.2 ± 1.10), while the SS muscle did not differ significantly from the LTL and ST muscles (Table 4.2). This may be due to the fact that the muscles from the hindquarter and back are coarse-grained muscles that are frequently used for exercise, while the more tender IS muscle has a more supportive function. When comparing the tenderness of the LTL of both male and female impala in this study (3.3 ± 0.14 kg/1.27 cm Φ; Table

4.2) to the shear force values (kg/1.27 cm Φ) obtained in previous research, impala meat was found to be more tender than that of blue wildebeest (4.9 ± 0.27 kg/1.27 cm Φ; Van Heerden, 2018) and kudu (4.1 ± 0.15 kg/1.27 cm Φ; Hoffman et al., 2009), similar to that of pigs (3.0 kg/1.27 cm Φ; Fisher et al. 2000) and mountain reedbuck (3.0 kg/1.27 cm Φ; Hoffman et al. 2008) and less tender than springbok (1.7-2.7 kg/1.27 cm Φ; Hoffman, Kroucamp, & Manley, 2007). Impala meat therefore compares favourably to meat from other game and domestic species.

Despite having a lower pH_u than meat from extensive system impala, the intensive system impala produced the least tender meat of all three production systems (Trial 2; Table 4.3), as indicated by the high shear force values observed in the meat from this system's impala (39.3 ± 1.85 N; pH_u 5.8). Meat from extensive system impala was more tender (29.0 ± 2.27 N; pH_u 6.2) than that of intensive system impala, while semi-extensive system impala produced the most tender meat (22.4 ± 1.94 N; pH_u 5.6). The differences in tenderness between production systems may be attributed to the tendency of meat tenderness to decrease as the meat pH_u increases from 5.5 to 6.1, after which tenderness increases with an additional rise in pH_u of up to 7.0 (Purchas & Aungsupakorn, 1993). The improved tenderness of the extensive system impala meat above that of meat from the intensive system impala may be the consequence of reduced moisture loss due to increased water-holding capacity and higher levels of protease activity as the pH_u increases above 6.1 to approach values close to neutrality (Yu & Lee, 1986). In addition, it has been found that meat with intermediate pH_u values (such as the intensive system impala meat) have less muscle protein degradation, which result in tougher meat than meat with either high or low pH_u values (Yu & Lee, 1986) This phenomenon can be observed in Figure 4.2, and may explain why meat from the intensive system impala is less tender than either the semi-extensive system impala with the lowest mean pH_u values, or the extensive system impala with the highest pH_u values.

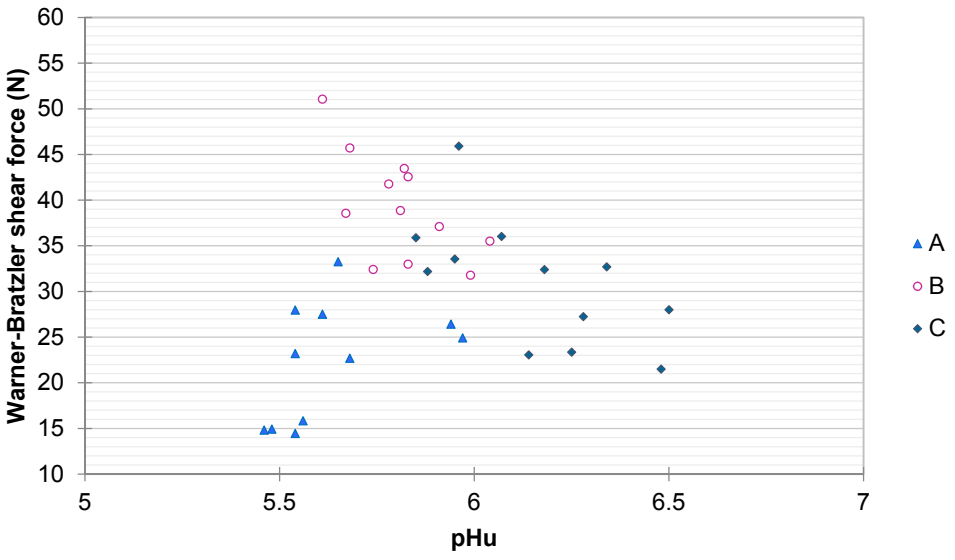


Figure 4.2 Scatter plot of pH and Warner-Bratzler shear force values of semi-extensive (A), intensive (B) and extensive (C) production system impala *Longissimus thoracis et lumborum* (LTL) muscles.

When compared to previous research, impala from the intensive boma system (Trial 2) had substantially higher shear force values (5.1 ± 0.05 kg/1.27 cm Φ; Table 4.2) than night-culled male impala from Maneze Wildlife Conservancy in Zimbabwe (4.1 ± 0.51 kg/1.27 cm Φ; Hoffman, 2000a), males from the Mabula District of Limpopo (4.1 ± 0.21 kg/1.27 cm Φ; Hoffman et al., 2009) and both day- and night-culled impala (4.3 ± 0.17 kg/1.27 cm Φ and 4.7 ± 0.20 kg/1.27 cm Φ) from Leeukop Game Ranch in KwaZulu-Natal (Hoffman & Laubser, 2009), all of which had similar or lower pH_u values. In contrast, meat from semi-extensive and extensive system impala was similar or more tender than the impala meat of previous studies. The *ante-mortem* stress caused by maintenance of impala in the intensive boma system may be an additional explanation for the decreased tenderness of meat from the intensive system impala in the present study above that of previous findings and the other production systems in the present study. While the pH_u and water-holding capacity of intensive system impala was not high enough for the meat to be classified as DFD, the decreased tenderness may be due to chronic *ante-mortem* stress and a conditioned response to human presence as a result of daily feedings in the limited 0.25 ha boma. Chronic stress may cause depletion of muscle glycogen prior to slaughter, resulting in reduced lactic acid formation, improper acidification of meat and consequently high pH_u (Viljoen et al., 2002). Chronic stress and its relation to increased pH_u values have been recorded in previous studies on deer (Macdougall et al., 1979; Pollard et al., 2002), and a study on the repeated capture of boma-confined impala has shown the relation between extreme stress response in impala in blood chemicals and high mortality rates (Knox, Hattingh, & Raath, 1992). However, the effect of *ante-mortem* stress on the blood chemicals and resulting physical meat composition *post-mortem* were not quantified for the impala of this study, and highlights an area for future research.

The overall classification of meat tenderness is determined by means of shear force values. Meat with shear force values above 52.7 N is classified as tough in beef, while meat with shear force values below 42.9 N may be classified as tender (Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008). Despite variation in shear force values between sexes, muscles and production systems, the meat of impala from both sexes and all muscles and production systems (Trial 1 & 2) in this study are classified as being tender overall due to all mean shear force values (range of 22.4-39.3 N) falling below the stipulated maximum of 42.9 N.

The surface colour measurements of impala were also found to be influenced by sex, muscle and production system. A sex-muscle interaction was recorded for the CIE a* values (Trial 1), which were higher in female impala for the LTL, BF, ST, and IS (Figure 4.1.c). The higher a* values in these muscles and overall higher chroma values of female impala meat (Table 4.1) in the present study may be the result of differences in the myoglobin content of the meat, which is influenced by sex and pH_u. In a study comparing the influence of stress levels and sex on the meat quality of red deer, female deer with low pH_u values were found to have meat that was redder and more saturated than meat from male deer, while male deer were observed to have higher pH_u values than females for all stress levels (Macdougall et al., 1979). The higher redness and saturation in the meat of female impala in this study may therefore also be the result of the lower pH_u recorded in female muscles. With the exception of the a* values and chroma values, the lack of differences between sexes for the surface colour of impala meat is in accordance with previous research (Hoffman, 2000a; Mostert, 2007).

The differences in surface colour between impala muscles (Trial 1) may be due to differences

in the biochemical composition and myoglobin content of the individual skeletal muscles. Myoglobin content varies depending on the muscle fibre type, with higher myoglobin contents found in red (oxidative) muscle fibre types than white (glycolytic) muscle fibre types. As a result, muscles with higher proportions of oxidative muscle fibres will appear darker due to an increased myoglobin content (Kohn et al., 2005; Lawrie & Ledward, 2006). The SS muscle, which is known as a "red muscle" due to the high content of oxidative muscle fibres, high concentration of connective tissue and low protein content associated with this muscle (Lawrie & Ledward, 2006), was observed to have the highest a* value in both male and female impala and thus had the reddest surface colour of all six muscles. Previous studies have also recorded the SS muscle to have the highest a* values in comparison to other muscles for impala and kudu (Mostert, 2007), fallow deer (Fitzhenry, 2016), eland (Laubser, 2018) and blue wildebeest (Van Heerden, 2018). The lightest surface colour was observed in the ST muscle at CIE L* = 36.8 in the present study and has also been reported as the muscle with the lightest colour in previous research for fallow deer, impala, kudu, and eland (Fitzhenry, 2016; Hoffman et al., 2009; Laubser, 2018). This is due to the high glycolytic (white) fibre content of the ST muscle, which has reduced discolouration from oxygen exposure due to the limited oxidative capacity of this muscle (Lawrie & Ledward, 2006). The less red colour of the LTL and BF muscles in this study may be the result of the lower oxymyoglobin content, colour stability, and decreased metmyoglobin reducing activity associated with these muscles (Neethling, Sigge, Hoffman, & Suman, 2018).

The difference between production systems was visually apparent with the surface colour of the meat. The extensive system impala produced meat that was significantly darker and less red with higher chroma values than meat from impala of the other two production systems (Table 4.3), while the latter two systems did not differ from one another for any of the surface colour parameters. The lack of significant differences between the intensive and semi-extensive production system impala for surface colour may be due to the fact that impala from both systems received the same feed, either as the entirety of their diet (intensive system) or as supplementary feed to the natural vegetation (semi-extensive system). Nutrition has been found to influence the surface colour of meat, and cattle and sheep fed on forage-based diets (such as the extensive system) had less muscle glycogen, higher pH_u values and darker meat than animals fed concentrates *ad libitum* (Sebsibe, 2008). The fact that both the intensive and semi-extensive system impala had *ad libitum* access to the supplementary feed and were not exposed to severe *ante-mortem* stress as the extensive system impala were, may explain the lack of differences between the surface colour of their meat. In contrast, the darker meat observed in meat from extensive system impala is similar to that recorded for a wounded male impala (CIE L* = 25.4; a* = 9.1; b* = 4.9) that ran for four minutes prior to being culled (Hoffman, 2000a). The pH_u of the LTL muscle of that wounded male (pH_u = 6.1) is also similar to that of the extensive system impala in the present study and is further confirmation that the meat from extensive system impala may be characterized as dark, firm and dry. The darker colour and reduced saturation of DFD meat is the result of reduced myoglobin oxidation and increased colour stability caused by the high pH_u values, which also encourages microbial growth and reduces meat quality (Lawrie & Ledward, 2006; Shange, Gouws, & Hoffman, 2019).

With the exception of the DFD-like meat from extensive system impala, the surface colour measurements of impala meat (Trial 1 & 2) in the present study (L* = 30.9-36.8; a* = 11.4-13.6; b* =

6.0-8.8) are in accordance with previous colour measurements for impala meat (Hoffman, 2000a; Hoffman & Laubser, 2009; Hoffman et al., 2009; Kritzinger et al., 2003). Impala meat is darker and less red than the surface colour recorded for lamb meat (L* = 34.2-36.0; a* = 16.4-17.6; b* = 5.6-6.1; Warner et al., 2005) and beef (L* = 41.0, a* = 12.9; b* = 12.6; Bartoň, Bureš, Kotrba, & Sales, 2014). This is to be expected, as game meat with normal pH_u values (pH_u < 6.06) is characterized to have CIE Lab values of L* = 33.1; a* = 13.6; b* = 10.3, as obtained for non-stressed black wildebeest (Shange et al., 2019). The surface colour measurements of impala meat in this study (Trial 1 & 2) is similar to the aforementioned values, as well as to that obtained for kudu meat (L* = 30.3-33.2; a* = 11.0-11.9; b* = 8.5-8.7; Mostert, 2007), eland meat (L* = 32.3-37.5; a* = 12.0-15.5; b* = 10.6-12.9; Laubser, 2018), and blue wildebeest meat (L* = 30.6-33.8; a* = 10.9-15.1; b* = 7.3-9.7; Van Heerden, 2018). The overall darker colour of impala meat compared to that of traditional livestock may be the result of a higher myoglobin content in the meat of impala (7.3-7.5 mg/g) than in that of beef (5.8 mg/g) or chicken (2.5 mg/g) (Hoffman, Kritzinger, & Ferreira, 2005a). Game animals generally have higher levels of daily activity than traditional livestock, resulting in increased muscle myoglobin content to increase oxygen carrying capacity, which in turn leads to a darker surface colour of the meat (Hoffman et al., 2005a). The darker colour of game meat may negatively impact consumer acceptability of meat quality, particularly in cases such as the extensive system impala where DFD characteristics are also present.

4.5 CONCLUSION

This study aimed to determine the physical meat quality composition of six main muscles from both sexes of impala (Trial 1) and to quantify the influence of three different production systems on the physical meat quality of the LTL muscle of sub-adult (±15-18 months old) male impala (Trial 2).

While the physical meat quality parameters of impala meat were influenced by sex, the differences were marginal and are unlikely to influence consumer acceptability. However, age differences between the sexes influenced tenderness, and therefore repetition of the experiment with confirmed ages of particularly female impala is recommended to obtain more reliable results of the influence of sex on physical meat quality of impala. All physical meat quality parameters were influenced by individual muscles, with variation in muscles similar to those observed in other game species. Therefore, it is recommended that muscles be marketed separately according to their meat quality characteristics.

Production system had a significant effect on the physical meat quality of impala, with high levels of daily activity and *ante-mortem* stress caused during culling resulting in DFD-like characteristics in meat from extensive system impala. These characteristics include a darker, less red surface colour and high water-holding capacity, which may have a negative impact on consumer perception of the meat. However, the meat of impala from both sexes, all muscles and all production systems in this study were classified as tender overall and compares favourably to other game and domestic species. Further research entailing the collection and analysis of blood samples is recommended to quantify the effect of both chronic and acute *ante-mortem* stress on the meat quality of impala as influenced by different production systems and culling methods.

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CHAPTER 5

PROXIMATE COMPOSITION OF IMPALA (*AEPYCEROS MELAMPUS*) MEAT AS AFFECTED BY SEX, MUSCLE AND PRODUCTION SYSTEM

ABSTRACT

The aim of this study was to determine the influence of sex, muscle (*Longissimus thoracis et lumborum*/LTL, *biceps femoris*/BF, *semimembranosus*/SM, *semitendinosus*/ST, *infraspinatus*/IS and *supraspinatus*/SS), and three contrasting production systems (intensive, semi-extensive and extensive) on the proximate composition (moisture, protein, intramuscular fat and ash) of impala meat. A total of 58 impala were culled, of which 11 male and 11 females were used to compare the influence of sex and muscle (Trial 1), while the remaining 36 sub-adult male impala (12 per production system) were used to compare the influence of production system on the proximate composition of the LTL muscle (Trial 2). Sex-muscle interactions ($P \leq 0.05$) were found for all four chemical components, and a negative correlation ($r = -0.49$; $P < 0.001$) was found between the protein and IMF content of the muscles. Production system had a significant influence on all components, with the highest protein (23.4 ± 0.12 g/100 g) and lowest IMF (1.5 ± 0.06 g/100 g) content found in extensive system impala and the highest IMF content (2.0 ± 0.05 g/100 g) found in intensive system impala. The proximate composition of all impala meat in this study ranged from 74.7-77.0 % moisture, 20.7-23.5 % protein, 1.2-2.2 % IMF and 1.1-1.3 % ash content. These values compare favourably to other game and domestic animal species, indicating that impala meat may serve as a biologically valuable alternative protein source.

Keywords: Game meat, Impala, Meat quality, Chemical composition

5.1 INTRODUCTION

The global demand for meat is increasing due to the expansion in the human population (Meissner, Scholtz, & Palmer, 2013), which is expected to surpass nine billion within the next few decades (Tscharntke et al., 2012). In order to meet the expanding needs of the growing human population, food production will have to increase by more than 50 % by 2050 (Ingram, Ericksen, & Liverman, 2010). Despite the fact that worldwide food production has stayed ahead of demand for the past fifty years, there are presently approximately one billion people that do not have sufficient food, and a further one billion are undernourished (Misselhorn et al., 2012). Southern Africa is currently a net importer of food, and its population is predicted to reach two billion people in the next few decades, thus creating a necessity to increase production of meat protein sources to address food insecurity (Conceicao, Fuentes-Nieva, Horn-Phathanothai, & Ngororano, 2011).

Meat is an important component of the human diet as a source of highly concentrated protein with a high biological value and an essential amino acid composition that complements cereals and other vegetable proteins (Bender, 1992; Listrat et al., 2016). This is vital in developing countries such as South Africa, where many diets consist of bulky root crops or cereals, which can limit the intake of dietary energy (Bender, 1992). In addition, meat and meat products are a valuable source of vital micronutrients such as essential fatty acids, zinc, iron and vitamins (A, B, and E) that are vital to human nutrition and the sustainment of good health throughout the lifetime of the consumer (Bender, 1992; Williams, 2007). However, the meat produced by the limited number of domesticated livestock species may not be capable of meeting the expanding demand for animal protein, resulting in a need to consider non-traditional alternative sources for meat production (Cawthorn & Hoffman, 2014). Meat production from indigenous game species may offer a practical solution to South Africa's protein shortage by contributing to food security, economic sustainability and the conservation of rare species and biodiversity (Hoffman & Cawthorn, 2012; Meissner et al., 2013).

When considering non-traditional species, such as game animals, for meat production for contribution to food security, it is necessary to research the meat quality and nutritive value of each potential species in order to improve productivity and to produce meat products with consistent quality (Cawthorn & Hoffman, 2014). The nutritional value of meat must fulfil the health requirements of consumers in a suitable manner, particularly with regards to obesity issues and cardiovascular disease related to diet (Schack, Bergh, & Du Toit, 2016). The nutritional quality and value of meat is principally characterized by the basic chemical composition, which is comprised of the moisture, protein, intramuscular fat (IMF) and ash content that constitutes almost 100 % of the animal tissue weight (Ang, Young, & Wilson, 1984). These parameters of the chemical composition of meat may vary due to differences in species, sex, age, nutrition, and the anatomical location of different skeletal muscles within the carcass of the animal (Hocquette et al., 2010). These factors also affect the composition and structure of the different skeletal muscles, and meat quality may be influenced largely by direct relationships between meat quality traits and intramuscular biological characteristics (Listrat et al., 2016). The high protein content found in meat from game animals (Hoffman & Wiklund, 2006) merits further investigation into additional game species such as the impala.

The impala (*Aepyceros melampus*) is a common antelope species that is indigenous to

southern Africa, with a wide distribution, rapid reproduction rate and adaptability to a variety of habitats and production systems that makes it an ideal species for game farming (Fairall, 1983; Furstenburg, 2005). In addition, this species has a high carcass yield (Chapter 3), favourable meat quality characteristics (Chapter 4) and can sustain an annual cropping rate of 25-30 % on farms that practice predator control, making it an ideal choice for meat production (Fairall, 1983). However, it is important to determine all aspects of the nutritional composition of the meat from impala to establish the meat production potential of this species, as well as whether it will meet modern market and consumer demands. While previous authors have investigated the nutritional composition of sections of the LTL muscle of impala (Hoffman, 2000b; Hoffman, Kritzinger, & Ferreira, 2005; Hoffman, Mostert, Kidd, & Laubscher, 2009; Van Zyl & Ferreira, 2004), the proximate composition of meat from the six main skeletal muscles (*Longissimus thoracis et lumborum/LTL, biceps femoris/BF, semimembranosus/SM, semitendinosus/ST, infraspinatus/IS,* and *supraspinatus/SS*) of both sexes of impala has not yet been investigated, nor has the influence of different production systems on the proximate composition of impala LTL muscles been determined. The aim of this study was therefore to determine the influence of sex, muscle and three different production systems on the chemical composition of impala meat.

5.2 MATERIALS AND METHODS

5.2.1 Experimental location and animals

A total of 58 impala were culled from two different farming locations for this study. The locations were Castle de Wildt, in the Central Sandy Bushveld bioregion near Modimolle in the Savanna Biome of the Limpopo province, and a farm in the Central Rûens Shale Renosterveld vegetation unit near Bredasdorp, located in the Fynbos Biome of the Western Cape province of South Africa. To compare the influence of sex and muscle (Trial 1), 22 (11 male and 11 female) of the 58 impala for this study were obtained from a semi-extensive production system at Castle de Wildt, while the other 36 impala were culled to compare three different production systems (Trial 2: intensive, semi-extensive and intensive), with 12 sub-adult (± 15-18 months old) male impala culled per production system.

The intensive production system consisted of a 0.25 ha boma system at Castle de Wildt, where the only source of feed intake for the impala consisted of feed supplied *ad libitum* in troughs, with a composition of 8.3 % moisture, 13.3 % crude protein, 91.7 % dry matter, 7.6 % ash and 27.99 % crude fibre. The semi-extensive system was a 200 ha camp system that was also located at Castle de Wildt, where the primary feed intake of impala consisted of the natural Savanna vegetation with *ad libitum* access to supplementary feed with the same composition of that supplied to the intensive system impala. The extensive production system consisted of an 800 ha camp on a farm in the Bredasdorp region, and required minimal management input as the entire diet for impala of this system was comprised of only the natural Renosterveld vegetation in the Fynbos biome. The aim for both trials was to cull only sub-adult impala within the 15-18 months age range, using horn shape and size as ageing criteria for male impala and body size as criteria for female impala. Further information regarding the description of vegetation and production of the impala can be found in the Materials and Methods of Chapter 3.2.1.

5.2.2 Culling, carcass processing and sampling

All impala obtained for this study were culled during the day (ethical clearance number 10NP_HOF02) with suppressor-equipped light calibre rifles (.22 or .243) with head shots, which has been shown to cause the minimum amount of shooting losses and the least detrimental effects to the quality of meat in comparison to shoulder or rib shots (Van Schalkwyk & Hoffman, 2016; Von La Chevallerie & Van Zyl, 1971). Impala were exsanguinated in the field immediately after shooting, tagged and loaded onto the back of a secure culling vehicle. Thereafter, they were taken to the on-site slaughtering facilities, where the impala carcasses were skinned, eviscerated and dressed according to the guidelines stipulated by Van Schalkwyk & Hoffman (2016). The dressed carcasses were hung by the Achilles tendons of both hind legs in a chiller set to 4 ± 1°C to undergo *rigor mortis*.

After ±24 hours, all impala carcasses were deboned and selected muscles were sampled for chemical analysis. For the sex and muscle comparison (Trial 1), the six main muscles were sampled from the left side of the carcasses of 11 female and 11 male impala, with samples consisting of three muscles from the hindquarters (BF, SM, and ST), two muscles from the forequarter (IS and SS) and the LTL muscle from the back. For the production system comparison (Trial 2), the left LTL muscle was sampled for each of the 36 impala from the three different production systems. All muscles sampled for the proximate analysis were weighed individually and vacuum sealed in labelled plastic bags, after which the samples were frozen at -20°C until chemical analysis could be performed.

5.2.3 Chemical analysis

5.2.3.1 Sample preparation and proximate analysis

The samples selected for proximate analysis were removed from the -20°C freezer and placed in a 4 ± 1°C chiller overnight to thaw prior to the homogenization process. After thawing, the samples were trimmed to remove excess external fat and collagen tissue and cut into smaller pieces, which were placed into a bowl fitted with a sharp blade for homogenizing. The individual samples were homogenized until resembling a paste to ensure homogeneity of the sample. Each homogenized meat sample was placed into separate bag, vacuum sealed and immediately frozen at -20°C until proximate analysis could be performed. The proximate analysis was performed in duplicate for each sample, with the mean value used as the final measurement. In the case of an error percentage of more than 20 % between the duplicates of each samples, analyses were repeated.

The moisture content (g/100 g) of each sample was determined according to the AOAC Official Method 934.01 (AOAC International, 2002c), which entails drying a 2.5 g portion of each homogenized muscle sample in an oven set to 100°C for a period of 48 hours. After determining the moisture content, the dried, moisture-free samples were placed inside a furnace set to 500°C for six hours according to the AOAC Official Method 942.05 (AOAC International, 2002a) to determine the ash content (g/100 g) of each sample.

The intramuscular fat (IMF) content (g/100 g) was determined for a 5.0 g homogenized portion of each muscle sample, using a rapid solvent extraction method as described by Lee, Trevino, & Chaiyawat, (1996). The solvent used was a mixture of chloroform/methanol in a 1:2 ratio (v/v), which is recommended for meat samples that are expected to have a low lipid content, such as game animals.

Following the extraction of fat from each meat sample, the remaining filtrate was collected, dried at 60°C, and grinded to a fine powder for determination of the crude protein content (g/100 g). One gram of each grinded sample was enclosed in a LecoTM tinfoil sheet and analyzed in a Leco Nitrogen/Protein Determinator (FP528 - Leco Corporation) according to the Dumas combustion method stipulated by the AOAC Official Method 992.15 (AOAC International, 2002b). The Leco Determinator was calibrated using a 0.15 g sample of EDTA (Leco Corporation, USA).

To ensure continuous accuracy throughout the analyses, the Leco Determinator was calibrated between every batch of either 11 or 12 samples, depending on whether the batch consisted of samples from the sex comparison or the production system comparison trial. The results of the analysis were obtained in the form of nitrogen percentage (% N) for each sample. This value was multiplied by a 6.25 conversion factor (assuming that meat protein consists of 16 % nitrogen, thus 100/16 = 6.25) in order to obtain the crude protein content (g/100 g) of each sample.

5.2.4 Statistical analysis

The experimental design of the sex and muscle comparison (Trial 1) was a split plot design with sex (male and female) as the main factor and muscle (LTL, BF, SM, ST, IS, and SS) as the sub-plot factor. The production system comparison (Trial 2) was a completely random experimental design with production system as the treatment and the LTL muscles of individual impala as the random repetitions.

The parameters of the proximate analysis (moisture, protein, IMF, ash) from both trials were analyzed with SAS software (Version 9.4; SAS Institute Inc., Cary, USA), using the General Linear Models (GLM) procedure to perform a univariate analysis of variance (ANOVA). The Shapiro-Wilk test was performed on the standardized residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In instances when an observation's standardized residual diverged with more than three standard deviations from the model value and thus significantly deviated from normality, this outlier's values were removed. A total of 20 outliers were removed from the 668 data points.

For the sex and muscle trial, two outliers were removed for moisture content, two for protein content, six for fat and five for ash content. For the production system trial, two outliers were removed for moisture content and three for fat content. Fisher's least significant difference was calculated at a significance level of 5 % to compare sex, muscle or production system means (Lyman Ott & Longnecker, 2010). A probability level of 5 % was considered significant for all significance tests, below which ($P \leq 0.05$) differences between the variables are deemed to be significant. Pearson's correlation coefficient (r) was used to quantify correlations between parameters.

5.3 RESULTS

5.3.1 Sex and muscle comparison (Trial 1)

Interactions were found between sex and muscle for the moisture content (P = 0.002), protein content (P < 0.001), intramuscular fat (IMF) content (P < 0.001) and ash content (P = 0.004) of impala meat (Table 5.1). Due to the significant interaction between sex and muscle for all proximate composition parameters, the values obtained for all six muscles of impala are presented separately for each sex in Table 5.2. The moisture content (g/100 g) was higher in the BF, SM and SS muscles of male impala than in females, while female impala had a higher protein content in the LTL, SM, and SS muscles than males. Female impala also had a higher IMF content than males for the BF muscle (1.6 ± 0.08 g/100 g for females vs. 1.3 ± 0.08 g/100 g for males), whereas male impala had a higher IMF content for the LTL, SM, ST and SS muscles. The ash content did not differ significantly between sexes for the BF, SM, IS and SS muscles, which had a pooled mean of 1.2 ± 0.02 g/100 g for both sexes. However, the LTL muscle of male impala had a significantly higher ash content (1.4 ± 0.03 g/100 g) than females (1.2 ± 0.02 g/100 g), while female impala had a higher ash content in the ST muscle than males.

Table 5.1 Level of statistical significance (P-values) for the main effects of sex and muscle, and their interaction for the chemical parameters of impala meat.

Parameter	Sex	Muscle	Sex*Muscle
Moisture (%)	0.002	< 0.001	0.002
Protein (%)	< 0.001	< 0.001	< 0.001
IMF (%)	< 0.001	< 0.001	< 0.001
Ash (%)	0.672	< 0.001	0.004

Abbreviation: IMF = Intramuscular fat content

Due to the lack of data published on the chemical meat quality of all six muscles of impala, the LSMeans of the pooled measurements for both sexes are also presented in Table 5.2 to depict the differences (P < 0.001) between the proximate compositions of the six main muscles of impala. Table 5.3 depicts the linear correlation coefficients between the protein and IMF content (g/100 g) for each muscle. An inverse relationship was found between the protein and IMF content of the SM, IS and SS muscles, as well as for the pooled total of all muscles. This indicates that the IMF content of impala meat will decrease as the protein content increases, and *vice versa*, for those muscles and for impala meat in general.

Table 5.2 LSMeans (± standard error) of the proximate composition (g/100 g) of six different muscles from impala (n = 22) as influenced by sex and muscle (Trial 1). Both the main effects and interactions have been included for all parameters.

Parameter (g/100 g)	Muscle	Sex		Muscle[#] (n = 22; P < 0.001)
		Female (n = 11)	Male (n = 11)	
Moisture	LTL[1]	76.0^{cd} ± 0.15	76.0^{c} ± 0.13	76.0^{b} ± 0.10
	BF[2]	75.2^{fg} ± 0.13	75.6^{de} ± 0.13	75.4^{c} ± 0.09
	SM[3]	74.8^{g} ± 0.13	75.3^{ef} ± 0.13	75.1^{d} ± 0.09
	ST[4]	76.1^{c} ± 0.13	76.0^{c} ± 0.13	76.0^{b} ± 0.09
	IS[5]	76.3^{bc} ± 0.13	76.5^{b} ± 0.13	76.4^{a} ± 0.09
	SS[6]	76.1^{c} ± 0.13	77.0^{a} ± 0.13	76.5^{a} ± 0.09
Sex (n = 22; P = 0.106)	**Pooled**	**75.7 ± 0.14**	**76.1 ± 0.14**	**75.9 ± 0.08**
Protein	LTL	22.6^{bc} ± 0.19	21.6^{ef} ± 0.18	22.1^{b} ± 0.13
	BF	23.1^{ab} ± 0.18	22.7^{bc} ± 0.18	22.9^{a} ± 0.12
	SM	23.5^{a} ± 0.18	22.3^{cd} ± 0.18	22.9^{a} ± 0.12
	ST	22.6^{cd} ± 0.18	22.8^{bc} ± 0.18	22.7^{a} ± 0.12
	IS	21.6^{ef} ± 0.18	21.4^{f} ± 0.18	21.5^{c} ± 0.12
	SS	21.5^{c} ± 0.12	20.7^{g} ± 0.19	21.4^{c} ± 0.13
Sex (n = 22; P < 0.001)	**Pooled**	**22.6 ± 0.10**	**21.9 ± 0.10**	**22.3 ± 0.09**
IMF	LTL	1.2^{f} ± 0.08	1.9^{b} ± 0.08	1.5^{b} ± 0.06
	BF	1.6^{c} ± 0.08	1.3^{def} ± 0.08	1.5^{b} ± 0.06
	SM	1.4^{cd} ± 0.08	2.2^{a} ± 0.08	1.8^{a} ± 0.06
	ST	1.1^{f} ± 0.08	1.4^{cde} ± 0.08	1.3^{c} ± 0.06
	IS	1.9^{b} ± 0.08	2.1^{ab} ± 0.09	2.0^{a} ± 0.06
	SS	1.2^{ef} ± 0.08	1.8^{b} ± 0.09	1.5^{b} ± 0.06
Sex (n = 22; P < 0.001)	**Pooled**	**1.4 ± 0.06**	**1.8 ± 0.06**	**1.6 ± 0.05**
Ash	LTL	1.2^{b} ± 0.02	1.4^{a} ± 0.03	1.3^{a} ± 0.02
	BF	1.2^{b} ± 0.02	1.2^{bc} ± 0.02	1.2^{b} ± 0.02
	SM	1.2^{bcd} ± 0.02	1.2^{bcd} ± 0.02	1.2^{b} ± 0.02
	ST	1.2^{b} ± 0.02	1.2^{cde} ± 0.02	1.2^{b} ± 0.02
	IS	1.1^{e} ± 0.02	1.1^{de} ± 0.02	1.1^{c} ± 0.02
	SS	1.1^{cde} ± 0.02	1.1^{cde} ± 0.02	1.1^{c} ± 0.02
Sex (n = 22; P = 0.672)	**Pooled**	**1.2 ± 0.01**	**1.2 ± 0.01**	**1.2 ± 0.01**

Abbreviations: [1]LTL = *Longissimus thoracis et lumborum*, [2]BF = *biceps femoris*, [3]SM = *semimembranosus*, [4]ST = *semitendinosus*, [5]IS = *infraspinatus*, [6]SS = *supraspinatus.* [a-g]Means with different superscripts within a parameter for muscle and sex differ significantly from each other (P ≤ 0.05). [#a-d]Means with different superscripts within a parameter for muscle differ significantly (P ≤ 0.05).

Table 5.3 Pearson linear correlation coefficients (*r*) and P-values between protein and intramuscular fat content (g/100 g) for each impala muscle.

Muscle	Correlation matrix	
	r	P-value
LTL[1]	-0.33	0.131
BF[2]	-0.21	0.355
SM[3]	-0.59	0.004
ST[4]	0.02	0.948
IS[5]	-0.55	0.009
SS[6]	-0.77	< 0.001
Pooled	-0.48	< 0.001

Abbreviations: [1]LTL = *Longissimus thoracis et lumborum*, [2]BF = *biceps femoris*, [3]SM = *semimembranosus*, [4]ST = *semitendinosus*, [5]IS = *infraspinatus*, [6]SS = *supraspinatus.*

5.3.2 Production system comparison (Trial 2)

Production system had a significant influence on the proximate composition of the *Longissimus thoracis et lumborum* (LTL) of sub-adult (± 15-18 months old) male impala at the 5 % significance level (Table 5.4). The highest (P < 0.001) moisture content was found in meat produced by semi-extensive system impala (75.7 ± 0.11 g/100 g), followed by intensive system impala (75.3 ± 0.10 g/100 g) and lastly by extensive system impala (74.7 ± 0.10 g/100 g). Extensive system impala produced meat with the highest (P < 0.001) protein content (23.4 ± 0.12 g/100 g) and lowest intramuscular fat (IMF) content (1.5 ± 0.06 g/100 g), while the highest IMF content was found in meat produced by intensive system impala (2.0 ± 0.05 g/100 g), which had an intermediate protein content of 22.7 ± 0.12 g/100 g. The semi-extensive system impala produced meat with the lowest protein content (22.0 ± 0.13 g/100 g), and an IMF content (1.8 ± 0.05 g/100 g) that was higher than that of the extensive system impala, but lower than that of impala from the intensive production system. While production system did not have a strong influence (P = 0.062) on the ash content of impala meat, the ash content was found to be the highest in intensive system impala and the lowest in extensive system impala, with semi-extensive system impala not differing significantly from either of the latter two systems (Table 5.4).

Table 5.4 LSMeans (± standard error) of the LTL proximate composition (g/100 g) of impala meat from different production systems

Parameter	Production system			P-value
	Intensive	Semi-extensive	Extensive	
Moisture	75.3^{b} ± 0.10	75.7^{a} ± 0.11	74.7^{c} ± 0.10	< 0.001
Protein	22.7^{b} ± 0.12	22.0^{c} ± 0.13	23.4^{a} ± 0.12	< 0.001
IMF	2.0^{a} ± 0.05	1.8^{b} ± 0.05	1.5^{c} ± 0.06	< 0.001
Ash	1.21^{a} ± 0.01	1.19^{ab} ± 0.01	1.18^{b} ± 0.01	0.062

[a,b,c]Means with different superscripts in the same row differ significantly from each other (P ≤ 0.05).

5.4 DISCUSSION

The objective of this study was to determine the influence of sex, six muscles and three different production systems on the chemical meat quality of impala by means of proximate analysis. Lean skeletal muscles generally have a biochemical composition of approximately 75 % moisture, 20 % protein, 1-10 % IMF and 1 % carbohydrates, vitamins and minerals, with the latter usually analyzed as ash (Huff-Lonergan & Lonergan, 2005; Listrat et al., 2016). The total of these constituents is commonly referred to as the proximate composition of meat, which will vary between different species, age, sex, and different muscles in a carcass (Hocquette et al., 2010; Hoffman et al., 2005, Hoffman et al., 2009; Sebranek, 2014). The proximate composition of meat may also be influenced by the production system in which animals are maintained due to differences in management practices, composition of the diet, and the feed intake and maintenance energy expenditure of animals (Olsson & Pickova, 2005).

There were significant interactions between sex and muscle for the moisture content of impala meat (Trial 1; Table 5.1). The moisture content of meat is generally inversely related to the IMF content; meaning that an increase in IMF content will be accompanied by a decrease in moisture content and *vice versa* (Sebranek, 2014). However, no correlation was found between moisture content and IMF content in the present study (r = -0.007; P = 0.938). This may be due to the low IMF content of game meat in general (Neethling, Hoffman, & Britz, 2014; Van Schalkwyk & Hoffman, 2010) or due to the small sample size of the present study. Consequently, the moisture content of game meat may have a stronger negative correlation to the protein content. Such a correlation was recorded in the present study (r = -0.842; P < 0.001) between the mean moisture and protein content of impala meat (Trial 1 & 2), The higher moisture content found in the SM and SS muscles of male impala compared with that of females (Trial 1) is thus inversely related to the significantly lower protein content of the SM and SS muscles of male impala (Table 5.2). While the protein content of the BF muscle did not differ significantly from that of female impala, it was slightly lower and may account for the high moisture content of the BF muscle in male impala. There were no differences between the sexes for the moisture content of impala LTL muscles, which is in accordance with the previous findings comparing the moisture content of impala meat (Hoffman, 2000a; Hoffman et al., 2005, 2009).

Production system had a significant effect on the moisture content of the LTL muscle of sub-adult male impala (Trial 2), with the highest moisture content found in semi-extensive system impala, followed by intensive system impala, with the lowest moisture content observed in impala from the extensive production system (Table 5.4). The abovementioned inverse relationship between moisture content and protein content may account for the differences in moisture content between production systems. This relationship can be observed with the lowest protein and highest moisture content found in the semi-extensive system impala, as well as with the highest protein and lowest moisture content in extensive system impala. A similar inverse relationship between moisture and protein content was found for blesbok meat (Neethling et al., 2014) and blue wildebeest meat (Van Heerden, 2018).

The moisture content of all impala meat in this study (Trial 1 & 2) ranged from 74.7-77.0 g/100 g (pooled mean of 75.7 ± 0.07 g/100 g). Previous studies on the moisture content of impala meat were limited to the LTL muscle, thus making it difficult to compare the proximate values obtained for all muscle types. Even so, the moisture content of only the LTL impala meat in the present study (75.5 ± 0.12

g/100 g; Trial 1 & 2) was comparable to the values previously obtained for the LTL muscles of impala, which ranged from 70.2-75.7 g/100 g (Hoffman, 2000b; Hoffman et al., 2005, 2009; Van Zyl & Ferreira, 2004; Von La Chevallerie, 1972). When compared with the LTL muscles of other game species, the moisture content of impala meat in the present study was higher than that recorded for springbok (65.3-65.8 g/100 g; North & Hoffman, 2015) and similar to that of fallow deer (73.4-76.6 g/100 g; Fitzhenry, 2016), red deer (74.27 g/100 g; Bureš, Bartoň, Kotrba, & Hakl, 2015), kudu (75.7-75.8 g/100 g; Hoffman et al., 2009) and blesbok (73.9-76.1 g/100 g; Neethling et al., 2014), but slightly lower than eland (75.6-77.8 g/100 g; Laubser, 2018) and blue wildebeest (75.9-78.5 g/100 g; Van Heerden, 2018). In comparison to domestic livestock, all impala meat (Trial 1 & 2) was found to have a higher moisture content than the LTL of White Dorper lambs (62.4-63.2 g/100 g; De Brito et al., 2016), pigs (70.44-73.03 g/100 g; Tomović et al., 2016), and Aberdeen Angus and Holstein cattle (72.9 and 73.4 g/100 g; Bureš et al., 2015). The lower moisture content in meat from domestic livestock may be the result of the inverse relationship with the higher IMF content of livestock compared with that of game species (Bureš et al., 2015).

Sex and muscle were shown to have significant interactions for the protein content of impala meat (Trial 1; Table 5.1), with a higher protein content observed in female impala for the LTL, SM and SS muscles than in male impala (Table 5.2). Significant negative correlations were found between the protein and IMF content of impala meat for the SM, IS, and SS muscles, as well as for the pooled total of all muscles (Table 5.3). The effects of the strong negative correlations can be observed in the SM and SS muscles, which had a higher protein content and lower IMF content in females than in males. Even though the correlation between protein and IMF was not significant for the LTL muscle (r = -0.33; P = 0.131), a similar inverse relationship was noted for this muscle with a higher protein and lower IMF content in females. When comparing the differences between sexes for the pooled results of all muscles (Trial 1), it was found that female impala produced meat with a significantly higher protein content (22.6 ± 0.10 g/100 g) than male impala (21.9 ± 0.10 g/100 g). This is contrary to expectation, as previous researchers found no significant differences between sexes for the protein content of impala LTL muscles (Hoffman, 2000b; Hoffman et al., 2005, 2009). The differences in protein content between sexes in the present study may be the result of age differences recorded between male and female impala. The female impala in the present study were found to be substantially older (estimated at 24 to 36 months old) than the male impala (±15-18 months old) as a result of difficulty classifying the age of female impala in the field by means of body conformation (Refer to Chapter 3.4.1 for more information). The higher protein content recorded for female impala may be the result of the correlation to the lower IMF content, which will be discussed below.

The strong negative correlation between the pooled protein and moisture values of all impala meat (r = -0.848; P < 0.001) may also account for the differences between the intensive, semi-extensive and extensive production systems for these components in sub-adult male impala LTL muscles (Trial 2). The differences in the protein and consequent moisture content of impala meat from different production systems may be due to variation in the vegetation and diet composition of the three production systems. Due to the higher variety of vegetation in the large camp of the extensive system, the mixed feeding behaviour of impala may have allowed the extensive system impala to select a diet

with a more concentrated protein content, which could be reflected in their meat. A similar production region effect was observed with the protein content of impala meat in previous research, where impala from the Musina experimental farm were shown to have a significantly higher protein content than impala from Mara Research Station (Hoffman et al., 2005). The results from both previous research and the present study indicate that both diet and production system have an influence on the proximate composition of impala meat as a result of nutritional differences.

The protein content of all impala in this study (Trial 1 & 2) ranged from 21.4-23.4 g/100 g. The mean pooled protein content (22.5 ± 0.15 g/100 g) of the LTL muscles of impala (Trial 1 & 2) is comparable to the values previously recorded for impala LTL muscles (Hoffman, 2000b; Hoffman et al., 2005, 2009). The protein content of impala in the present study is also similar to that of ostrich (22.2 ± 1.13 g/100g; Paleari et al., 1998), blesbok (19.0-23.1 g/100 g; Neethling, Hoffman, & Muller, 2016) and blue wildebeest (19.3-22.3 g/100 g; Van Heerden, 2018), lower than springbok (31.1 ± 0.45 g/100 g; North & Hoffman, 2015) and higher than that of turkey (20.4 ± 0.77 g/100 g; Paleari et al., 1998), Aberdeen Angus cattle (21.4 g/100 g; Bureš et al., 2015) and spent dairy cattle (20.1 ± 0.85 g/100 g; Paleari et al., 1998). The results of the present study therefore confirms that impala meat has the high protein content associated with game meat and compares favourably to that of traditional livestock species. This makes impala meat a biologically valuable source of protein that can serve as a healthy alternative or addition to traditional red meat.

Game meat is characterized as a low-kilojoule, low-fat product with an intramuscular fat (IMF) content that generally falls below three percent (Schack et al., 2016). The IMF content of meat is an important characteristic of the meat quality due to its relation to the juiciness (Sookhareea, Taylor, Woodford, Dryden, & Shorthose, 1995), tenderness and flavour of meat, particularly during cooking or heat treatment (Geldenhuys, Hoffman, & Muller, 2014; Purslow, 2005; Tshabalala, Strydom, Webb, & De Kock, 2003). The IMF in meat is primarily comprised of phospholipids, structural lipids, and storage lipids (triglycerides), with the latter stored mainly (± 80 %) in muscle adipocytes between muscle fibres and fibre bundles, while the remaining portion is stored as intracellular lipids (Essén-Gustavsson & Fjelkner-Modig, 1985). The size and number of intramuscular adipocytes has a large influence on the IMF content of meat (Listrat et al., 2016).

The significantly higher IMF content of the LTL, SM, ST and SS muscles of male impala than in females (Trial 1; Table 5.2) and higher pooled IMF content of all male impala muscles (1.8 ± 0.06 g/100 g for males vs. 1.4 ± 0.06 g/100 g for females) found in the present study was in contrast with the general trends expected between sexes for the protein content of impala meat. At the same age, female impala have a higher IMF content than males, as was reported by most of the previous studies on impala chemical composition (Hoffman, 2000; Hoffman, Kritzinger, & Ferreira, 2005; Hoffman et al., 2009; Van Zyl & Ferreira, 2004). The male impala of the present study were found to have a higher mean IMF content for the LTL muscle than male impala near Bredasdorp (1.2 ± 0.1 g/100 g; Van Zyl & Ferreira, 2004) and from Musina Experimental farm and Mara Research Station in Limpopo (1.4 ± 0.51 g/100 g; 1.4 ± 0.24 g/100 g; Hoffman et al., 2005), but had a lower IMF content than recorded for sub-adult male impala in the Mabula District of Limpopo (2.0 ± 0.22 g/100 g; Hoffman et al., 2009). In contrast to the male impala from previous studies with a lower IMF content (Hoffman et al., 2005), the

male impala in the present study were too young to go into rut, and thus would not experience the weight loss and consequent reduced IMF associated with rutting as reported for the impala from the Musina Experimental Farm and Mara Research Station (Hoffman et al., 2005).

The IMF content of the female impala LTL muscle in the present study (Table 5.2) was also lower than the previous values reported for female impala, which ranged from 1.9 ± 0.73 g/100 g at Mara Research Station (Hoffman et al., 2005) and 2.4 ± 0.19 g /100 g in the Mabula District of Limpopo (Hoffman et al., 2009) to 3.4 ± 0.17 g/100 g in Zimbabwe (Hoffman, 2000b) and 4.3 ± 0.8 g/100 g near Bredasdorp in the Western Cape (Van Zyl & Ferreira, 2004). The much lower IMF content of female impala LTL muscles compared with males in the present study (Trial 1, Table 5.2) and with that of females in previous research may be due to a combination of seasonal effects and the previously mentioned age differences between the sexes in the present study. In addition to the substantially older mean age of female impala compared to males, four of the female impala were found to be lactating at the time of culling. Lactation depletes the fat reserves of female animals (Oftedal, 2000), and may contribute to the low IMF content found in the female impala of the present study. Previous research was performed in different seasons and no lactation was reported, thus explaining a higher IMF content of female impala in these studies (Hoffman et al., 2005, 2009) as there was no draining on fat reserves. In addition, there was a drought in the area (Modimolle) in the year of culling in the present study, which has a negative impact on the quality and quantity of the pasture. Lactating females that do not have sufficient nutrient intake are prone to deplete fat stores for milk production in order to sustain their young (Oftedal, 2000). Consequently, depletion of the lipid stores may have caused the reduced IMF content of the female impala in the present study. In contrast, previous research found high IMF content (> 5 g/100 g) in female springbok that did not lamb (Hoffman, Kroucamp, & Manley, 2007), thus reiterating the effect of lambing on the IMF content of female antelope.

Production system was found to have a significant effect on the IMF content of meat from sub-adult male impala (Trial 2). The significant differences in the IMF content of the LTL muscle between impala from different production systems (Table 5.4) may be the result of variation in adipocyte size, which has been shown to be affected by different dietary energy intakes in animals with the same genetic origin (Gondret & Lebret, 2002). While a drought was experienced throughout the country in the year of harvesting in the present study, the conditions were particularly detrimental in the Western Cape area where the extensive system was located. This may have influenced the condition of the extensive system impala prior to slaughter and resulted in a reduced IMF content in the meat *post-mortem*. While a diet of only supplied feed resulted in a significantly higher IMF content for the intensive system impala, the difference was numerically only 0.5 g/100 g more than the IMF content found in the extensive system impala. These differences are therefore numerically too small to provide a substantial nutritional advantage for meat produced from sub-adult impala in intensive production systems compared with impala from semi-extensive or extensive production systems.

The IMF content of meat from impala of both sexes, all muscles and all production systems in this study (Trial 1 & 2) ranged from 1.3-2.0 g/100 g. The IMF content of all impala LTL meat (Trial 1 & 2; pooled mean of 1.7 ± 0.06 g/100 g) is similar to that of 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 g/100 g; Hoffman et al., 2009) and

blue wildebeest (1.6-2.1 g/100 g; Van Heerden, 2018), and lower than that of blesbok (2.3-3.4 g/100 g; Neethling et al., 2014). The IMF content of impala meat in the present study was also lower than that of turkey (3.8 ± 0.79 g/100 g; Paleari et al., 1998), Aberdeen Angus cattle (3.62 g/100 g; Bureš et al., 2015), Holstein cattle (2.77 g/100 g; Bureš et al., 2015) and spent dairy cattle (4.5 ± 0.93 g/100 g; Paleari et al., 1998). The low IMF content of impala meat indicates the leanness of meat from this game species, which makes it an appealing option for health-conscious consumers.

The ash content of meat provides information on the inorganic constituent such as minerals and vitamins and comprises approximately 1 % of the total proximate composition of the meat (Huff-Lonergan & Lonergan, 2005). While there was a significant interaction between sex and muscle for the ash content of impala meat (Trial 1; Table 5.1) and significant differences between production systems for ash content (Trial 2; Table 5.4), the differences were marginal and may thus not be of biological significance to human nutrition. Nonetheless, the ash content of all impala in this study (Trial 1 & 2) ranged from 1.09-1.36 g/100 g, and the pooled mean for all impala LTL muscles (Trial 1 & 2; 1.24 ± 0.01 g/100 g) is comparable to those found in impala LTL in previous studies (1.4-2.4 g/100 g; Hoffman et al., 2005, 2009), as well as to that of other game species including the 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).

5.5 CONCLUSION

This study aimed to determine the influence of sex, six different muscles and three different production systems on the proximate composition of impala meat. Significant interactions were recorded between sex and muscle for all components of the proximate composition (moisture, protein, IMF, and ash) of impala meat (Trial 1). While significant differences were found between sex and muscle, the differences were not more than three grams per 100 grams between the highest and lowest values obtained for each component. However, it is recommended that the study be repeated with increased animal numbers and impala of both sexes that are confirmed to be the same age prior to slaughter to eliminate the influence of age differences.

Production system had a significant influence on the proximate composition of the LTL muscles of sub-adult male impala (Trial 2), with differences most likely caused by environmental differences in climate and the nutritional quality of the dietary regimes between production systems. However, the differences in proximate composition of impala meat from the different production systems were also numerically small and may therefore not be biologically relevant to human nutrition, nor provide a substantial advantage in raising impala in more management-intensive boma systems above that of semi-extensive or extensive production systems. Nonetheless, the differences in chemical meat quality may have an impact on the sensory meat quality, and it is therefore recommended that the influence of production system on the aroma and flavour characteristics of impala meat should be investigated.

Overall, this study found all impala meat (Trial 1 & 2) to be high in protein (22.5 g/100 g pooled mean) and low in intramuscular fat (1.7 g/100 g pooled mean) content, comparing favourably to traditional livestock species and other species of game. Impala meat can therefore be considered as a valuable protein source with appealing qualities for health-conscious consumers. The results from this

study may be useful in the marketing and sale of impala meat according to the nutritive content and highlights the nutritional potential of this species for possible contribution to the food security of South Africa as an addition to traditional red meat species.

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CHAPTER 6

SENSORY MEAT QUALITY OF MALE IMPALA (*AEPYCEROS MELAMPUS*) AS INFLUENCED BY PRODUCTION SYSTEM

ABSTRACT

The objective of this study was to determine the influence of three different production systems (intensive, semi-extensive and extensive) on the descriptive sensory profile and fatty acid profile of sub-adult (±15-18 months old) male impala *Longissimus thoracis et lumborum* (LTL) muscles. The overall aroma and flavour intensities had strong positive correlations ($P < 0.001$) with gamey, beef-like, herbaceous and sweet-associated aromas and flavours. The discriminant analysis plot showed that extensively produced impala from the Central Rûens Shale Renosterveld region in the Western Cape had a sensory profile distinct from the intensive and semi-extensive system impala from the Central Sandy Bushveld region in the Limpopo province of South Africa. Extensively produced impala had the highest sensory ratings for overall intensity (69.1 and 65.7), gamey (58.5 and 56.7), beef-like (42.4 and 45.0), herbaceous (13.2 and 12.1) and sweet-associated (11.5 and 12.6) aroma and flavour of their meat. The intensive and semi-extensive system impala did not differ ($P > 0.05$) for the majority of the sensory attributes, with the exception of higher ratings for gamey flavour, liver-like flavour, tenderness and mealiness, and lower ratings for residue found in semi-extensive system impala. Impala meat from all three production systems had desirable fatty acid profiles, with PUFA:SFA ratios (1.0-1.1) above the recommended 0.45 minimum and n6:n3 PUFA ratios (1.0-1.1) well below the 4:1 recommended maximum, as well as low IMF contents (1.7-2.0 %). Impala meat from all three production systems may therefore be classified as a health food commodity with a high nutritional value, based on their fatty acid profiles.

Keywords: Game meat, Sensory characteristics, Fatty acids

6.1 INTRODUCTION

The South African game industry has expanded significantly in the last few decades. The growth in the industry was accompanied by the increased utilization of intensive, semi-extensive and extensive production systems to improve animal production, particularly for the breeding of high-value game and colour variants (Bothma, Sartorius Von Bach, & Cloete, 2016). With the intensification of production systems, feed supplementation is often practiced to different extents for the improvement of the average daily gain (ADG) of game animals to facilitate overall improvements in production efficiency (Hoffman & Cawthorn, 2013). While the aim of using smaller camps and higher intensity of feeding management is primarily for the improvement of animal breeding and management, the subsequent high animal turnover results in a surplus of animals that may be culled for meat production (Hoffman, 2007; Oberem & Oberem, 2016).

A species that is frequently farmed in different production systems is the impala (*Aepyceros melampus*), which is a popular choice for the breeding of colour variants such as the black impala (Furstenburg, 2005, 2016). The impala is typically the most abundant game species on private game farms, with a high fecundity, rapid reproduction rate and mixed feeding behaviour that allows it to adapt to a variety of habitats across southern Africa (Fairall, 1983; Taylor, Lindsey, & Davies-Mostert, 2016). Furthermore, this species has been recorded to attain high carcass yields and produce meat with acceptable physical and nutritional quality, with a high protein and low intramuscular fat (IMF) content that is considered desirable by consumers (Chapters 2, 3, 4, & 5; Hoffman, 2000; Hoffman, Kritzinger, & Ferreira, 2005). Based on these characteristics and the suitability of this species for sustainable culling (Fairall, 1983), impala may be well-suited for meat production. However, the influence of different production systems on the sensory meat quality of impala has yet to be determined. Additionally, while impala reportedly adapt well to supplementary feeding and different diets (Furstenburg, 2016), the composition of the feed ingested by animals has been found to affect nutritional characteristics such as the fatty acid content of meat and may consequently influence the sensory meat quality of impala from different production systems (Neethling, 2016; Nuernberg et al., 2005).

The sensory characteristics of meat are considered to be the most important attributes of meat quality due to their essential role in the satisfaction of consumers (Hoffman, Muller, Schutte, & Crafford, 2004; Listrat et al., 2016; Oltra et al., 2015). The sensory quality of meat is comprised of all aspects that affect the consumer's perception, which are the visual, retronasal and aroma, flavour, juiciness and textural characteristics. These characteristics may be affected by the sex, species and dietary regime of the animals (Calkins & Hodgen, 2007; Melton, 1990; Neethling, 2016). Furthermore, the consistency of sensory attributes may be affected by natural variations in meat quality, which in turn has a negative impact on the consumer's perception of the reliability of the product (Issanchou, 1996). While sensory quality and the consistency thereof remain imperative to consumer acceptability of the product, the recent increase in consumer health consciousness has resulted in an increased awareness of dietary requirements and demand for meat products that have high nutritional quality as well as acceptable sensory attributes (Hoffman & Wiklund, 2006; Wood et al., 2003).

Meat is considered to be of high nutritional quality when it contains lipids with a high proportion

of polyunsaturated fatty acids (PUFAs) and essential amino acids (Listrat et al., 2016). In addition to PUFAs, the lipid component of meat is also comprised of saturated fatty acids (SFA). The SFA of meat have been related to the onset of atherosclerosis and consequently coronary vascular disease in humans (Williamson, Foster, Stanner, & Buttriss, 2005; Wood, Enser, Richardson, & Whittington, 2008). The resulted in a recommendation by the World Health Organisation (WHO) to increase the PUFA:SFA ratio to above 0.4 (World Health Organisation., 2003). The meat from various game species has been found to be high in PUFAs, with PUFA:SFA ratios above the recommended 0.4 and low n6:n3 fatty acid ratios (Hoffman & Wiklund, 2006). However, the fatty acid profile of meat can vary depending on the species and diet of the animal, as well as the anatomical origin of the muscle from which the meat originates (Shingfield, Bonnet, & Scollan, 2013). In order to make informed choices regarding the best animal protein source to meet the requirements of consumers, it is crucial to determine the fatty acid composition of game meat and the influence of factors that may alter it (Hoffman & Wiklund, 2006).

Limited research has been conducted to compare the sensory meat quality and fatty acid content of impala meat to that of other game species, as well as between sexes (males and females) within the same species (Hoffman, Kritzinger, & Ferreira, 2005a; Hoffman, Mostert, & Laubscher, 2009; Neethling, 2016). While sex was found to have a negligible influence, production region and feeding regime was speculated to be an influential factor concerning the sensory meat quality within a species (Neethling, 2016). Furthermore, the physical meat quality and chemical composition of impala meat has been found to be affected by both production region and production system (Chapters 4 & 5; Hoffman et al., 2005). These *ante-mortem* factors may in turn influence the sensory meat quality and fatty acid profile of impala meat. Therefore, the aim of this study was to investigate the influence of three different production systems (intensive, semi-extensive and extensive) on the sensory meat quality and fatty acid content of meat from sub-adult (±15-18 months old) impala males, as determined by descriptive sensory analysis (DSA) by means of a trained panel of judges.

6.2 MATERIALS AND METHODS

6.2.1 Experimental location and animals

For this trial, a total of 36 sub-adult (±15-18 months old) male impala were obtained from two experimental locations in March during the summer of 2017, namely Castle de Wildt near Modimolle in the Central Sandy Bushveld bioregion of the Savanna biome in the Limpopo province (intensive and semi-extensive), and a farm near Bredasdorp in the Central Rûens Shale Renosterveld vegetation unit of the Western Cape province of South Africa (extensive). Further information regarding the description of vegetation and production of the impala can be found in the Materials and Methods of Chapter 3.2.1 (Trial 2).

6.2.2 Culling, carcass processing and sampling

All impala obtained for this study were culled during the day (ethical clearance number 10NP_HOF02) with suppressor-equipped light calibre rifles (.22 or .243). Thereafter, the impala were exsanguinated, skinned, eviscerated and dressed as described in Chapter 3.2.2., after which the carcasses were hung in a chiller set to 4 ± 1°C to undergo *rigor mortis*. After ±24 hours in the chiller, all impala carcasses

were deboned and both the left and right *Longissimus thoracis et lumborum* (LTL) muscles were excised. The right LTL muscles were trimmed of excess fat and connective tissue and subsequently halved. Both halves were weighed separately and vacuum sealed, with one half designated for the training phase of the descriptive sensory analysis and the other half designated for the descriptive analysis testing. The LTL muscles from the left side of the carcasses were weighed and vacuum sealed in labelled composite plastic bags for chemical analysis. All LTL samples were frozen at -20°C for approximately two months prior to analysis, with prolonged freezing deemed acceptable as it is considered standard protocol during air shipment for southern African game meat designated for export (Dahlan & Norfarizan Hanoon, 2008).

6.2.3 Sensory analysis

6.2.3.1 Sample preparation and physical measurements

The descriptive sensory analysis was conducted on impala meat from the three different production system treatments with twelve replications per treatment, where one impala LTL muscle represents one replication. The impala meat was removed from the freezer and thawed at 4 ± 1°C for 24 hours prior to the pre-determined sensory analysis sessions. On the day of each session, each muscle sample was removed from its respective vacuum bag, blotted dry with paper towels and weighed to determine thaw loss as a percentage of the muscle weight before freezing (AMSA, 2015). Thereafter, each sample was placed onto an aluminium foil-covered oven roasting pan and inserted into a separate oven bag (Glad®). A thermocouple probe attached to a handheld digital temperature monitor (Hanna Instruments, South Africa) was inserted into the middle of each meat sample and the cooking bags were firmly secured with care taken to not detach the probes. The prepared samples were placed in a conventional oven (Hobart, France) preheated to 163°C (AMSA, 2015) and cooked until an internal temperature of 71°C was reached.

The meat samples were then removed from the oven and the cooking bags to be rested for 10 minutes at room temperature, after which the samples were blotted dry and weighed to determine cooking loss as a percentage of the raw muscle weight (AMSA, 2015). Each meat sample was cut into ±1.0 cm thick steaks, which were the further cut into 1.0 cm^3 meat cubes, and individually wrapped in aluminium foil. Prior to each sensory analysis, the wrapped meat cubes were placed into ramekins (four cubes per ramekin) and re-heated for 10 minutes in pre-heated oven at 100°C. The ramekins containing the samples cubes were then transferred to water baths set at a temperature of 70°C to maintain the heat of the meat samples for the duration of the training or testing session (AMSA, 2015).

After descriptive sensory analysis (see below), the tenderness of impala meat was measured by determining the Warner Bratzler shear force (WBSF) of the remaining portions of the cooked meat samples after removal of the steaks used for DSA. Six 1 x 1 x 2 cm rectangular cuboids were cut from each meat sample, with the longitudinal axis of the cuboid cut parallel to the direction of the muscle fibres. The shear force of each cuboid was measured with an Instron Universal Testing Machine (Instron UTM, Model 2519-107) that was used to cut through the middle of each cuboid at a right angle to the longitudinal axis. The Warner Bratzler blade had a triangular opening that lead into a 1 mm thick cutting blade that was shaped like a half circle with a 0.508 mm radius. The blade was attached to a crosshead

that cut through each sample at a speed of 200 mm per minute. The average of the six readings was calculated to determine the Warner Bratzler shear force (N) of each impala LTL sample.

6.2.3.2 Descriptive sensory analysis (DSA)

A panel of 11 judges were selected for the descriptive sensory analysis based on their previous experience with sensory analysis of meat and various meat products. The panellists were trained according to the guidelines depicted by AMSA (2015) and the consensus method described by Lawless & Heymann (2010). The training consisted of two sessions per day for a total of four days. During these sessions, each judge received four meat cubes of each of the four reference samples (Table 6.1) as well as four meat cubes from each impala from the three different production system treatments. The reference samples served as a baseline measure that allowed the panel to decide on a total of 23 sensory attributes; consisting of eight aroma attributes, 10 flavour attributes and five texture attributes (Table 6.2) to further evaluate the study samples. Once all panellists were confident with the agreed-upon descriptors, testing commenced.

Testing consisted of two sessions per day for a duration of six days, with the 36 impala LTL muscles from the three different production systems randomly allocated into the 12 sessions. For the descriptive sensory analysis, the test re-test method was used (AMSA, 2015). The 11 panellists received the three production system treatments in a completely randomised order. Each panellist was allocated to a separate tasting booth equipped with computers upon which the Compusense® Five (Compusense, Guelph, Canada) software programme has been installed. The meat samples were rated by the panellists using an unstructured line scale ranging from zero (signifying “low intensity”) to 100 (signifying “high intensity”) for each of the sensory attributes (AMSA, 2015). The DSA was held inside a temperature-controlled room (22°C). Each panellist received distilled water, apple slices and biscuits to cleanse their palates between each meat sample.

6.2.4 Fatty acid analysis

The fatty acid (FA) profiles of the LTL muscles of each impala from the three different production systems were determined independently. The left LTL muscles from all impala were thawed overnight at 4 ± 1°C. After thawing, each muscle was trimmed of excess fat and connective tissue and homogenized. Each homogenized meat sample was placed into separate bag, vacuum sealed and immediately frozen at -20°C until fatty acid analysis could be performed.

The homogenized meat samples were thawed overnight at 4 ± 1°C prior to analysis. One gram of each raw homogenized sample was weighed out for fat extraction using a chloroform:methanol (2:1; v/v) solution with 0.01 % butylated hydroxytoluene (BHT) included as an anti-oxidant. Each sample was homogenized in the extraction solution with a polytron mixer (WiggenHauser, D-500 Homogenizer) for 30 seconds. For the quantification of each meat sample’s individual fatty acids, heptadecanoic acid (C17:0) was used as an internal standard (catalogue number H3500, Sigma-Aldrich, Gauteng, South Africa). A 250 µl sub-sample was collected from the extracted fat solution and transmethylated in a water bath set to 70°C for two hours, with methanol:sulphuric acid (19:1; v/v) used as the transmethylating agent. Thereafter, the samples were removed from the water bath and allowed to cool

at room temperature. Once cooled, water and hexane were used to extract the fatty acid methyl esters (FAMEs). Once the FAME-containing hexane solution and the distilled water were separated, the top hexane phase was transferred to a spotting tube to be dried in a water bath under nitrogen. After the sample had been dried, 50 µl of hexane was added to the spotting tube, which was then centrifuged. Of this final mixture, 1 µl was collected for injection into the gas chromatograph for analysis of separation fatty acids methyl esters (FAMEs).

The FAMEs of each impala LTL sample were analyzed with a Thermo Scientific TRACE 1300 series gas-chromatograph (Thermo Electron Corporation, Milan, Italy) equipped with a flame-ionisation detector (GC-FID), using a 30 m ZB-WAX Zebron 7HG-G007-11 capillary column with a 0.25 mm internal diameter, a 0.25 µm film thickness and a runtime of approximately 45 minutes. One µl of sample was injected in a 5:1 split ratio, with helium used as the carrier gas (1 ml/min flow rate) and an injector temperature maintained at 260°C. The oven temperature settings were as follows: initial temperature of 100°C maintained for two minutes, followed by an increase at a rate of 10°C per minute for four minutes until a 140°C oven temperature was reached, after which the temperature was immediately increased by 3°C per minute to reach 190°C. This was followed by a final increase at 30°C per minute until the final temperature of 260°C was reached, which was maintained for a minimum of five minutes. The FAME of each impala LTL sample was identified by comparing the retention times to those of a standard FAME mixture (Supelco™ 37 Component FAME mix, Cat no. 47885-U, Supelco, USA) and quantified by comparing the integrated areas to those of the internal standard. The results are given as a percentage of the total FAME content. The *cis* and *trans* isomers of C18:1n9 and C18:2n6 are expressed as single combined values due to the co-elusion of these isomers in the majority of the samples.

6.2.5 Statistical analysis

The experimental design for this trial was a completely random experimental design with twelve male impala culled at random for each production system (intensive, semi-extensive and extensive; n = 36). Production system served as the treatment and the LTL muscles of the impala were the replicates, with twelve replicates for each of the three treatments in each analysis (physical, sensory or chemical). The results provided by the panellists for the descriptive sensory analysis were monitored with PanelCheck Software (Version 1.4.0, www.panelcheck.com). Thereafter, the data obtained for the physical, sensory and chemical analyses of impala meat was analyzed 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 from the model to test for deviation from normality (Shapiro & Wilk, 1965). For this trial, no outlier values were removed. Fisher's least significant difference was calculated at a significance level of 5 % to compare production system means (Lyman Ott & Longnecker, 2010). Pearson's Correlation coefficient (r) was used to quantify correlations between parameters, and a probability level of 5 % ($P \leq 0.05$) was considered significant for all tests. A compilation of these correlations can be found in Addendum II. Associations between the sensory characteristics were illustrated by means of Principal Component Analysis (PCA) and Discriminant Analysis (DA) using XLSTAT® (Version 2014.2.03; Addinsoft, New York, USA).

Table 6.1 Reference samples used during the training phase for the descriptive sensory analysis (DSA) of impala meat.

Reference sample	Reference for	Final internal temperature	Scale
Beef fillet	Beef-like aroma and flavour, initial juiciness, sustained juiciness, tenderness, residue, mealiness	71°C	0 = low intensity; 100 = high intensity
Beef ox liver	Liver-like aroma and flavour	No probe used	0 = low intensity; 100 = high intensity
Beef rib-eye	Initial juiciness, sustained juiciness, toughness, residue, mealiness	72°C	0 = low intensity; 100 = high intensity
Ostrich fillet	Metallic aroma and flavour	71°C	0 = low intensity; 100 = high intensity

Table 6.2 Description and scale of the sensory attributes (aroma, flavour and texture) decided upon by the trained sensory panel.

Sensory attribute	Description of attributes	Scale
Aroma and flavour		
Overall intensity[a]	Intensity of aroma in the first few sniffs and the intensity of the sum of all flavours	0 = low intensity; 100 = high intensity
Gamey[a]	Aroma /flavour associated with meat from wild animal species	0 = low intensity; 100 = high intensity
Beef-like[a]	Aroma /flavour associated with cooked beef fillet	0 = low intensity; 100 = high intensity
Metallic[a]	Aroma /flavour associated with raw meat/blood-like aroma/flavour	0 = low intensity; 100 = high intensity
Liver-like[a]	Aroma/flavour associated with pan-fried beef liver	0 = low intensity; 100 = high intensity
Herbaceous[a]	Aroma/flavour associated with earthy, Fynbos-like herbs	0 = low intensity; 100 = high intensity
Off/sour/sweat-like[a]	Aroma/flavour associated with an off/sour/sweat-like characteristic of meat	0 = low intensity; 100 = high intensity
Sweet-associated aroma	Aroma associated with the browning of a cooked meat surface (Maillard reaction)	0 = low intensity; 100 = high intensity
Sweet-associated taste	Taste associated with a sucrose solution	0 = low intensity; 100 = high intensity
Salty taste	Taste associated with sodium ions	0 = low intensity; 100 = high intensity
Sour taste	Taste associated with a citric acid solution	0 = low intensity; 100 = high intensity
Texture		
Initial juiciness	Amount of fluid extruded on the meat surface when pressed between the thumb and forefinger (pressed perpendicular to muscle fibres)	0 = dry; 100 = extremely juicy
Sustained juiciness	Amount of moisture perceived during mastication (after five chews)	0 = dry; 100 = extremely juicy
Tenderness	Impression of tenderness after mastication (after five chews)	0 = tough; 100 = extremely tender
Residue	Residual tissue remaining after mastication (difficult to chew through - after 10 chews)	0 = none; 100 = abundant
Mealiness	Disintegration of muscle fibre wear mealy disintegrates into very small particles (perception within first few chews)	0 = none; 100 = abundant

[a]Sensory attribute was evaluated for both aroma and flavour.

6.3 RESULTS

6.3.1 Physical measurements

The influence of production system on the physical measurements of impala LTL meat is presented in Table 6.3. Impala from the extensive production system produced meat with a significantly lower thaw loss percentage than impala from the intensive or semi-extensive production systems, while the latter two systems did not differ significantly from each other at the 5 % level. The most tender meat was produced by impala from the semi-extensive production system, as indicated by the lowest mean shear force value. The highest shear force values were found in impala from the intensive and extensive production systems, which did not differ significantly from each other (Table 6.3). No differences (P = 0.921) were found between production systems for cooking loss percentage, for which a pooled mean of 29.9 ± 1.18 % was recorded.

Table 6.3 LSMeans (± standard error) of the physical parameters of sub-adult male impala *Longissimus thoracis et lumborum* (LTL) meat as influenced by production system.

Parameter	Production system			P-value
	Intensive	Semi-extensive	Extensive	
Thaw loss (%)	9.9^{a} ± 0.50	10.1^{a} ± 0.50	4.0^{b} ± 0.50	< 0.001
Cooking loss (%)	29.9 ± 2.09	29.3 ± 2.09	30.5 ± 2.09	0.921
WBSF (N)	52.5^{a} ± 5.13	37.2^{b} ± 5.13	52.3^{a} ± 5.13	0.068

^{a,b,c}Means with different superscripts in the same row differ significantly (P ≤ 0.05) from each other.

6.3.2 Sensory analysis

Production system had an influence (P ≤ 0.05) on all sensory characteristics (Table 6.4) except liver-like aroma (1.8 ± 0.35 pooled mean), salty taste (9.1 ± 0.01 pooled mean), initial juiciness (39.5 ± 0.98 pooled mean) and sustained juiciness (46.1 ± 0.83 pooled mean). Impala from the extensive production system produced meat with the highest overall aroma (69.1 ± 0.49) and overall flavour (65.7 ± 0.61) intensities. Intensive and semi-extensive system impala did not differ significantly from each other for overall aroma intensity. However, the lowest overall flavour intensity was found in impala from the intensive production system, while semi-extensive system impala did not differ significantly from either of the other two systems (Table 6.4).

Extensively produced impala had a significantly higher intensity for gamey aroma (58.5 ± 0.59), beef-like aroma (42.4 ± 0.53) and flavour (45.0 ± 0.66), herbaceous aroma (13.2 ± 0.52) and flavour (12.1 ± 0.48), sweet-associated aroma (11.5 ± 0.42) and sweet-associated taste (12.6 ± 0.32), and lower metallic aroma (2.4 ± 0.56), metallic flavour (3.3 ± 0.51) and off, sour, sweat-like flavour (0.2 ± 0.24) than the other two systems' impala, which did not differ from each other for these characteristics. Gamey flavour was found to have the lowest (P < 0.001) intensity in meat from intensive system impala (54.0 ± 0.42) compared to that of semi-extensive and extensive system impala, while the latter two systems did not differ significantly from each other. While the liver-like aroma did not differ (P = 0.461) between production systems, liver-like flavour had a higher (P = 0.002) intensity in semi-extensive system impala than in intensive or extensive system impala, which did not differ from each other. Semi-

extensive system impala also had the highest (P = 0.041) intensity for sour taste, while the lowest sour taste intensity was found in extensive system impala. Impala from the intensive system did not differ significantly from either of the other two systems for the sour taste characteristic. In terms of texture attributes, the most tender (P = 0.016) meat was found in semi-extensive system impala (66.9 ± 1.90), while the intensive (59.9 ± 1.90) and extensive (59.7 ± 1.90) system impala did not differ from one other. Impala from the semi-extensive system also produced meat with the lowest residue (6.9 ± 1.31) and highest mealiness (9.9 ± 0.85) scores, while the other two systems did not differ significantly from each other for these characteristics (Table 6.4).

Table 6.4 LSMeans (± standard error) of the sensory ratings of sub-adult male impala *Longissimus thoracis et lumborum* (LTL) meat as influenced by production system.

Sensory characteristic	Production system			P-value
	Intensive	Semi-extensive	Extensive	
Aroma				
Overall aroma intensity	65.1^{b} ± 0.49	66.3^{b} ± 0.49	69.1^{a} ± 0.49	< 0.001
Gamey aroma	54.7^{b} ± 0.59	56.1^{b} ± 0.59	58.5^{a} ± 0.59	< 0.001
Beef-like aroma	37.2^{b} ± 0.53	38.5^{b} ± 0.53	42.4^{a} ± 0.53	< 0.001
Metallic aroma	6.3^{a} ± 0.56	6.0^{a} ± 0.56	2.4^{b} ± 0.56	< 0.001
Liver-like aroma	1.8 ± 0.35	2.2 ± 0.35	1.5 ± 0.35	0.461
Herbaceous aroma	6.8^{b} ± 0.52	8.0^{b} ± 0.52	13.2^{a} ± 0.52	< 0.001
Off, sour, sweat-like aroma	5.5^{a} ± 0.69	3.6^{ab} ± 0.69	2.4^{b} ± 0.69	0.014
Sweet-associated aroma	8.4^{b} ± 0.42	9.5^{b} ± 0.42	11.5^{a} ± 0.42	< 0.001
Flavour				
Overall flavour intensity	62.9^{b} ± 0.61	64.2^{ab} ± 0.61	65.7^{a} ± 0.61	0.008
Gamey flavour	54.0^{b} ± 0.42	55.9^{a} ± 0.42	56.7^{a} ± 0.42	< 0.001
Beef-like flavour	39.4^{b} ± 0.66	38.5^{b} ± 0.67	45.0^{a} ± 0.66	< 0.001
Metallic flavour	8.4^{a} ± 0.51	8.4^{a} ± 0.51	3.3^{b} ± 0.51	< 0.001
Liver-like flavour	1.2^{b} ± 0.30	2.2^{a} ± 0.30	0.6^{b} ± 0.30	0.002
Herbaceous flavour	7.1^{b} ± 0.48	8.2^{b} ± 0.48	12.1^{a} ± 0.48	< 0.001
Off, sour, sweat-like flavour	1.3^{a} ± 0.24	0.9^{a} ± 0.24	0.2^{b} ± 0.24	0.012
Sweet-associated taste	10.5^{b} ± 0.32	10.2^{b} ± 0.32	12.6^{a} ± 0.32	< 0.001
Salty taste	9.1 ± 0.01	9.1 ± 0.01	9.1 ± 0.01	1.000
Sour taste	4.2^{ab} ± 0.22	4.5^{a} ± 0.22	3.7^{b} ± 0.22	0.041
Texture				
Initial juiciness	39.4 ± 0.98	39.3 ± 0.98	39.7 ± 0.98	0.950
Sustained juiciness	46.0 ± 0.83	45.7 ± 0.83	46.5 ± 0.83	0.772
Tenderness	59.9^{b} ± 1.90	66.9^{a} ± 1.90	59.7^{b} ± 1.90	0.016
Residue	11.3^{a} ± 1.31	6.9^{b} ± 1.31	12.2^{a} ± 1.31	0.015
Mealiness	6.0^{b} ± 0.85	9.9^{a} ± 0.85	4.7^{b} ± 0.85	< 0.001

^{a,b,c}Means with different superscripts in the same row differ from one another (P ≤ 0.05)

Figure 6.1 depicts a PCA bi-plot, which illustrates the correlation between the different sensory characteristics of impala meat. The combination of F1 and F2 explained 57.7 % of the total variance, of which 41.9 % is explained by F1 and 15.9 % is explained by F2. The discriminant analysis (DA) plot

(Figure 6.2.a) depicts the classification of the observations (intensive, semi-extensive or extensive production system) and their association with all the variables used to classify the observations as presented in the DA variable loadings plot (Figure 6.2.b). The DA plot accounts for 100.0 % of the total variance between treatments (production system), with F1 and F2 accounting for 91.8 % and 8.2 % of the variation between the treatments, respectively. From Figure 6.2, it can be observed that the extensive production system impala are strongly associated with the sensory characteristics on the right side of F1, while both intensive and semi-extensive system impala show stronger associations with the attributes on the left side of F1. The intensive and semi-extensive treatments also show a substantial amount of overlap for the variables on the left of F1, whereas the extensive production system shows very little overlap with either of the other two treatments (Figure 6.2.a).

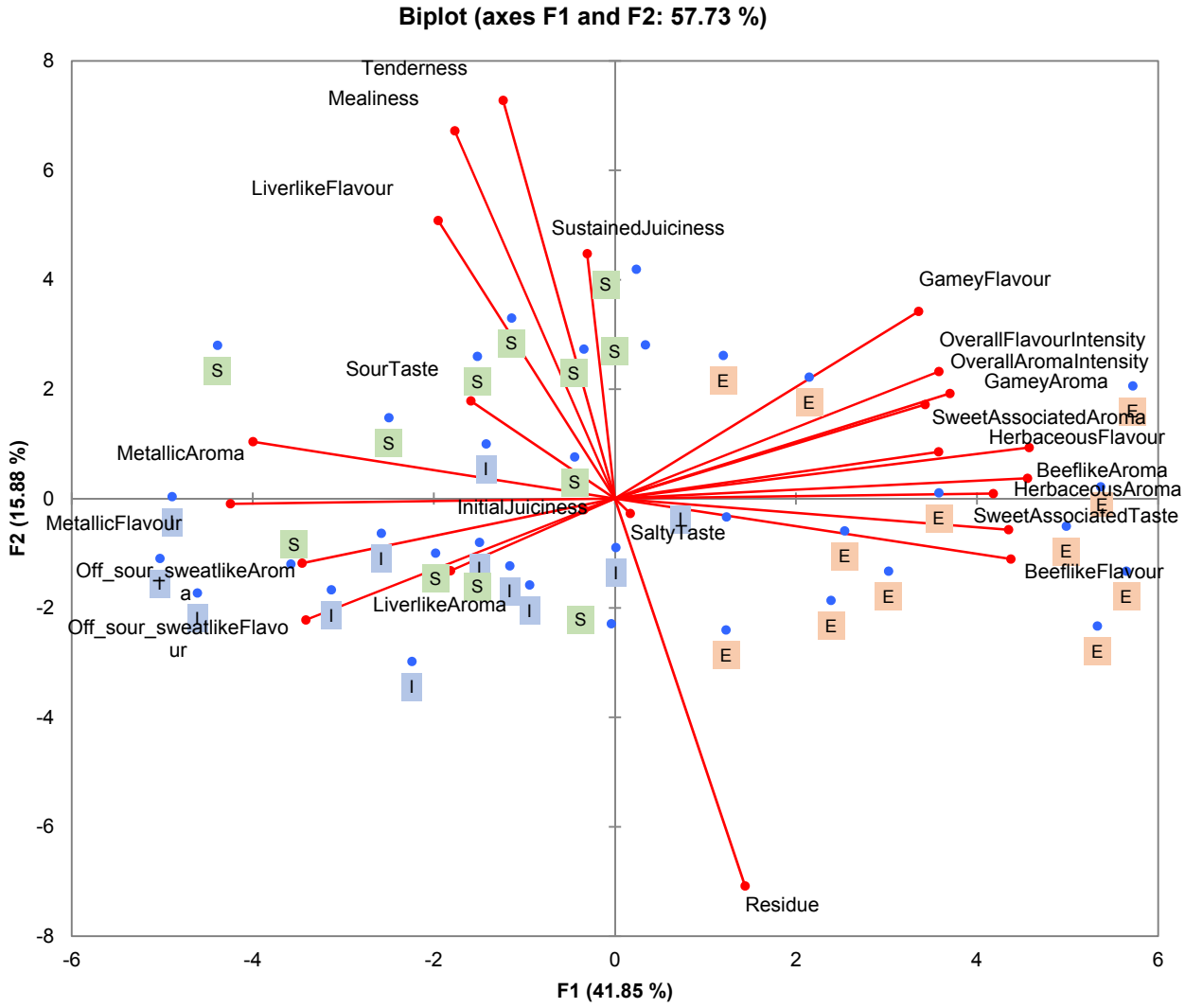

Figure 6.1 Principal component analysis (PCA) bi-plot depicting the means of the sensory attributes of sub-adult male impala *Longissimus thoracis et lumborum* (LTL) meat. The intensive system impala are represented by the letter "I" highlighted in blue, the semi-extensive system impala are represented by the letter "S" highlighted in green and the extensive system impala are represented by the letter "E" highlighted in orange.

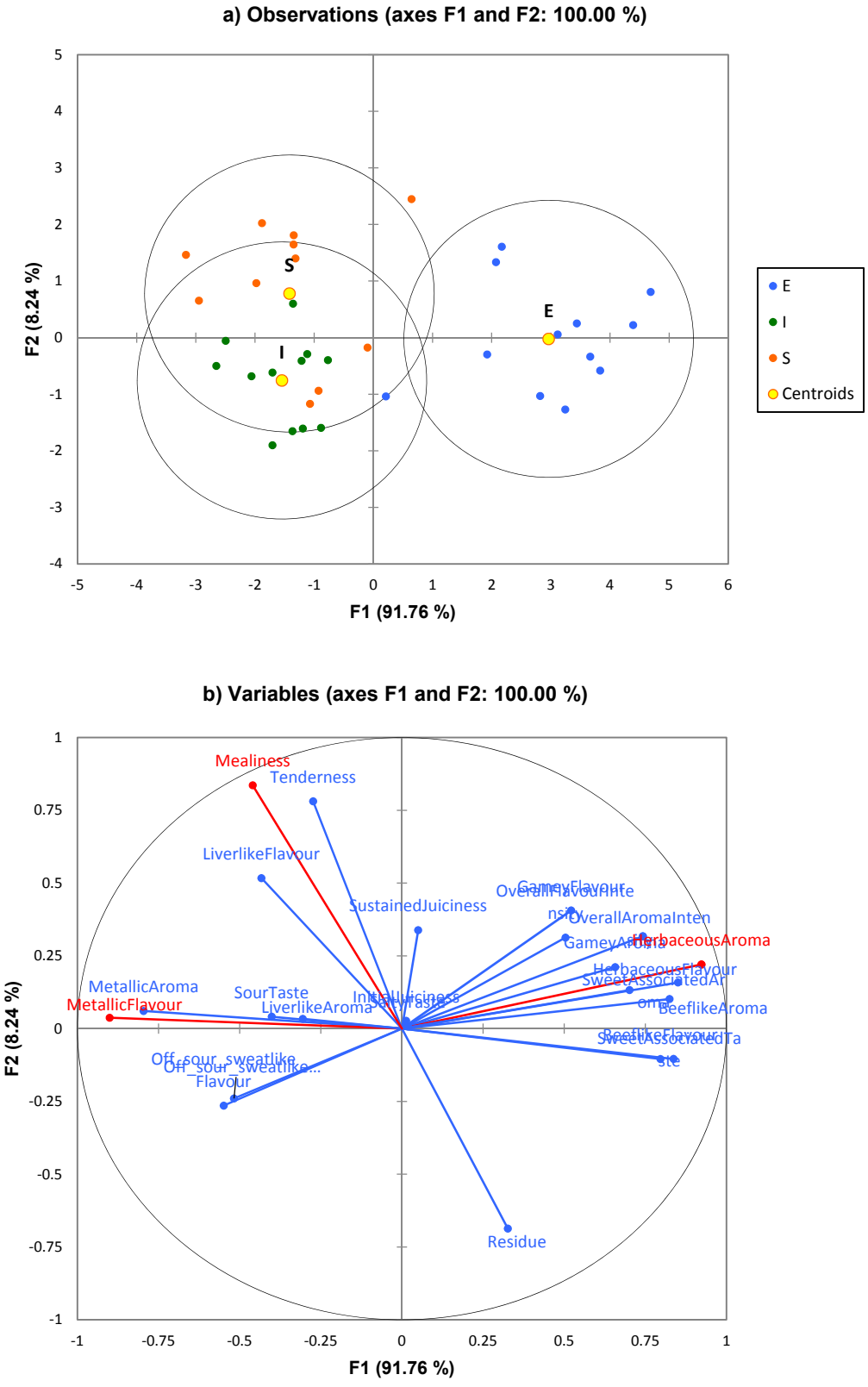

Figure 6.2 Discriminant analysis (DA) plot **(a)** and DA variable loadings plot **(b)** of the sensory characteristics of sub-adult male impala *Longissimus thoracis et lumborum* (LTL) meat. In the DA plot, the letter "E" refers to extensive production system impala, the letter "I" refers to intensive system impala and the letter "S" refers to semi-extensive production system impala.

6.3.3 Fatty acid composition

Table 6.5 depicts the fatty acid profile (%) of the LTL muscles of sub-adult male impala as influenced by production system. With proximate analysis, the highest ($P < 0.001$) IMF content was found in intensive system impala, followed by semi-extensive system impala, while extensive system impala had the lowest IMF content (Chapter 5, Table 5.4). Intensive system impala also had the highest ($P \leq 0.05$) fatty acid content for the C6:0 (Hexanoic acid; 2.5 ± 0.07 %) and C24:0 (Lignoceric acid; 2.9 ± 0.10 %) saturated fatty acids (SFA), while the semi-extensive and extensive production system impala did not differ for these fatty acids. Extensive system impala had a significantly lower C12:0 (Lauric acid) and C14:0 (Myristic acid) content than both intensive and semi-extensive impala, with no differences recorded between the latter two systems for these fatty acids (Table 6.5). The C16:0 (Palmitic acid) content was the highest ($P \leq 0.05$) in semi-extensive system impala (11.8 ± 0.48 %), while the other two systems did not differ from each other (9.4-10.0 ± 0.48 %). Behenic acid (C22:0) was the highest in extensive system impala and the lowest in intensive system impala, while the behenic acid content of semi-extensive system impala did not differ significantly from either of the former two systems. The total SFA content was the highest ($P = 0016$) in semi-extensive system impala (44.2 ± 0.82 %) and the lowest in extensive system impala (40.7 ± 0.82 %), while intensive production system impala (42.7 ± 0.82 %) did not differ significantly from either intensive or extensive system impala (Table 6.5).

Of the six monounsaturated fatty acids (MUFA) detected in impala meat, only C15:1n9t (cis-10-Pentadecenoic acid) was significantly influenced by production system, with a higher ($P \leq 0.05$) mean content found in extensive system impala than in both intensive and semi-extensive system impala (Table 6.5). While no differences ($P = 0.176$) were found between the three production systems for the total polyunsaturated fatty acid (PUFA) content of impala LTL meat, production system was found to influence alpha-linolenic acid (C18:3n3; $P < 0.001$), eicosatrienoic acid (C20:3n3; $P = 0.001$) and eicosapentaienoic acid (C20:5n3; $P = 0.045$). Intensive system impala had the lowest C18:3n3 (1.5 ± 0.14 %) and the highest C20:3n3 (10.0 ± 0.39 %) polyunsaturated fatty acid contents, while the semi-extensive and extensive production system impala did not differ from each other (Table 6.5). The eicosapentaienoic acid (C20:5n3) content was the highest in extensive system impala and the lowest in intensive system impala, while semi-extensive system impala did not differ significantly from either of the former two systems.

Production system did not have a significant influence on the content (%) of n6 PUFAs, n3 PUFAs, n6:n3 PUFA ratio, or the total fatty acid content. The pooled means for these characteristics were calculated as 22.6 ± 0.05 % for n6 PUFA, 21.9 ± 0.99 % for n3 PUFA, 1.0 ± 0.05 for the n6:n3 ratio and 18.4 ± 0.88 mg/g of meat for the total fatty acid content. However, the PUFA:SFA ratio differed significantly between production systems, with the highest ($P \leq 0.05$) ratio found in extensive system impala (1.1 ± 0.05) and the lowest found in semi-extensive system impala (1.0 ± 0.05), while intensive system impala did not differ from either of the other two systems. Overall, total PUFA had the highest contribution for intensive and extensive system impala, followed by total SFA, whereas the opposite was true for semi-extensive system impala (Table 6.5).

Table 6.5 LSMeans (± standard error) of the fatty acid profile (%) of sub-adult male impala *Longissimus thoracis et lumborum* (LTL) meat as influenced by production system.

Fatty Acid	Production system			P-value
	Intensive	Semi-extensive	Extensive	
Total fatty acids (mg/g)	19.7 ± 0.88	17.8 ± 0.88	17.6 ± 0.88	0.181
Total IMF* (g/100 g)	2.0^{a} ± 0.05	1.8^{b} ± 0.05	1.5^{c} ± 0.06	< 0.001
C6:0 (Hexanoic)	2.5^{a} ± 0.07	2.3^{b} ± 0.07	2.3^{b} ± 0.07	0.061
C8:0 (Caprylic)	2.5 ± 0.09	2.5 ± 0.09	2.3 ± 0.09	0.416
C10:0 (Capic)	2.6 ± 0.11	2.5 ± 0.11	2.4 ± 0.11	0.634
C12:0 (Lauric)	2.7^{a} ± 0.12	2.8^{a} ± 0.12	2.4^{b} ± 0.12	0.043
C14:0 (Myristic)	3.0^{a} ± 0.10	3.0^{a} ± 0.10	2.7^{b} ± 0.10	0.027
C15:0 (Pentadecyclic)	1.1 ± 0.13	1.1 ± 0.13	1.0 ± 0.13	0.722
C16:0 (Palmitic)	10.0^{b} ± 0.48	11.8^{a} ± 0.48	9.4^{b} ± 0.48	0.003
C18:0 (Stearic)	12.3 ± 0.35	12.4 ± 0.35	12.3 ± 0.35	0.967
C20:0 (Arachidic)	1.2 ± 0.04	1.2 ± 0.04	1.1 ± 0.04	0.127
C22:0 (Behenic)	1.9^{b} ± 0.12	2.1^{ab} ± 0.12	2.3^{a} ± 0.12	0.089
C24:0 (Lignoceric)	2.9^{a} ± 0.10	2.5^{b} ± 0.10	2.5^{b} ± 0.10	0.009
Total SFA	42.7^{ab} ± 0.82	44.2^{a} ± 0.82	40.7^{b} ± 0.82	0.016
C14:1n9c (Myristoleic)	1.1 ± 0.04	1.1 ± 0.04	1.0 ± 0.04	0.146
C15:1n9t (Cis-10-pentadecenoic)	1.7^{b} ± 0.27	1.8^{b} ± 0.27	2.6^{a} ± 0.27	0.048
C16:1n7 (Palmitoleic)	1.7 ± 0.06	1.8 ± 0.06	1.6 ± 0.06	0.154
C17:1 (Heptadecenoic)	1.7 ± 0.09	1.6 ± 0.09	1.5 ± 0.09	0.237
C18:1n9 (Oleic)	5.0 ± 0.44	6.0 ± 0.44	5.8 ± 0.44	0.307
C20:1n9 (Gondoic)	1.0 ± 0.04	1.1 ± 0.04	1.0 ± 0.04	0.444
Total MUFA	12.3 ± 0.56	13.3 ± 0.56	13.5 ± 0.56	0.269
C18:2n6 (Linoleic)	7.5 ± 0.22	7.7 ± 0.22	7.8 ± 0.22	0.687
C18:3n6 (Gamma-linolenic)	4.5 ± 0.15	4.4 ± 0.15	4.2 ± 0.15	0.202
C18:3n3 (Alpha-linolenic)	1.5^{b} ± 0.14	2.6^{a} ± 0.14	3.0^{a} ± 0.14	< 0.001
C20:2n6 (Eicosadienoic)	4.0 ± 0.73	2.6 ± 0.73	3.8 ± 0.73	0.325
C20:3n6 (Dihomo-gamma-linolenic)	2.0 ± 0.07	2.0 ± 0.07	1.9 ± 0.07	0.555
C20:3n3 (Eicosatrienoic)	10.0^{a} ± 0.39	8.3^{b} ± 0.39	7.8^{b} ± 0.39	0.001
C20:5n3 (Eicosapentaienoic)	2.4^{b} ± 0.61	2.9^{ab} ± 0.61	4.6^{a} ± 0.61	0.045
C22:2n6 (Docosadienoic)	4.5 ± 0.41	3.5 ± 0.41	4.2 ± 0.41	0.239
C22:6n3 (Docosahexaenoic)	7.5 ± 0.24	7.5 ± 0.24	7.5 ± 0.24	0.989
Total PUFA	45.0 ± 1.28	42.5 ± 1.28	45.8 ± 1.28	0.176
PUFA:SFA ratio	1.1^{ab} ± 0.05	1.0^{b} ± 0.05	1.1^{a} ± 0.05	0.098
n6 PUFA	23.7 ± 0.99	21.2 ± 0.99	23.0 ± 0.99	0.201
n3 PUFA	21.4 ± 0.56	21.3 ± 0.56	22.9 ± 0.56	0.102
n6:n3 PUFA ratio	1.1 ± 0.05	1.0 ± 0.05	1.0 ± 0.05	0.144

^{a,b,c}Means with different superscripts in the same row differ significantly (P ≤ 0.05) from each other. Abbreviations: SFA = Saturated fatty acids (includes C6:0, C8:0, C10:0, C12:0, C14:0, C15:0, C16:0, C18:0, C20:0, C22:0 and C24:0); MUFA = Monounsaturated fatty acids (includes C14:1n9c, C15:1n9t, C16:1n7, C17:1, C18:1n9c and C20:1n9); PUFA = Polyunsaturated fatty acids (includes C18:2n6c, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:5n3, C22:2n6 and C22:6n3); IMF = Intramuscular fat.
*Obtained from Chapter 5, Table 5.4.

6.4 DISCUSSION

The aim of this study was to compare the influence of three different production systems (intensive, semi-extensive and extensive) on the physical measurements, sensory characteristics and fatty acid profile of the *Longissimus thoracis et lumborum* (LTL) meat of sub-adult male impala.

The freezing and subsequent thawing of meat influences the distribution and content of moisture within the meat, and consequently the amount of moisture lost as exudate (thaw loss) (Leygonie, Britz, & Hoffman, 2012a). The significantly lower thaw loss percentages (Table 6.3) and drip loss percentages (Chapter 4) found for extensively produced impala meat compared with that of impala from the intensive and semi-extensive systems is one of the characteristics of the DFD (dark, firm, dry) condition found in impala from the former system (Chapter 4). The high pH_u values of extensive system impala (mean of 6.2 ± 0.06; Chapter 4, Table 4.3) caused by *ante-mortem* stress experienced during the culling procedure resulted in the high water-holding capacity of meat from these impala (Shange, Gouws, & Hoffman, 2019), as demonstrated by the strong negative correlation (r = -0.772; P < 0.001) between the pH_u values (Chapter 4) and the thaw loss percentages obtained for impala during the sensory trial.

The lack of differences between production systems for cooking loss (Table 6.3) may be the result of the standardized cooking process (Leygonie et al., 2012a), with samples remaining in the oven until the pre-determined internal temperature of 71°C was attained, rather than cooking all samples for the same time period. These findings are in accordance with those of a study comparing the influence of two production systems (semi-extensive vs. extensive) on the sensory meat quality of blue wildebeest, with no differences recorded for cooking loss percentages, nor for initial or sustained juiciness (Van Heerden, 2018). Similarly, no differences were found between production systems for the initial juiciness or sustained juiciness sensory texture attributes (Table 6.4) of impala meat, with a strong negative correlation (r = -0.534; P = 0.001) found between the latter attribute and cooking loss percentage. The negative correlation between sustained juiciness and cooking loss percentage has also been recorded in previous research on game meat (Neethling, 2016). In the present study, no correlations were found between initial or sustained juiciness and thaw loss, or between either of the juiciness sensory attributes and the pH_u of impala meat (Addendum II). It may therefore be deduced that the DFD-like physical characteristics found in extensive system impala did not have a negative impact on the juiciness of impala meat.

The tenderness of meat is one of the most important parameters of meat quality for consumers, as it is related to the palatability of meat and thus influences consumer experience and acceptance (Troy & Kerry, 2010; Von La Chevallerie, 1972). In the present study, a strong negative correlation (r = -0.745; P < 0.001) was found between the WBSF values (N) and the tenderness sensory rating of impala. This was to be expected, as higher WBSF values indicated decreased tenderness, whereas sensory tenderness ratings closer to 100 indicate extremely tender meat and ratings closer to zero indicate tough meat (Table 6.2). Similar inverse correlations were found between the WBSF values and sensory tenderness ratings for springbok meat (Hoffman, Kroucamp, & Manley, 2007), eland meat (Laubser, 2018) and blue wildebeest meat (Van Heerden, 2018). The most tender meat was found in semi-extensively produced impala for the sensory tenderness and WBSF values in sensory analysis

(Table 6.4) and for the WBSF values of fresh meat (Chapter 4). This confirms that the lack of *ante-mortem stress* and consequently lower pH_u (5.6 ± 0.05; Chapter 4, Table 4.3) in semi-extensively produced impala results in consistently more tender meat compared to that of the other two systems. Additionally, the strong correlations of tenderness to the residue (r = -0.916; P < 0.001) and mealiness (r = -0.577; P = < 0.001) of impala meat may account for the lower residue and higher mealiness sensory ratings of semi-extensive system impala. While mealiness is often considered to be a negative characteristic (Neethling, 2016), the mealiness ratings of impala from all three production systems was low (Table 6.4) an may not have an impact on consumer acceptability of impala meat.

The mean tenderness values obtained for thawed impala meat from all three production systems during sensory analysis (Table 6.3) were substantially higher than those obtained for fresh meat (39.3 ± 1.85 N, 22.4 ± 1.94 N and 29.0 ± 2.27 N, respectively; Chapter 4, Table 4.3). The higher shear force values may be the consequence of freezing the meat, which has also been reported to decrease tenderness in ostrich meat (Leygonie, Britz, & Hoffman, 2012b). Additionally, the differences in cooking methods used for the samples may also have had a contribution, with fresh meat samples cooked using a water bath maintained at a constant temperature of 80°C for 60 minutes (Chapter 4), whereas the thawed meat samples were cooked in an oven set to 163°C until an internal temperature of 71°C was obtained in each impala LTL sample. Furthermore, different instruments were used to measure WBSF, with a standard Warner-Bratzler field model used for the cooked fresh meat samples (Chapter 4.2.3.4; Honikel, 1998) and an Instron Universal Testing Machine used for the oven-cooked thawed meat samples (Chapter 6.2.3). Nonetheless, the sensory tenderness ratings of impala from all three production systems (59.7-66.9; Table 6.4) were comparable to the ratings obtained during previous sensory analyses of impala meat (57.5-63.8; Hoffman et al., 2009; Neethling, 2016). While only semi-extensive system impala meat had WBSF values below the 42.9 N threshold to be classified as tender, the meat from intensive and extensive system impala had WBSF values below the 52.7 N minimum for meat to be considered tough (Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008) and are thus considered to be intermediately tender. Therefore, impala meat from all production systems is suitably tender for consumer approval, irrespective of cooking methods and freezing period.

In addition to textural sensory characteristics such as water-holding capacity, juiciness and tenderness, consumer satisfaction is driven by aroma and flavour (Listrat et al., 2016; Neethling, 2016; Radder & Le Roux, 2005). Game species have a characteristic aroma and flavour that is distinct from that of domestic livestock (Wiklund, Johansson, & Malmfors, 2003), with “gamey” attributes specifically defined for game meat (Neethling, 2016) as an aroma or flavour associated with meat from wild animal species (Table 6.2). While consumer approval has been positively correlated to higher beef-like aroma and flavour and sweet-associated aroma and taste (Oltra et al., 2015), consumer approval is negatively correlated to sensory ratings for gamey, metallic and liver-like aromas and flavours, as well as sour taste, residue and mealiness (Wiklund et al., 2003). In the present study, gamey aroma and flavour were the largest contributors to the overall aroma and flavour intensity of impala meat from all production systems, followed by beef-like aroma and flavour as the second largest contributors (Table 6.4). This is demonstrated by the strong positive correlations (P < 0.001) found between overall intensity and the gamey and beef-like attributes for aroma and flavour, respectively (Addendum II). The overall flavour intensity may thus be used as an indicator of both the gamey and beef-like flavour intensities of

impala meat. Furthermore, strong positive correlations ($P < 0.005$) were found between the aroma and flavour of the overall intensity, gamey, beef-like, metallic, herbaceous, sweet-associated and off, sour, sweat-like sensory attributes (Addendum II), thus confirming that flavour is related to the aromas that are released inside the mouth upon consumption of the meat product (Listrat et al., 2016; Radder & Le Roux, 2005).

Production system had a significant influence on most of the sensory attributes of impala meat (Table 6.4). While the substantial overlap between the ellipses of the intensive and semi-extensive production system impala in the DA plot (Figure 6.2.a) show the similarity of these two treatments, the almost complete isolation of the ellipse representing extensive system impala shows that the latter system has very little similarities to impala from the other two production systems. The distinctiveness of extensive system impala was to be expected, as these impala have also been found to differ significantly from the other two systems for carcass yields, physical meat quality and meat chemical composition (Chapters 3, 4, & 5). The similarities between intensive and semi-extensive system impala for the sensory attributes (Table 6.4; Figure 6.1; Figure 6.2) may primarily be attributed to the fact that impala from both systems were raised in the same production environment in Limpopo from birth until approximately nine months of age, after which the intensive system impala were transferred to the boma system six months prior to slaughter. Therefore, intensive system impala were only subjected to their new feeding regime for a short time period, thereby having little effect on the fatness and fatty acid profile, both of which are major contributors to meat flavour. Additionally, the semi-extensive system impala had *ad libitum* access to supplementary feed with the same composition as the feed provided as the sole source of intake for intensive system impala. In contrast, the extensive system impala were raised in a completely different production region and only consumed the natural Fynbos vegetation found in the area (Chapter 6.2.1).

While the range for gamey flavour intensity obtained for all impala (54.0-56.7; Table 6.4) is comparable to that of impala harvested in the Mabula district of Limpopo (60.4; Hoffman et al., 2009) and to impala obtained near Pongola in KwaZulu-Natal (62.6; Neethling, 2016), gamey flavour intensity was found to be significantly lower in intensive system impala in the present study compared to impala from the other two systems. The causal factor for the higher ($P < 0.001$) gamey flavour intensity in the meat of impala from the semi-extensive and extensive systems (Table 6.4) may be the natural vegetation that formed part of the dietary regime of these impala. In studies on reindeer (*Rangifer tarandus*) and red deer (*Cervus elaphus*), it was found that animals finished on grazing (the equivalent of natural vegetation in the present study) produced meat with higher ratings for gamey flavour compared to deer finished on pellets. These differences in flavour were thought to be the consequence of natural grazing and partially due to differences in fatty acid compositions of the meat resulting from differences in the dietary regimes of animals (Wiklund et al., 2003; Wiklund, Stevenson-Barry, & Cummings, 2000). Impala finished on dietary regimes with higher grass contents have been found to produce meat with higher contents of the polyunsaturated C18:3n3 (Alpha-linolenic) fatty acid (Hoffman et al., 2005a). The C18:3n3 polyunsaturated fatty acid is naturally found in high concentrations in grasses and plant leaves and has been reported to have beneficial effects on human health (Bézard, Blond, Bernard, & Clouet, 1994; Wood et al., 2008).

In the present study, the highest alpha-linolenic acid content was found in semi-extensive and

extensive production system impala (Table 6.5), with large amounts of grazing and browsing material forming part of the natural vegetation of both systems. In contrast, intensive system impala did not have access to any natural vegetation, and the composition of the supplied feed may thus have been low in grazing material such as grasses in favour of a more concentrated feed composition. The influence of alpha-linolenic acid on the flavour of impala meat was observed with the strong correlations of this fatty acid to herbaceous aromas and flavours (r = 0.556; P < 0.001 and r = 0.477; P = 0.003, respectively), which were detected in higher intensities in the extensive system impala in particular (Table 6.4). These distinctive herbaceous sensory attributes were thus defined as an aroma or flavour associated with earthy, Fynbos-like herbs (Table 6.2), with the latter featuring prominently in the Fynbos biome from which extensive system impala were obtained. Positive correlations were also found between C18:3n3 and gamey aroma and flavour in both the present study (Addendum II) and in a study on Egyptian goose meat (Geldenhuys, Hoffman, & Muller, 2014). The positive relationship between alpha-linolenic acid and the gamey and herbaceous sensory attributes may thus explain the higher intensities of the latter characteristics in extensively produced impala (Table 6.4), with the higher selection variety, nutritional quality and C18:3n3 content of the natural vegetation in this system resulting in a higher C18:3n3 content in the meat. The differences in natural vegetation may also account for the higher sweet-associated aroma and taste ratings of extensive system impala (Table 6.4), as higher sweet taste ratings have been found grass-fed reindeer meat than in reindeer on a more concentrated-based diet (Wiklund et al., 2003). In combination with the highest (P < 0.001) beef-like aroma and flavour, these attributes resulted in the highest overall intensity of both aroma and flavour of extensively produced impala meat, resulting in a sensory profile that may be regarded as unique relative to that of impala from the other two production systems (Table 6.4).

The distinct sensory profile and intense herbaceous attributes of extensive system impala may be caused by the fragrant Fynbos vegetation that comprises the diet of these animals. In a study on extensively produced South African Dorper lambs, it was found that lambs that consumed a diet with high quantities of aromatic Karoo bushes and shrubs produced meat with distinctive herbaceous sensory characteristics (Erasmus, Hoffman, Muller, & Van der Rijst, 2016), which were perceived as negative attributes. These lambs are produced in the Karoo region in Northern parts of South Africa and are this known as “Karoo lambs” (Weissnar & Du Rand, 2012). The unique herbaceous characteristics of meat from Karoo lambs were found to be caused by a high concentration of terpenes in the Karoo vegetation, which are volatile compounds that often have a strong aroma (Erasmus et al., 2017). The Fynbos vegetation consumed by extensively produced impala may contain similar characteristic volatile compounds that may in turn result in the intense herbaceous characteristics of extensive system impala, whereas the lower intensity of these characteristics in intensive and semi-extensive system impala may be due to a diet comprised of less fragrant plants and grasses with different volatile compound contents. However, as the fatty acid profile and volatile compounds of the vegetation and/or feed consumed by the impala in the present study were not determined, it cannot be stated with certainty that the differences in the sensory profiles of impala were caused by dietary differences, and thus highlights an area for future research.

It is also possible that the DFD condition observed extensively produced impala meat (Chapter 4) may have influenced sensory profile thereof. The negative influence of high pH_u values and

consequently DFD on the sensory attributes of meat has been recorded in several studies (Dransfield, 1981; Dransfield, Nute, Mottram, Rowan, & Lawrence, 1985; Young, Reid, & Scales, 1993). In a study on beef, it was found that desirable flavours related to cooked beef tended to decrease with increasing pH_u values (Dransfield, 1981). The decrease in sensory ratings for desirable flavours were thought to be the result of the reduced concentrations of sugars and sugar phosphates in beef classified as DFD due to high pH_u values, thus resulting in a decreased number of substrates available for Maillard reactions, the products of which are crucial for flavour development in meat (Dransfield, 1981). The decreased intensity of desirable flavours due to high meat pH_u values was also observed in a study on pork, in addition to an increased intensity of "foreign" flavours as the pH increased (Dransfield et al., 1985). It has also been found that lamb meat with high pH_u (> 6.0) values were strongly associated with the undesirable "fishy/stale/rancid" and "bland" attributes, but had lower intensities of the desirable "beefy" sensory attributes. Nonetheless, in an evaluation of product acceptability, all lamb meat (ranging from pH_u 5.14-7.12) scored above 5.0 on a scale of 1.0 (dislike intensely) to 9.0 (like extremely), indicating that the product was acceptable regardless of pH_u (Young et al., 1993). The results of the present study were thus contrary to expectation for DFD meat, with the highest intensities of the desirable beef-like and sweet-associated attributes recorded in extensive system impala (Table 6.4), which also had the highest pH_u and DFD-like characteristics (Chapter 4). Furthermore, extensive system impala scored the lowest for negative attributes such as metallic and off, sour, sweat-like aroma and flavour and sour taste (Table 6.4). As these findings are in contrast to the aforementioned sensory characteristics that typically result from DFD meat, it is more likely that the diet of natural Fynbos vegetation had a more significant effect than the pH_u levels of extensive system impala. In addition, as no analysis of consumer acceptability has been performed, the impact of the high gamey and herbaceous sensory attribute intensities found in extensive system impala on consumer approval of the product has yet to be determined.

In contrast to the distinct sensory profile of extensively produced impala, the sensory profiles of intensive and semi-extensive system impala were found to be very similar, with only a few significant differences found for the textural attributes and gamey flavour mentioned previously, as well as for the liver-like sensory characteristic (Table 6.4). The higher liver-like flavour intensity found in semi-extensive system impala may be the result of the positive correlation (r = 0.338; P = 0.044) between this characteristic and the C18:1n9c (oleic) fatty acid, which was also found to be higher (although not significant) in semi-extensively produced impala. Oleic acid has also been found to be positively correlated to liver-like, off flavours in beef (Yancey et al., 2006). Despite the significant differences between impala from the three different production systems, the contribution of the liver-like aroma and flavour attributes to sensory profile of impala were very low (Table 6.4). In addition, the negatively perceived metallic, sour taste and off, sour, sweat-like sensory attributes were also rated on the lower end of the scale for impala meat from all three production systems (Table 6.4), and are thus are not expected to have a negative impact on consumer perception.

A negative correlation (r = -0.352; P = 0.035) was found between gamey flavour and total intramuscular fat (IMF) content of impala meat (Addendum II), thus indicating that the intensity of gamey flavour will increase as the IMF content decreases. This is in contrast to previous research that found strong positive correlations (r = 0.412, P < 0.05; and r = 0.645, P < 0.001, respectively) between gamey

flavour and the IMF content of impala and kudu meat, and of the meat of the six game species mentioned previously (Hoffman et al., 2009; Neethling, 2016). The inverse relationship between the IMF content and gamey flavour may be due to differences in fatty acid composition between impala in the present study and those in previous research, most likely due to differences in the dietary regimes between production systems and consequently, the IMF content in the meat. The IMF content of the impala meat samples from all production systems in the present study was very low (1.5-2.0 %; Table 6.5) as is characteristic for meat from the majority of game species (Neethling, 2016). However, this may have resulted in specific fatty acids not being detected during FAME analysis, particularly saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs), as these fatty acids primarily occur in the triacylglycerol fraction of lipids within IMF deposits in meat (Bézard et al., 1994).

In previous studies, small amounts of C22:1n9 (eructic acid) and C24:1n9 (nervonic acid) were detected in impala meat (Hoffman et al., 2005a, 2009), whereas these MUFAs were not detected in the present study. Similarly, C20:4n6 (arachidonic acid) was also not detected, whereas relatively high contents of this polyunsaturated fatty acid (7.8-9.8 %) were found in impala meat in previous studies (Hoffman et al., 2005a, 2009). Furthermore, the *cis* and *trans* isomers of C18:1n9 and C18:2n6 co-eluded in the majority of the samples during FAME analysis in the present study and had to be expressed as single combined values (Chapter 6.2.4). The 5.0-6.0 % for C18:1n9 and 7.5-7.8 % for C18:2n6 obtained for impala in the present trial were substantially lower than the range obtained for the combination of both isomers of C18:1n9 and C18:2n6, respectively, for impala meat in previous studies (12.9-19.3 % and 14.9-22.7 %, respectively) across different production regions (Hoffman et al., 2005a, 2009). While these differences may be the result of the co-elusion of isomers during analysis in the present study or the differences in methodology for FAME analysis between studies (e.g. a 30 m column was used in the present study while a 60 m column was used by Hoffman et al., 2009), it is probable that differences between production regions or dietary regimes contributed to the different contents of these fatty acids in impala meat between studies. However, the fatty acid profiles of the vegetation consumed by impala of different production regions have not yet been investigated and thus the influence of specific vegetation components on the fatty acid profile of impala meat is currently unknown.

Nonetheless, C16:0 (stearic acid), C18:0 (palmitic acid) and C18:2n6 (linoleic acid) were found to be the major fatty acids in impala meat from all three production systems in the present study (Table 6.5) and from both sexes (male and female) and different production regions in previous research (Hoffman et al., 2005a, 2009; Neethling, 2016). This indicates that the fatty acid profile of impala meat is relatively constant, despite the differences in fatty acid content that is most likely the result of differences in dietary regimes, production regions and management practices. The differences in fatty acid content of impala meat are apparent between production systems in the present study, particularly with regards to the total saturated fatty acid (SFA) content (Table 6.5). As extensive system impala had the lowest quantities of lauric acid (C12:0), myristic acid (C14:0) and palmitic acid (C16:0), this resulted in a lower total SFA content than that of semi-extensive system impala, while intensive system impala did not differ significantly from either of the other two systems (Table 6.5). The low SFA content of extensive impala may be the result of the significantly lower IMF content of impala in this system (1.5 ± 0.06 %; Table 6.5), resulting in fewer triglycerides and consequently in less SFA, increased

phospholipids and higher PUFA contents. This is evident with the positive correlation (r = 0.938; P < 0.001) that was found between the IMF content and SFA content of impala meat. Therefore, meat with lower IMF contents will have lower SFA contents.

Meat with lower SFA contents is often considered more desirable by health-conscious consumers (Wood et al., 2008). However, the composition of the fatty acids in meat is important as certain saturated fatty acids such as lauric, myristic, and palmitic acid have been found to increase low-density lipoprotein (LDL) cholesterol levels in the blood, which increases the risk of atherosclerosis and may consequently cause coronary vascular disease (CVD) in humans (Sundram, Hayes, & Siru, 1994; Williamson et al., 2005). In contrast, stearic acid (C18:0) has no influence on plasma cholesterol levels and may therefore be considered a desirable fatty acid, despite the fact that stearic acid is also a SFA (Van Elswyk & McNeill, 2014; Wood et al., 2008). The stearic acid content of impala meat comprises 28.1-30.2 % of the total SFA content across all three production systems, indicating that a large proportion of the SFA in impala meat from all three production systems is desirable to consumers. In addition, all unsaturated fatty acids (MUFAs and PUFAs) are also considered to be desirable fatty acids as they decrease the levels of LDL cholesterol in the blood (Wood et al., 2008). When calculating the total content of unsaturated fatty acids and stearic acid (C18:0) relative to the total fatty acid content, it may be observed that the desirable fatty acid content of intensive, semi-extensive and extensive system impala comprises 69.6 %, 68.2 % and 71.6 %, respectively, of all fatty acids in impala meat. Therefore, impala meat may be considered as a health food commodity due to its potential to reduce LDL cholesterol levels in the blood (Hoffman & Ferreira, 2004).

The mono- and polyunsaturated fatty acids were only significantly influenced by production system with regards to C15:1n9t, C18:3n3, C20:3n3 and C20:5n3 (Table 6.5), with differences most likely the result of differences in the dietary regimes between production systems, particularly with regards to C18:3n3 that is found in plant leaves and grasses (Wood et al., 2008). Alpha-linolenic acid (C18:3n3) is an important n3 essential fatty acid for the health of humans, and regular consumption would be beneficial due to the proactive influence of this fatty acid on cardiovascular deterioration (Williamson et al., 2005). Alpha-linolenic acid can also be elongated to long-chain n3 PUFAs such as eicosapentaenoic acid (C20:5n3) and docosahexaenoic acid (C22:6n3) (Williams & Burdge, 2006), which may explain the higher (P = 0.045) docosahexanoic acid content of meat from extensive system impala. Eicosatrienoic (C20:3n3) acid was found to have a negative correlation (r = -0.401; P = 0.015) to alpha-linoleic acid, and therefore impala with lower alpha-linolenic acid contents will have higher eicosatrienoic acid contents, as may be observed with intensive system impala (Table 6.5). These differences may be related to the potentially more concentrated diet of intensive system impala, as a previous study on fallow deer found lower PUFA concentrations in the meat of deer finished on a concentrate-based diet than in fallow deer grazed on pasture (Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003).

The differences in the fatty acid compositions of impala from the three different production systems had a significant effect on the PUFA:SFA ratios, which were the highest in extensive system impala and the lowest in semi-extensive system impala (Table 6.5). While extensive system impala would therefore have the most favourable PUFA:SFA ratio in terms of health implications for consumption of the meat, the numerical differences between treatments for the PUFA:SFA ratio were

marginal, with a range of 0.97-1.14 (Table 6.5). This range is higher than the 0.73 ± 0.07 for impala from the Mabula District of Limpopo (Hoffman et al., 2009), similar to the 0.93 ± 0.12 obtained for impala culled near Pongola in KwaZulu-Natal (Neethling, 2016) and lower than the 1.42-1.62 for impala from Musina Experimental Farm and Mara Research Station (Hoffman et al., 2005a), which further reiterates the influence of dietary regime and production region on the fatty acid composition of impala. Nonetheless, all the aforementioned PUFA:SFA ratios are higher than the 0.45 minimum ratio recommended by the British Department of Health (1994).

While high PUFA contents are considered beneficial from a health-related point of view, it is important to distinguish between n3 and n6 PUFAs. While consumption of n3 PUFAs have been found to reduce the risk of cardiovascular disease (Williamson et al., 2005), the metabolism of n6 PUFAs produces eicosanoids that are related to immune responses, including fever and inflammation. Even so, modern human diets have insufficient n3 PUFA contents and n6:n3 ratios that are too high, which has resulted in a recommendation from the British Department of Health (1994) that the n6:n3 PUFA ratio should have a 4:1 upper limit. Impala meat from all production systems had n6:n3 ratios that were well below the recommended maximum (1.0-1.1; Table 6.5), with no differences found between treatments. The n6:n3 ratio found for impala meat in the present study was lower than that previously recorded for impala (2.67-3.76) (Hoffman et al., 2009; Neethling, 2016), kudu (2.22 ± 0.47; Hoffman et al., 2009), eland meat (1.77 ± 0.07; Laubser, 2018) and extensively raised black wildebeest (4.2 ± 1.37; Van Heerden, 2018), but similar to black wildebeest raised in a semi-extensive production system (1.3 ± 0.19; Van Heerden, 2018) and to both wild and farmer fallow deer (0.27 ± 0.06; Daszkiewicz et al., 2015). Based on the IMF content, the PUFA:SFA ratios and the n6:n3 PUFA ratios, the meat obtained from impala from all three production systems may be considered to have a high nutritional value and meets the requirements to be classified as a health food commodity.

6.5 CONCLUSION

The aim of this trial was to determine the influence of production system (intensive, semi-extensive and extensive) on the sensory meat quality and fatty acid profile of sub-adult male impala LTL muscles. The sensory meat quality of impala was significantly affected by production system. Extensive system impala had a sensory profile that was distinct from the other two systems, whereas the sensory profiles of the intensive and semi-extensive system impala did not differ from each other, except for a few textural attributes and liver-like and gamey flavour intensity. The distinctive herbaceous sensory attributes of extensive impala may be caused primarily by the fragrant Fynbos vegetation in their diet, although the high pH_u values caused by *ante-mortem* stress may have also have affected the sensory characteristics of the meat. It is therefore recommended that the volatile compounds of the diet and the meat of impala should be analyzed to determine the correlation between the vegetation of the area and the herbaceous flavour in impala meat in particular. Furthermore, as high intensities of the desirable beef-like and sweet-associated attributes were found in extensive system impala, it is debatable whether the sensory profile of these impala, although unique, will have a negative impact on consumer acceptability of the meat. It is therefore recommended that research should be conducted with the focus on consumer acceptability of meat derived from impala raised on distinctively different vegetation types.

The fatty acid profile of impala meat was also significantly influenced by production system. As

the highest PUFA:SFA ratio was found in extensive system impala, it may be argued that these impala have the most favourable fatty acid profile, while the opposite would be true for semi-extensive system impala. However, the PUFA:SFA ratio ranged from 0.97-1.14 for impala from all three production systems, and it is therefore debatable whether such a small range numerically would have an impact on the biological value of impala meat. Nonetheless, the PUFA:SFA ratio of impala from all three production systems was well above the 0.45 minimum recommended by the British Department of Health (1994), while the n6:n3 ratio did not differ between treatments (1.0 ± 0.05 pooled mean) and was below the 4:1 recommended maximum. In combination with the low intramuscular fat, it may be concluded that impala meat from all three production systems produce meat with a high nutritional value and may thus be marketed as a health food commodity.

6.6 REFERENCES

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CHAPTER 7

POST-MORTEM AGEING OF IMPALA (*AEPYCEROS MELAMPUS*) *LONGISSIMUS THORACIS ET LUMBORUM* STEAKS

ABSTRACT

The objective of this study was to determine the ideal ageing period for maximum tenderness of *Longissimus thoracis et lumborum* (LTL) steaks of male and female impala. The LTL muscles of 11 male and 11 female impala were divided into eight portions each, with each portion randomly allocated to age for 1, 2, 4, 6, 8, 10, 12, or 14 days, vacuum-sealed and stored at 4°C. The pH, surface colour, weep loss, cooking loss and Warner-Bratzler shear force (WBSF) were determined for each ageing period. Significant interactions were observed between sex and ageing period for all parameters except weep loss percentage, CIE b* value and hue-angle. The pH and weep loss increased as the ageing period progressed. Ageing improved the bloomed surface colour of both sexes until day 8 (L* = 33.2 ± 0.32; a* = 13.1 ± 0.18; b* = 9.2 ± 0.23; chroma = 15.9 ± 0.22; hue = 33.2 ± 0.73°), after which some discolouration occurred. The WBSF showed a general decline for both sexes until day 8 (13.5 ± 0.91 N), after which a plateau was reached until the end of the ageing period. At day 8, ageing successfully negated the initial significant differences in tenderness between the sexes. Therefore, it is recommended that impala LTL steaks should be vacuum-aged at 4°C for eight days to achieve optimum tenderness and minimize variability between individual animals irrespective of sex.

Keywords: *Post-mortem* ageing, Tenderness, Impala, Game meat

7.1 INTRODUCTION

The South African livestock sector is currently facing the challenge of desertification and bush encroachment brought on by climate change, to which beef cattle are particularly vulnerable (Otieno & Muchapondwa, 2016). In addition, the expansion in the human population is increasing the global demand for meat (Meissner, Scholtz, & Palmer, 2013). Southern Africa is currently a net importer of food with a population that is predicted to reach two billion people in the next few decades (Conceicao, Fuentes-Nieva, Horn-Phathanothai, & Ngororano, 2011). Furthermore, the majority of land available for traditional livestock production has already been utilised with limited prospects for future expansion (Hoffman, 2008). The meat produced by the limited number of domesticated livestock species may thus not be capable of meeting the expanding demand for animal protein. Therefore, it is necessary to explore non-traditional alternative sources for meat production to address food insecurity (Cawthorn & Hoffman, 2014; Conceicao et al., 2011).

A practical solution to this problem may be the increased utilisation of South African game species. Indigenous game species have evolved to be well-adapted to arid African environments, with improved utilization of low-quality vegetation and lower susceptibility to overgrazing in comparison to traditional domestic livestock (Oberem & Oberem, 2016). With the expansion of the South African game industry and the intensification of production systems for improved animal production and breeding, more animals are available to be culled for meat production (Bothma, Sartorius Von Bach, Cloete, 2016). In meat production, the primary aspects by which consumers evaluate meat quality are tenderness, colour and healthiness. These qualities are affected by a variety of *ante-* and *post-mortem* factors, including species, age and sex, environmental and dietary factors, slaughtering conditions and the *post-mortem* processing of meat (Listrat et al., 2016). The meat of the impala (*Aepyceros melampus*) has been found to have a high protein and low intramuscular fat content (Chapter 5), which makes it an appealing alternative protein source to traditional livestock for meat production (Hoffman, 2000; Hoffman & Wiklund, 2006). However, there is a common perception among consumers that game meat is tough and dry due to low product uniformity and a lack of quality standards and knowledge on the proper cooking methods (Radder & Le Roux, 2005). The variability in meat quality was found to be apparent in impala meat in the present study, with significant differences found between sexes and production systems for physical meat quality parameters (Chapter 4). In order to develop the consumer market for game meat, food supply chains have to be capable of supplying products with consistently high quality standards (Hutchison, Mulley, Wiklund, & Flesch, 2010) in addition to improving consumer perception concerning the “toughness” of game meat. It is therefore necessary to investigate methods that may improve the texture and quality of meat from game species. One such method is the *post-mortem* ageing of meat, which is the process of ageing refrigerated meat to achieve maximum tenderness (Dransfield, 1993).

Post-mortem ageing improves the tenderness of meat by means of loss of tissue integrity resulting from numerous changes in the micro- and ultrastructure of muscle fibres caused by the degeneration of proteins by endogenous proteinases (Nowak, 2011). In addition to improving tenderness, ageing can also influence other meat quality attributes such as juiciness, aroma and flavour (Monsón, Sañudo, & Sierra, 2005; Sitz, Calkins, Feuz, Umberger, & Eskridge, 2006). The influence of

post-mortem ageing on these factors can vary depending on the method and packaging technique used, such as dry or wet ageing. Wet ageing, also known as vacuum ageing, refers to the ageing of refrigerated meat in vacuum sealed packaging, whereas dry ageing refers to the ageing of unpackaged meat at controlled humidity and temperatures (Smith et al., 2008). The method used most frequently in the meat industry is wet ageing, which has the benefit of decreased moisture loss and shrinkage due to ageing, and higher convenience during transport and storage of the meat (Hodges, Cahill, & Ockerman, 1974; Warren & Kastner, 1992). Therefore, it could be suitable to use the same method for game meat if the aim is to produce meat for commercial marketing.

Post-mortem ageing has been proven to increase the tenderness of meat from traditional livestock species such as beef (Monsón et al., 2005), and has recently been shown to have a similar effect on game meat from species such as springbok (North, Frylinck, & Hoffman, 2015), eland (Laubser, 2018) and blue wildebeest (Van Heerden, 2018). Another game species that may benefit from *post-mortem* ageing of meat is the impala. In addition to the high protein and low intramuscular fat content found for the meat of this species (Chapter 5), the high carcass yields and dressing percentages (Chapter 3) make impala an ideal species for meat production (Hoffman, 2000; Hoffman, Mostert, Kidd, & Laubscher, 2009). However, the influence of *post-mortem* ageing on the meat quality of impala has not yet been determined, nor has the optimum ageing period to improve meat tenderness of high value muscles such as the *Longissimus thoracis et lumborum* (LTL) been defined. The aim of this trial was therefore to determine the ideal *post-mortem* ageing period for the LTL muscle of impala meat from both sexes to achieve maximum tenderness.

7.2 MATERIALS AND METHODS

7.2.1 Experimental location and animals

For this trial, 11 male and 11 female impala (n = 22) were obtained during summer in March of 2017 from Castle de Wildt, located near Modimolle in the Limpopo province (as discussed in Chapter 3.2.1.). The farm was situated in the Central Sandy Bushveld bioregion of the Savanna biome. The impala were raised in a 200 ha semi-extensive production system, where the natural vegetation comprised the majority of their feed intake. Supplementary feed (8.3 % moisture, 13.3 % crude protein, 91.7 % dry matter, 7.6 % ash, 27.9 % crude fibre) was also supplied *ad libitum* in troughs daily. The aim was to cull sub-adult impala of both sexes at approximately 15-18 months of age with the use of horn shape and length in males and body size in females as age criteria. Further information regarding the description of the vegetation can be found in the Materials and Methods of Chapter 3.2.1 (Trial 1).

7.2.2 Culling, processing and sampling

All impala were culled during the day (ethical clearance number 10NP_HOF02) using suppressor-equipped light calibre rifles (.22 or .243). Thereafter, the impala were exsanguinated, transported to the on-farm slaughter facilities and skinned, eviscerated and dressed according to standard guidelines (Van Schalkwyk & Hoffman, 2016). The dressed carcasses were then hung in a chiller set to 4 ± 1°C to undergo *rigor mortis*. Further information on the culling and slaughter procedures can be found in Chapter 4.2.2.

After ±24 hours in the chiller, all impala carcasses were deboned and the left *Longissimus thoracis et lumborum* (LTL) muscles were excised. Each LTL muscle was divided into eight equal steaks with a thickness of approximately two centimetres each, cut at a right angle to the longitudinal axis of the muscle. Each steak was randomly allocated to one of the following ageing trial days: 1, 2, 4, 6, 8, 10, 12 and 14 for physical analysis on the specified day (Table 7.1). The samples allocated to day 1 were analyzed on the day of deboning (24 hours *post-mortem*), whereas each steak allocated to the remaining days were weighed, 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 $g/m^2/24h/1atm$) with a 5 mb residual pressure (according to the pressure reading of the machine gauge; Multivac, Model C200, Sepp Haggenmuller, Wolfertschwenden, Germany) and stored in a chiller at 4 ± 1°C until the allocated day of physical analysis.

Table 7.1 Experimental layout summary of the trial per main effect (sex and ageing period).

Number of animals	Sex	Ageing period (days *post-mortem*)							
11	Female	1	2	4	6	8	10	12	14
11	Male	1	2	4	6	8	10	12	14

7.2.3 Physical analysis

7.2.3.1 Moisture loss

Total moisture loss was determined by measuring the weep loss and cooking loss percentages of each LTL steak on the allocated ageing days, with one LTL steak representing one replicate/animal, with 11 replicates for male impala and 11 replicates for female impala per ageing day. On days 2-14, the respective LTL steaks were removed from the vacuum packaging, blotted dry with absorbent paper to remove excess moisture and weighed to record the weight of each aged steak. Weep loss was calculated using the final weight as a percentage of the initial weight of each LTL steak prior to ageing.

For determination of the cooking loss (%), each LTL steak was weighed to obtain an initial weight and placed inside a labelled thin plastic bag. All 22 LTL steaks for the relevant ageing day were subsequently placed into a preheated water bath set to a constant temperature of 80°C for a period of 60 minutes. Each steak was fully submerged for the duration of the cooking period. After 60 minutes, the cooked steaks were removed from the water bath and excess water in the cooking bag drained. The LTL steaks were kept in their individual bags and placed inside a chiller at 4 ± 1°C for approximately six hours until cooled. Thereafter, the steaks were blotted dry with absorbent paper and weighed to record the final cooked weight of each steak for the determination of moisture lost through cooking. Cooking loss was determined by expressing the final weight of the cooked steak as a percentage of the initial weight of the uncooked steak prior to cooking in the water bath (Honikel, 1998).

7.2.3.2 Acidity (pH)

The acidity (pH) was recorded at every allocated ageing day once each LTL steak had been weighed back to determine weep loss. The pH of each LTL steak was measured with a two-point calibrated (using standard buffers of pH 4 and pH 7) Crison pH25 portable pH meter (Crison instruments, Barcelona, Spain) with a glass electrode. Measurements were taken by inserting the electrode at an angle as close to the centre of each steak as possible. Between each measurement, the electrode was cleaned by rinsing with distilled water and blotted dry with absorbent paper.

7.2.3.3 Colour

The surface colour of each LTL steak was measured on the allocated ageing day, prior to performance of the cooking loss procedure. Colour measurements were taken with a calibrated Colour-guide 45°/0° 4 mm aperture colorimeter (4 mm aperture, 2° observer angle; BYK-Gardner GmbH, Gerestried, Germany) at five random positions on the cut surface of the meat after a blooming period of ±30 minutes. Measurements were in accordance with the CIE Lab colour system, which reported values according to lightness (CIE L*), red-green spectrum (CIE a*) and blue-yellow spectrum (CIE b*). The recorded CIE a* and CIE b* values were used for the calculation of the hue-angle (colour definition) and chroma values (saturation/colour intensity). Calculations were performed according to the following equations:

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

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

7.2.3.4 Warner-Bratzler shear force

Following the measurement of pH, surface colour and the determination of cooking loss for each LTL steak allocated to the respective ageing day, the tenderness of each LTL steak was measured at each ageing time point by determining the Warner-Bratzler shear force (WBSF) of the cooked meat samples used for determination of cooking loss. Six cylindrical core samples (with a diameter of 1.27 cm) were taken from the centre of each steak, ensuring that visible collagen tissue was excluded. Each core sample was sheared at a right angle to the longitudinal axis of the muscle fibres with a Warner-Bratzler blade at a speed of 3.33 mm/s. The blade was fitted to an electronic scale that measured the peak force required to cut through the sample. Measurements were recorded in kg/1.27cm Φ and converted to Newton (N) (See Chapter 4.2.3.4 for more information on the conversion). The tenderness of each LTL steak was obtained by calculating the mean of the six measurements taken per steak, with lower shear force values associated with more tender meat (Honikel, 1998).

7.2.4 Statistical analysis

The experimental design was a randomised block split plot, where the impala number (animal) was the block replicates for the main plot factor (sex). The ageing period (days *post-mortem*) served as the split plot factor. Both main effects were tested, as well as the interaction between the main effects. The parameters of the physical analysis (pH, weep loss, cooking loss, Warner-Bratzler shear force and

colour) were analyzed with SAS software (Version 9.4; SAS Institute Inc., Cary, USA), using the General Linear Models (GLM) procedure to perform a univariate analysis of variance (ANOVA). The Shapiro-Wilk test was performed on the standardized residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). It was not required to remove any outlier values from the data in the present trial. Fisher's least significant difference was calculated at a significance level of 5 % to compare sex, muscle and ageing period means (Lyman Ott & Longnecker, 2010). A probability level of 5 % ($P \leq 0.05$) was considered significant for all tests. Pearson's Correlation coefficient was used to quantify correlations between parameters.

7.3 RESULTS

Significant interactions were observed between sex and ageing period (days *post-mortem*) for pH ($P = 0.028$), cooking loss percentage ($P = 0.020$), Warner-Bratzler shear force ($P < 0.001$), CIE L* value ($P = 0.004$), CIE a* value ($P = 0.001$) and chroma value ($P = 0.001$) of impala meat (Table 7.2). No interactions were recorded between sex and ageing period for weep loss percentage, CIE b* value or the hue-angle of impala meat.

Table 7.2 Level of statistical significance (P-values) for the main effects of sex and day (*post-mortem*) and their interaction for the physical parameters of impala meat.

Parameter	Sex	Day	Sex*Day
pH	**0.050**	**< 0.001**	**0.028**
Weep loss (%)	0.427	**< 0.001**	0.468
Cooking loss (%)	**0.034**	0.222	**0.020**
Shear force (N)	**0.026**	**< 0.001**	**< 0.001**
L* (lightness)	0.692	**< 0.001**	**0.004**
a* (redness)	0.945	**< 0.001**	**0.001**
b* (yellowness)	0.557	**< 0.001**	0.201
Chroma	**0.010**	**< 0.001**	**0.001**
Hue°	0.384	**< 0.001**	0.481

The significant interaction between sex and days aged *post-mortem* for pH is presented in Figure 7.1. Male impala were found to have a significantly higher pH than female impala at days 2, 4, 6, 10, and 14, with the highest pH recorded for male impala at day 14 (5.9 ± 0.03). No significant differences between sexes were recorded for days 1, 8, or 12.

While significant interactions were found between the main effects for pH and the majority of the other parameters, the influence of *post-mortem* ageing on impala meat regardless of sex has not yet been determined. In addition, the culling of game animals for meat is often indiscriminate between sexes, and consumers are thus more interested in the influence of *post-mortem* ageing of meat overall. Therefore, the physical parameters of impala meat as influenced by the main effects of sex and ageing period, respectively, are presented in Table 7.3 to provide a more thorough description of the data. From the table, it can be observed that the overall pH was the lowest on day 1 *post-mortem* (5.6 ± 0.02), followed by a steady increase until day 8, after which the pH peaked at 5.8 ± 0.02 on day 10, where it remained for the duration of the ageing period until day 14 (Table 7.3).

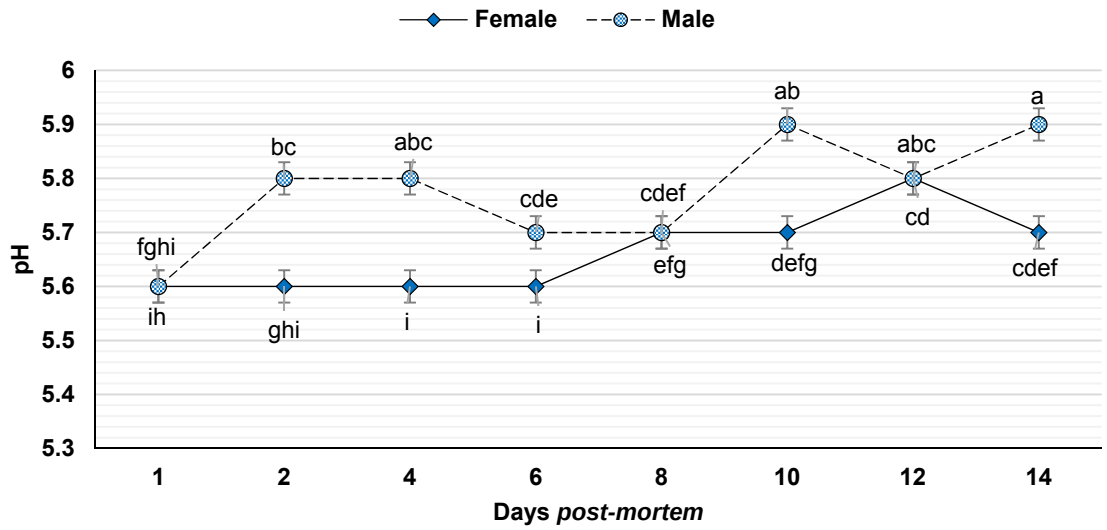

Figure 7.1 LSMeans (± standard error) of the pH of female and male *Longissimus thoracis et lumborum* (LTL) muscles during ageing up to 14 days *post-mortem*. [a-i]Means with different superscripts differ from one another (P ≤ 0.05).

The significant interaction between sex and *post-mortem* ageing period for cooking loss is presented in Figure 7.2. Female impala were found to have significantly higher cooking loss percentages than males at 1, 2, 4, 8, and 14 days *post-mortem*. The highest cooking loss percentage (33.3 ± 0.46 %) was recorded on day 4 for female impala and the lowest cooking loss percentage (29.5 ± 0.46 %) was recorded on day 1 for male impala. However, no differences were recorded between the sexes for days 6, 10 and 12. Despite the lack of significant differences between sexes at the latter three time periods, a general trend can be observed with higher overall cooking loss percentages recorded in female impala than in males for the duration of the ageing period. This trend is also apparent in the mean values for male and female impala (Table 7.3), where female impala had a significantly higher mean cooking loss percentage (32.4 ± 0.54 %) than males (30.7 ± 0.53 %).

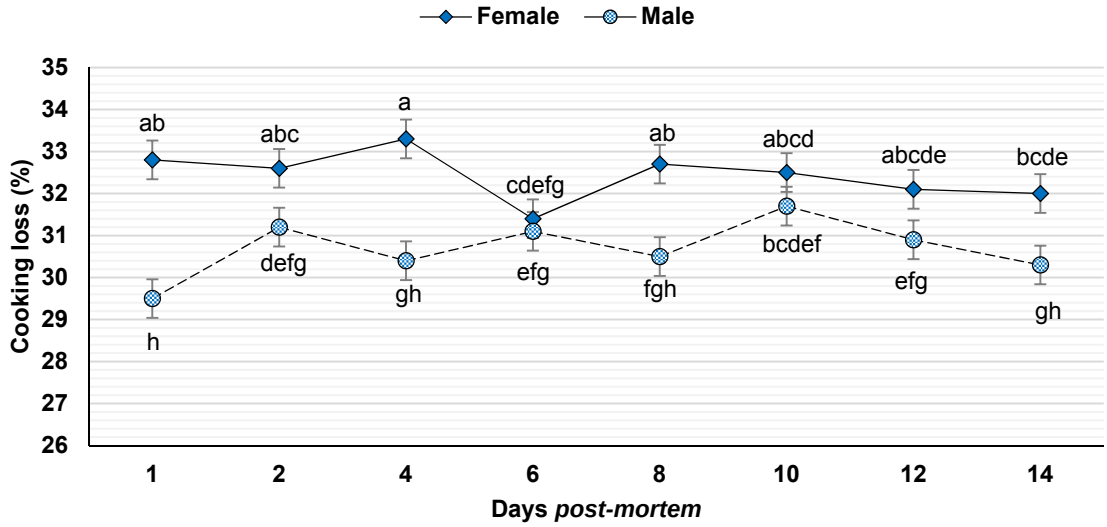

Figure 7.2 LSMeans (± standard error) of the cooking loss percentage of female and male *Longissimus thoracis et lumborum* (LTL) muscles during ageing up to 14 days *post-mortem*. [a-h]Means with different superscripts differ from one another (P ≤ 0.05

The interaction between sex and ageing period for Warner-Bratzler shear force values (N) is presented in Figure 7.3. Female impala had significantly higher shear force values than males at day 1, 2, and 4, while no differences (P > 0.05) were recorded between the sexes from day 6 to day 14 (Figure 7.3). All interaction groups showed a gradual decline in shear force values until day 8, after which a plateau was reached until the end of the ageing period at day 14. Overall meat from female impala had higher (P = 0.026) shear force values (18.3 ± 1.00 N) than males (14.9 ± 1.00 N), thus indicating that the male impala had more tender meat (Table 7.3).

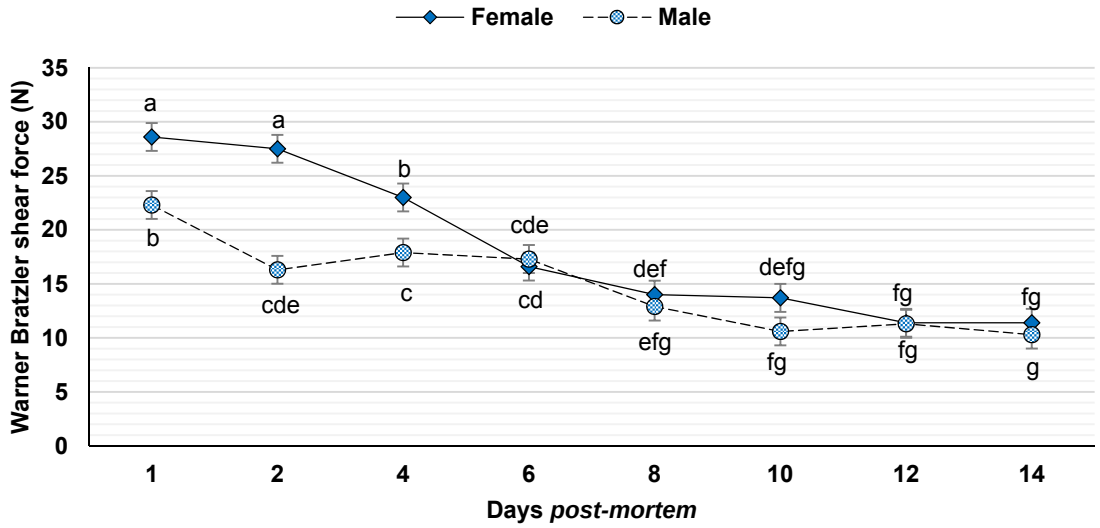

Figure 7.3 LSMeans (± standard error) of the Warner-Bratzler shear force (N) of female and male *Longissimus thoracis et lumborum* (LTL) muscles during ageing up to 14 days *post-mortem*. [a-h]Means with different superscripts differ from one another (P ≤ 0.05).

No interaction (P = 0.468) was recorded between sex and ageing period for weep loss percentage, thus the main effects are interpreted separately. Sex did not have an influence (P = 0.427) on the weep loss percentage of impala meat (Table 7.3). However, weep loss was influenced (P < 0.001) by the ageing period, with the lowest weep loss percentage recorded at day 2 (3.7 ± 0.27 %). Thereafter, weep loss percentage increased until day 6 (5.9 ± 0.28 %), after which a plateau was reached until the end of the ageing period at day 14 (6.4 ± 0.27 %). There were no differences (P > 0.05) in weep loss between the last five time points from day 6 to day 14.

The colour measurements of impala meat as influenced by the main effects of sex and ageing period are presented in Table 7.3. Interactions (P = 0.004) were found between sex and days *post-mortem* for the L* colour values (Figure 7.4). Female impala had higher (P ≤ 0.05) L* values than male impala on day 8 and day 10. While there were no significant differences between sexes for the remaining six time points, the L* values showed different general trends for each sex. While the L* values of female impala showed a steady incline to day 10 followed by a slight decline thereafter, the L* values of males peaked at day 2, declined to day 8 and peaked again at day 12.

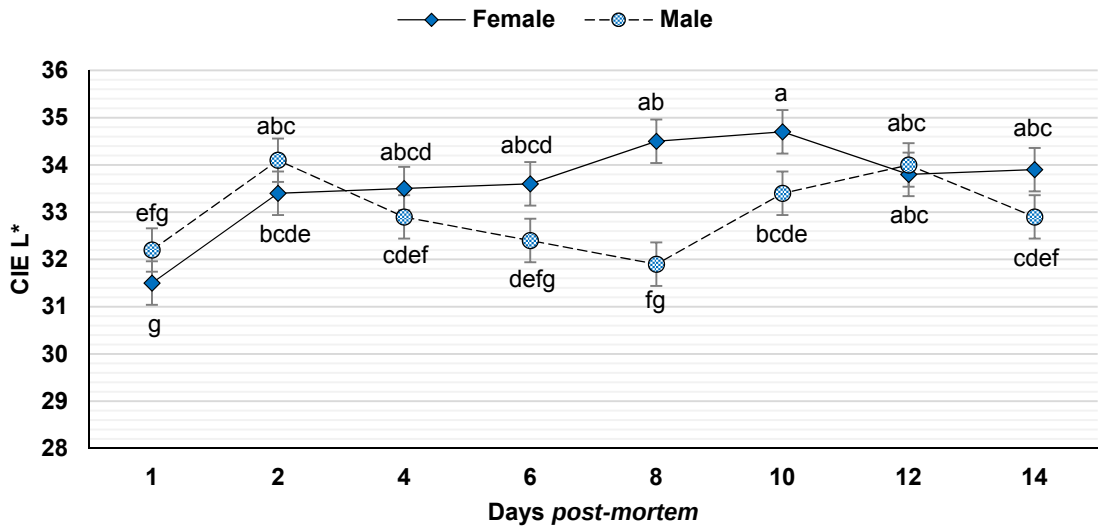

Figure 7.4 LSMeans (± standard error) of the L* values of female and male *Longissimus thoracis et lumborum* (LTL) muscles during ageing up to 14 days *post-mortem*. [a-g]Means with different superscripts differ from one another (P ≤ 0.05).

A sex-day interaction (P = 0.001) was also recorded for the a* values (Figure 7.5). Female impala had higher a* values on day 4 (13.0 ± 0.26) than male impala (11.8 ± 0.26), whereas males had higher (P ≤ 0.05) a* values on day 12 (13.4 ± 0.26) than females (12.5 ± 0.26). No significant differences between sexes were recorded for days 1, 2, 6, 8, 10, or 14. From Table 7.3, it can be observed that there are no differences (P = 0.945) between sexes overall for the a* values. When evaluating the ageing period alone as main effect, the a* values decline from day 1 to reach the lowest a* values at day 2, after which the a* values inclined to a plateau from day 6 onwards (Table 7.3).

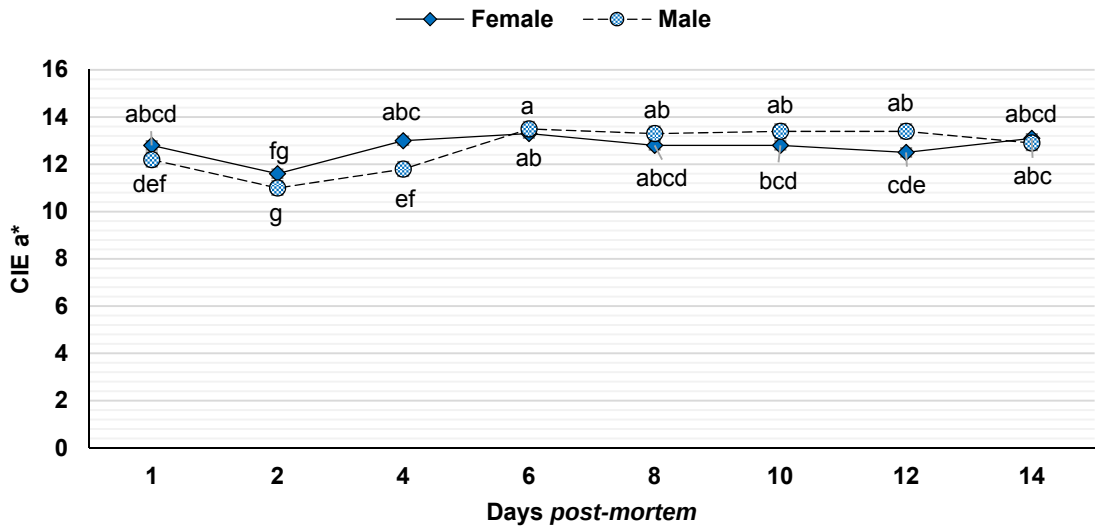

Figure 7.5 LSMeans (± standard error) of the a* values of female and male *Longissimus thoracis et lumborum* (LTL) muscles during ageing up to 14 days *post-mortem*. [a-g]Means with different superscripts differ from one another (P ≤ 0.05).

No interactions (P = 0.201) were recorded between sex and ageing period for the b* values of impala LTL muscles (Table 7.2). There were no differences (P = 0.557) between sexes for the b* value, with a pooled mean of 8.6 ± 0.77 recorded for both sexes (Table 7.3). However, the *post-mortem* ageing period had a significant influence on the b* values of impala LTL meat. The lowest b* values were recorded on day 1 (7.6 ± 0.23), with a steady increase as the ageing period progresses until a plateau was reached at the highest b* values from day 10 onwards.

The interaction (P < 0.001) between sex and ageing period for the chroma values of impala meat is presented in Figure 7.6. Female impala had higher (P ≤ 0.05) chroma values than males at day 1, 2, 4 and 14 *post-mortem*, while males had higher chroma values than female impala on day 12. The general trend for both sexes indicates a decrease in the chroma values from day 1 to day 2, followed by an increase to day 6 where a plateau was reached.

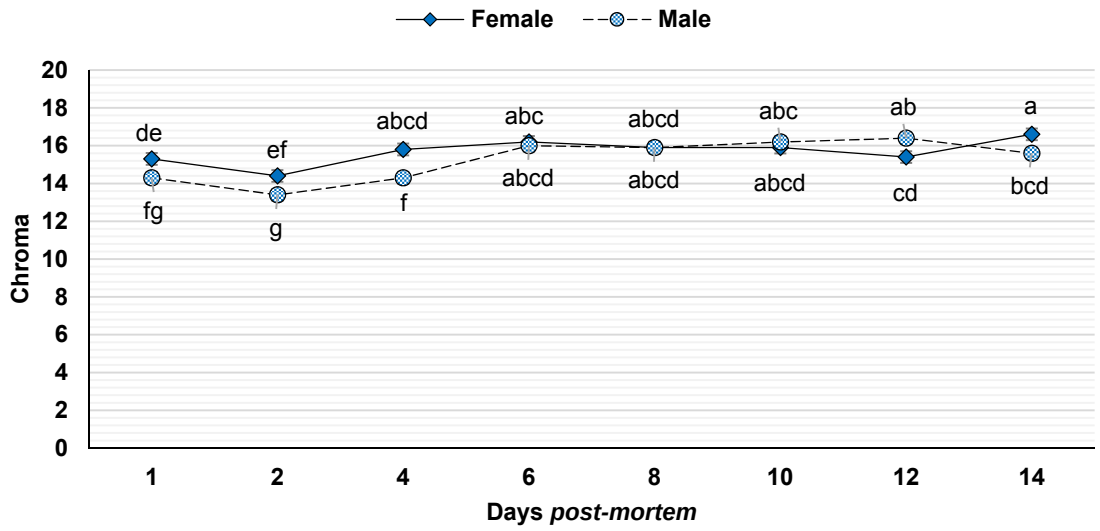

Figure 7.6 LSMeans (± standard error) of the chroma values of female and male *Longissimus thoracis et lumborum* (LTL) muscles during ageing up to 14 days *post-mortem*. [a-g]Means with different superscripts differ from one another (P ≤ 0.05).

No interaction (P = 0.481) was recorded between sex and *post-mortem* ageing period for the hue-angle (Table 7.2). In addition, the hue-angle did not differ (P = 0.384) between male and female impala (Table 7.3) and a pooled mean for both sexes was calculated as 34.7 ± 1.81°. However, the *post-mortem* ageing period had an influence (P < 0.001) on the hue-angle, which had the lowest value on day 1 *post-mortem* (30.5 ± 0.73°), followed by a peak at day 2 (34.5 ± 0.73°) after which the hue-angle decreased to 32.2 ± 0.73° on day 6. Thereafter, the hue-angle increased until day 8, after which it reached a plateau from day 10 until day 14. The latter four time points (day 8, 10, 12, and 14) did not differ significantly from each other for the hue-angle of impala meat.

Table 7.3 LSMeans (± standard error) of the physical parameters of impala *Longissimus thoracis et lumborum* (LTL) meat as influenced by sex and ageing period (Days *post-mortem*).

Main effect		pH	Weep loss (%)	Cooking loss (%)	Shear force (kg/1.27cm Φ)	Shear force (N)	L*	a*	b*	Chroma	Hue°
Sex	**Female**	5.6^{b} ± 0.04	6.0 ± 0.459	32.4^{a} ± 0.54	2.4^{a} ± 0.13	18.3^{a} ± 1.00	33.6 ± 1.11	12.7 ± 0.46	8.9 ± 0.77	15.7 ± 0.80	36.5 ± 1.81
	Male	5.8^{a} ± 0.04	5.5 ± 0.455	30.7^{b} ± 0.53	1.9^{b} ± 0.13	14.9^{b} ± 1.00	33.0 ± 1.11	12.7 ± 0.46	8.3 ± 0.77	15.3 ± 0.80	32.8 ± 1.81
Day	**1**	5.6^{c} ± 0.02	*	31.1^{b} ± 0.33	3.3^{a} ± 0.12	25.5^{a} ± 0.91	31.8^{c} ± 0.32	12.5^{bc} ± 0.18	7.6^{d} ± 0.23	14.8^{b} ± 0.22	30.5^{c} ± 0.73
	2	5.7^{b} ± 0.02	3.7^{c} ± 0.27	31.9^{ab} ± 0.34	2.8^{b} ± 0.12	21.9^{b} ± 0.94	33.8^{ab} ± 0.32	11.3^{d} ± 0.18	7.9^{cd} ± 0.23	13.9^{c} ± 0.22	34.5^{a} ± 0.73
	4	5.7^{b} ± 0.02	4.7^{b} ± 0.27	31.8^{ab} ± 0.33	2.6^{b} ± 0.12	20.5^{b} ± 0.91	33.2^{ab} ± 0.32	12.4^{c} ± 0.18	8.4^{bc} ± 0.23	15.1^{b} ± 0.22	33.4^{ab} ± 0.73
	6	5.7^{bc} ± 0.02	5.9^{a} ± 0.28	31.2^{ab} ± 0.33	2.2^{c} ± 0.12	16.9^{c} ± 0.94	33.0^{b} ± 0.32	13.4^{a} ± 0.18	8.7^{ab} ± 0.23	16.1^{a} ± 0.22	32.2^{bc} ± 0.73
	8	5.7^{b} ± 0.02	6.4^{a} ± 0.27	31.6^{ab} ± 0.33	1.7^{d} ± 0.12	13.5^{d} ± 0.91	33.2^{ab} ± 0.32	13.1^{a} ± 0.18	8.8^{ab} ± 0.23	15.9^{a} ± 0.22	33.2^{ab} ± 0.73
	10	5.8^{a} ± 0.02	6.5^{a} ± 0.27	32.1^{a} ± 0.34	1.6^{ed} ± 0.12	12.2^{ed} ± 0.91	34.0^{a} ± 0.32	13.1^{a} ± 0.18	9.2^{a} ± 0.23	16.1^{a} ± 0.22	34.5^{a} ± 0.73
	12	5.8^{a} ± 0.02	6.5^{a} ± 0.27	31.5^{ab} ± 0.33	1.5^{ed} ± 0.12	11.3^{ed} ± 0.91	33.9^{ab} ± 0.32	12.9^{ab} ± 0.18	9.1^{a} ± 0.23	15.9^{a} ± 0.22	34.6^{a} ± 0.73
	14	5.8^{a} ± 0.02	6.4^{a} ± 0.27	31.1^{b} ± 0.33	1.4^{e} ± 0.12	10.8^{e} ± 0.91	33.4^{ab} ± 0.32	13.0^{ab} ± 0.18	9.3^{a} ± 0.23	16.1^{a} ± 0.22	34.7^{a} ± 0.73

$^{a-e}$Means with different letters in the same column (within a main effect) differ from each other ($P \leq 0.05$).

*No weep loss was measured on day one as physical analysis occurred prior to packaging.

7.4 DISCUSSION

The objective of this trial was to determine when maximum tenderness is achieved and Warner-Bratzler shear force values plateau in vacuum-packaged impala meat during a 14-day *post-mortem* ageing period at 4°C of the *Longissimus thoracis et lumborum* (LTL) muscle of male and female impala.

Whilst *post-mortem* ageing has been shown to improve meat tenderness, ageing is often accompanied by weep loss, also known as cumulative purge loss, an unfavourable side-effect caused by moisture lost from raw meat (Huff-Lonergan & Lonergan, 2005). It can be observed as bloody liquid in packaging and is considered unattractive to consumers. Weep loss is influenced by *post-mortem* pH levels and the rate and extent of proteolysis and protein oxidation, with degradation of cytoskeletal proteins resulting in shrinkage of muscle cells. This reduces their ability to retain water and results in moisture lost from the meat (Huff-Lonergan & Lonergan, 2005). In the present study, the general trend for the weep loss percentage of impala LTL steaks followed the increase expected with *post-mortem* ageing, until a plateau was reached at day 6 (5.9 ± 0.28 %) with no further significant increases until the end of the ageing period at day 14 (Table 7.3). The plateau in weep loss percentage as the ageing period progresses is similar to trends previously reported in literature (Hodges et al., 1974; North, 2014), and is the consequence of only a limited amount of moisture available to be released from the meat.

For vacuum-aged meat, a weep loss of one to two percent is considered acceptable by consumers, while more than four percent may be considered excessive (Colle et al., 2016). A weep loss of up to 6.5 ± 0.27 % of the initial mass of each impala LTL steak was recorded over the 14 day *post-mortem* ageing period (Table 7.3). These values are higher than the 1-2 % maximum previously recorded for vacuum-aged beef (Hodges et al., 1974; Lagerstedt, Enfält, Johansson, & Lundström, 2008), the 4.2 % for eland (Laubser, 2018) and the 3.5 % for blue wildebeest steaks (Van Heerden, 2018), but similar to the 6.0 % recorded for springbok (North et al., 2015). It would be expected that the impala LTL steaks would have higher weep loss percentages as the muscles were divided into eight steaks for each of the eight ageing time points, thereby increasing the surface area to volume ratio and allowing for increased moisture loss from the cut surfaces. Furthermore, while no weep loss was recorded for impala at day 1 as physical analyses were conducted prior to vacuum packaging, it can be observed that 60 % of the maximum moisture loss was already reached by day 2. This indicates that a large amount of moisture was lost most probably due to compression during vacuum packaging, a phenomenon that has been observed in previous research on beef (Payne, Durham, Scott, & Devine, 1998) and on springbok meat, for which 13 % of the moisture loss on day 2 is accountable to losses from vacuum sealing (North, 2014).

A significant interaction was found between sex and days aged *post-mortem* for the cooking loss percentages of impala LTL steaks, with female impala having a cooking loss percentage of up to 3.3 % higher than that of males on some ageing days (Table 7.1; Figure 7.2). The difference in cooking loss between the sexes may be the result of the difference in pH, with a significant negative correlation (r = -0.35; $P < 0.001$) found between these parameters. The higher cooking loss percentages in female impala compared to that of males (Figure 7.2; Table 7.3) may therefore be explained by the lower pH values of females (Figure 7.1; Table 7.3). The relationship between the water-holding capacity and the pH of meat is explained in literature (Huff-Lonergan & Lonergan, 2005; Lawrie & Ledward, 2006). The

influence of sex on water-holding capacity has also been observed in both cattle and pigs, where a higher pH_u of males above that of females or castrated males has resulted in an improved water-holding capacity and thus lower moisture loss in males compared to females or castrated males (Den Hertog-Meischke, Van Laack, & Smulders, 1997).

Despite the significant interaction between sex and ageing period for pH, a general increase in pH can be observed for both sexes as the ageing period increased (Figure 7.1). A similar overall increase in pH occurred in eland LTL steaks from day 2 to day 21 (Laubser, 2018) and for springbok from day 1 until day 5 (North et al., 2015). Boakye & Mittal (1993) also recorded an overall pH increase in vacuum-aged beef until day 16 *post-mortem* and attributed this increase to fluctuations in the charge of meat proteins as a consequence of proteolytic enzyme activity. This may also explain the general increase in the pH of impala LTL steaks, although the biochemical mechanism of this hypothesis is unknown.

The surface colour of meat is an important meat quality attribute that influences consumer acceptability at the point of purchase, as colour is often equated to meat "freshness" (Mancini & Hunt, 2005; Troy & Kerry, 2010). Discolouration in meat is a primary cause of lost retail sales that force producers to discard or devalue substantial amounts of retail meat (McKenna et al., 2005). Discolouration can occur on the surface of meat due to oxidative processes and increased metmyoglobin formation, resulting in a brown colour that is considered unacceptable by consumers (Neethling, Suman, Sigge, & Hoffman, 2016). Therefore, it is important to monitor the colour stability of meat throughout the *post-mortem* ageing process to ensure that discolouration does not occur, as consistent and desirable meat colour and sustained colour stability will increase the profits and sales of the game meat (Neethling, Suman, Sigge, Hoffman, & Hunt, 2017).

Despite the interaction between sex and ageing period for the L*, a* and chroma values (Table 7.2), the general increase in these colour parameters for impala LTL steaks show that the surface colour becomes lighter, redder and more saturated as the ageing period progresses (Figures 7.4-7.6; Table 7.3). The redness and chroma values reach a plateau from day 6, with the 13.1-13.4 redness values from day 6 to day 10 falling well above the established minimum of 12 for consumer acceptability (Wiklund, Stevenson-Barry, Duncan, & Littlejohn, 2001). A similar effect can be observed with the b* and hue-angle values (Table 7.3). While no differences were recorded between sexes for these colour parameters, a significant increase was observed for both the b* and hue-angle values from day 1 until day 8, after which a plateau was reached from day 10 onwards (Table 7.3). The increase in hue angle shows that the impala LTL steaks became duller and browner in colour after 10 days of ageing, with this discolouration potentially indicating microbial spoilage (Shange, Gouws, & Hoffman, 2019). Therefore, while *post-mortem* ageing improves the colour of impala LTL steaks to a lighter, redder and more saturated colour than non-aged impala meat, it would be recommended to age impala steaks no further than 8 days *post-mortem* to prevent discolouration.

Tenderness and its variability is the most important sensory meat quality characteristics for consumers (Listrat et al., 2016). The tenderness of meat is influenced by its structural components; primarily the intramuscular connective tissue (predominantly the total and insoluble collagen content), and the cytoskeletal, myofibrillar and sarcoplasmic proteins (Purslow, 2005). The concentration of the

collagen, and the extent of collagen cross-linking, determines the baseline toughness of the meat, the latter of which can only be altered to a limited extent (Purslow, 2005; Sentandreu, Coulis, & Ouali, 2002). Meat tenderness is therefore primarily improved by means of *post-mortem* proteolysis of the structural proteins within muscle fibres during ageing of raw meat (Sentandreu et al., 2002).

The tenderness of the impala meat (Warner-Bratzler shear force) was influenced by the *post-mortem* ageing period. The interaction effect for the Warner-Bratzler shear force values may be the result of the average age differences between the sexes. The female impala in the present study were older (estimated at 24 to 36 months old) than the male impala (±15-18 months old) as a result of difficulty classifying the age of female impala in the field by means of body conformation (Refer to Chapter 3.4.1 for more information). The age of an animal at the point of slaughter has been shown to influence the tenderness of the cooked meat (Purslow, 2005). Meat from older animals have been recorded to have higher shear force values and thus less tender meat than younger animals, therefore indicating a decrease in tenderness with increasing age at slaughter, most likely due to reduced collagen solubility in intramuscular connective tissue with age (Purslow, 2005). In addition, the size of individual muscle fibres increase as the animal matures, therefore it would be expected that older animals, such as the female impala, in this study would have tougher meat than younger animals (Sebsibe, 2008). It would be interesting to see how the amount and form of collagen changes with age within sex for impala so as to see whether these changes occur between 18 and 36 months of age as the data would seem to indicate.

However, from day 6 of ageing onward, no differences were seen between the sexes for the Warner-Bratzer shear force values (Figure 7.3) despite the differences in the mean slaughter ages of male and female impala. In addition to increasing the overall tenderness of both male and female impala LTL steaks, *post-mortem* ageing allowed for more uniform Warner-Bratzler shear force values, thus improving product uniformity. When evaluating the general trend in shear force values for both sexes throughout the ageing period, it can be observed that there is little change in the tenderness of impala LTL meat for both the interaction values (Figure 7.3) and with ageing period as main effect (Table 7.3) from day 8 onwards. Overall, *post-mortem* ageing decreased the shear force values of impala LTL steaks from 25.5 ± 0.91 N on day 1 to 13.5 ± 0.91 N on day 8, after which a plateau was reached with no further decrease (Table 7.3). This 12.0 N mean decrease in the shear force values of the LTL steak in impala is similar to the 13.8 N decrease found in springbok LTL steaks after five days of ageing (North et al., 2015), the 10-16 N decrease until day 14 in beef (Crouse & Koohmaraie, 1990; Shackelford, Wheeler, & Koohmaraie, 1997), and less than the 16 N decline in blue wildebeest LTL steaks after the first 14 days of ageing (Van Heerden, 2018). The eight-day ageing period until tenderness reaches a plateau (ultimate tenderness) in impala LTL steaks is also similar to the seven to 10 days required for lamb (Koohmaraie & Geesink, 2006), but longer than the three to seven days for reindeer (Barnier, Wiklund, Van Dijk, Smulders, & Malmfors, 1999). The ultimate tenderness of meat is determined by the rate and extent that myofibrillar proteins are degraded during *post-mortem* proteolysis (Nowak, 2011). The rate of proteolysis has been recorded to be higher in certain game species than beef due to increased activity of proteolytic enzymes (Barnier et al., 1999); this phenomenon needs to be explored further in impala as the results in the present study seem to indicate

that this is applicable.

The shear force values recorded for non-aged (day 1 *post-mortem*) female (28.6 ± 1.29 N) and male impala (22.3 ± 1.29 N; Figure 7.3) is lower than the 42.9 N upper limit for meat (beef) to be classified as tender (Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008). This is in agreement with previous findings that game meat is more tender than beef, with some game species not requiring any *post-mortem* ageing to attain suitable levels of tenderness (Hutchison et al., 2010). Similarly, it may not be necessary to age impala LTL steaks for the meat to be considered acceptably tender. However, *post-mortem* ageing successfully negated the significant differences in tenderness between the adult female and sub-adult male impala. This resulted in consistently improved tenderness in impala LTL steaks with no further significant differences between sexes and indirectly, between ages, when maximum tenderness is attained at day 8 *post-mortem*. Therefore, it is recommended to age all impala meat to reduce the variability often associated with meat from game species.

7.5 CONCLUSION

This study aimed to determine the ideal ageing period (days *post-mortem*) for optimum tenderness of male and female impala *Longissimus thoracis et lumborum* (LTL) steaks. The maximum tenderness and acceptable instrumental surface colour of vacuum-aged LTL steaks for both male and female impala was reached at eight days *post-mortem* at 4°C. This ageing period also successfully negated the initial significant differences in tenderness between the adult female and sub-adult male impala, resulting in consistently improved tenderness in impala LTL steaks. Furthermore, ageing until eight days improved the surface colour of the steaks, while an increased ageing period beyond this point resulted in some discolouration and no further improvement in tenderness. Therefore, it is recommended that all impala LTL steaks should be vacuum-aged to eight days *post-mortem* to reduce the variability associated with meat from game species caused by variation in the sex and age of individual animals.

However, it would be necessary to evaluate the sensory meat quality, as well as microbial safety, of vacuum-aged impala LTL steaks to determine whether sensory attributes such as aroma, flavour and texture are significantly altered by *post-mortem* ageing. This will also help to confirm whether the recommended ideal ageing period for maximal tenderness is also the ideal ageing period for optimum consumer acceptability and safety.

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CHAPTER 8

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The aim of this research was to investigate the influence of sex, muscle, production system and *post-mortem* ageing on the meat quality of impala (*Aepyceros melampus*) obtained in South Africa. While sexual dimorphism with regards to carcass weights is generally typical with same-aged impala, no such differences were observed between male and female impala in the present study. The lack of significant sexual dimorphism can be explained by the substantial age difference between the sexes, with male impala falling into the sub-adult category, while the female impala were substantially older and thus classified as adults. This reiterates the difficulty of age estimation using only body conformation for female impala in the field, as well as highlighting the need for an in-field animal identification system if meat production should become the focus of a game farm (Trial 1; Chapter 3).

Meat tenderness was significantly lower in the female impala than in males. This was most likely the result of the age differences between the sexes and this needs to be quantified with animals where their specific ages are known once a reliable technique for live age estimation has been finalized or once records of individual animals can be monitored by producers. While sex also had an influence on the other physical meat quality parameters of impala, the differences were marginal and are unlikely to influence consumer acceptability. However, the physical meat quality differed significantly between muscles as a consequence of the differences in muscle function, anatomical location and structural properties. This information generated about the variability in physical meat quality of different impala muscles may be useful in determining which muscles would be suitable for fresh meat production and which would be better suited to further processing (Trial 1; Chapter 4).

When investigating the influence of *post-mortem* ageing of vacuum-sealed LTL steaks of male and female impala, it was found that the maximum tenderness and acceptable instrumental surface colour of the steaks from both sexes were reached at eight days *post-mortem* at 4°C (Chapter 7). In addition, the initial significant differences in tenderness between the sub-adult male impala and the adult female impala were successfully negated by the eight-day *post-mortem* ageing period, resulting in consistently improved tenderness in impala LTL steaks. This ageing period also improved the surface colour of the LTL steaks, while extending the ageing period beyond eight days resulted in some discolouration and no further improvement in meat tenderness. Therefore, it is recommended that impala LTL steaks should be vacuum-aged at 4°C for eight days *post-mortem* to reduce the variability associated with meat from this species caused by differences in the sex and slaughter age of individual animals.

Intensively produced impala showed no advantage over semi-extensive or extensively produced impala regarding carcass traits. Extensively produced impala yielded the highest carcass weights due to environmental and nutritional differences between the Central Rûens Shale Renosterveld region of the former system and the Central Sandy Bushveld production region of the intensive and semi-extensive systems (Trial 2; Chapter 3). However, physical meat quality was adversely affected by extrinsic factors within the extensive system during production and culling,

resulting in DFD-like (dark, firm, dry) characteristics such as a darker, less red surface colour and a high water-holding capacity that may negatively impact consumer perception of the meat. Even so, fresh impala meat from all production systems were classified as tender overall and compares favourably to other game and domestic species, with the most tender meat found in semi-extensive system impala (Trial 2; Chapter 4). After a two-month freezing period at -20°C, thawed impala meat cooked in an oven for sensory analysis (Trial 2, Chapter 6) were less tender than the fresh impala meat cooked in a water bath (Chapter 4). However, the oven-cooked impala meat had shear force values below the 52.7 N minimum for meat to be considered tough, and impala meat from all three production systems may therefore be classified as suitably tender for consumers.

The sensory meat quality of the intensive and semi-extensive system impala from the same production region did not differ with the exception of gamey flavour, liver-like flavour and a few textural attributes. However, extensively produced impala had a distinct sensory profile with high intensities of Fynbos-like herbaceous attributes that may be the result of the fragrant natural vegetation consumed by impala in the Central Rûens Shale Renosterveld production region in the Western Cape. Even so, without determination of the fatty acid profile and volatile compounds of the vegetation/diet consumed by the impala from the different production systems (Trial 2), the extent of the influence of dietary regime on the sensory meat quality of impala could not be established (Chapter 6). This highlights an area for future research, as the unique sensory profile of the extensive system impala indicates that impala meat may have to be marketed according to the production region in which they were raised. It is also recommended that a consumer sensory analysis should be performed to establish consumer acceptability of impala meat from the different production systems, as well as between impala meat with normal pH_u values and impala meat classified as DFD ($pH_u > 6.0$) within the same production system. Additionally, further research entailing the collection and analysis of blood, saliva and urine samples is recommended to quantify the effect of both chronic and acute *ante-mortem* stress of impala as influenced by different production systems and culling methods.

Despite the limitations of this research in terms of age differences between sexes (Trial 1) and the DFD condition found in extensive system impala (Trial 2), impala meat from both sexes, all muscles and all three production systems were found to have a desirable nutritional composition, and all impala meat had acceptable physical meat quality, with the potential exception of extensive system impala. Furthermore, despite the significant differences between production systems, the sensory ratings of impala meat is indicative of meat with a desirable sensory profile (Chapter 6). In combination with their high dressing percentages, impala are confirmed to be a species that is well-suited to the production of lean, high quality game meat. The results of this study indicate that while significant differences were found between sexes, these differences were marginal, and thus it appears that sex would not have to be considered for the marketing of impala meat. In addition, it may be deduced that impala produced in the semi-extensive production system will produce meat with the most desirable physical and chemical meat quality, with less management input required in terms of feeding in comparison to intensive system impala, and no detrimental effects caused by *ante-mortem* stress as those observed in extensive system impala. The knowledge gained from this study will therefore aid in the improvement of the overall quality, production, marketing and promotion of impala meat as an alternative to traditional red meat products. However, a larger study with higher animal numbers is

warranted to support these conclusions.

It is also apparent from this study that there are a number of factors that warrant future research for the efficient implementation of impala meat production for contribution to the food security of South Africa. To eliminate the influence of unintentional differences in slaughter age, it is recommended that Trial 1 should be repeated with both male and female impala that are confirmed to be the same age at culling by means of accurate recordkeeping and animal identification. Another recommendation for future research is the establishment of an accurate growth curve by means of a serial slaughter study of impala from multiple locations across southern Africa, which would be useful for age determination of both male and female impala with the use of carcass weights. Such a study would also help to determine the slaughter age at which meat production would be optimum in terms of both carcass yields and meat quality of impala. This meat production should also be calculated on kg meat/per time unit/acreage. Additionally, the differences found between muscles warrants further investigation into muscle fibre typing and determination of the collagen content of each muscle of impala in order to improve understanding of the different muscle properties and their impact on impala meat quality. It is also recommended that the production system comparison should be repeated with the intensive, semi-extensive and extensive production systems situated in the same production region to eliminate the influence of environmental differences in climate, natural vegetation and parasite loads.

Furthermore, to confirm whether the eight-day recommended optimum *post-mortem* ageing period for maximal tenderness is also the ideal ageing period for optimum consumer acceptability and safety, it would be necessary to evaluate the sensory meat quality, as well as microbial safety, of vacuum-aged impala LTL steaks to determine whether sensory attributes such as aroma, flavour and texture are significantly altered by *post-mortem* ageing. While *post-mortem* ageing succeeded in improving product uniformity of impala LTL steaks, it would also be useful to determine the influence of *post-mortem* ageing on other muscles, such as the BF muscle from the hindquarter, to determine whether muscle has an influence on the optimum ageing period for maximum tenderness of impala meat. Ultimately, the quantification of all these factors that may influence impala meat quality will aid in optimization of impala meat production and the expansion and success of the South African game meat industry.

ADDENDUM I

IMPALA CARCASS YIELDS

Table I Impala carcass weights and dressing percentages according to age classification.

Age classification	Sex	Location	n	Live weight ± SE (kg)	Warm CW (kg)	Cold CW (kg)	Dressing %	Reference
6 months	Male	Kruger National Park, RSA	-	25.00 ± 2.2	-	-	-	Fairall & Braack (1976)
	Female	Kruger National Park, RSA	-	24.32 ± 1.6	-	-	-	Fairall & Braack (1976)
Young (7-10 months)	Male	Mara Research Station, RSA	5	31.0 ± 1.1	-	20.0 ± 1.1	64.2 ± 1.7	Du Plessis et al (2006)
		Messina Experimental Farm, RSA	23	27.0 ± 0.9	-	15.8 ± 0.6	58.3 ± 0.6	Du Plessis et al (2006)
	Female	Mara Research Station, RSA	7	27.7 ± 1.3	-	17.8 ± 0.8	64.2 ± 1.1	Du Plessis et al (2006)
		Messina Experimental Farm, RSA	9	23.6 ± 1.1	-	13.5 ± 0.9	56.8 ± 1.6	Du Plessis et al (2006)
8 months	Male	Kruger National Park, RSA	-	22.47 ± 3.65	-	-	-	Fairall & Braack (1976)
		Mara Research Station, RSA	3	33.16 ± 0.35	21.08 ± 0.81	-	63.51 ± 2.17	Hoffman et al. (2005)
	Female	Kruger National Park, RSA	-	23.00 ± 2.31	-	-	-	Fairall & Braack (1976)
		Musina Experimental Farm, RSA	1	26.00 ± 0.00	15.00 ± 0.00		57.69 ± 0.00	Hoffman et al. (2005)
9 months	Male	Kruger National Park, RSA	5	19.1	10.2	-	53.1	Fairall (1983)
10 months	Male	Kruger National Park, RSA	-	25.93 ± 2.99	-	-	-	Fairall & Braack (1976)
	Female	Kruger National Park, RSA	-	23.03 ± 3.63	-	-	-	Fairall & Braack (1976)
12 months	Male	Kruger National Park, RSA	-	32.59 ± 1.07	-	-	-	Fairall & Braack (1976)
		Nyala Game Ranch, RSA	9	25.24 ± 2.67	-	-	-	Anderson (1982)
		Lake Mburo region, Uganda	-	26.7	-	-	-	Averbeck (2002)
	Female	Kruger National Park, RSA	-	27.34 ± 1.01	-	-	-	Fairall & Braack (1976)

Abbreviations: SE = standard error; CW = carcass weight; RSA = Republic of South Africa.

Table I Continued

Age classification	Sex	Location	n	Live weight ± SE (kg)	Warm CW (kg)	Cold CW (kg)	Dressing %	Reference
Juvenile	Male	Ndzalama Wildlife Reserve, RSA	15	58.3 ± 6.6	30.0 ± 4.8	-	-	Theobald (2002)
		Selati Game Reserve, RSA	15	54.0 ± 3.7	28.0 ± 6.9	-	-	Theobald (2002)
		Mara Research Station, RSA	6	56.1 ± 4.2	26.2 ± 6.4	-	-	Theobald (2002)
		Nyaminyami Rural District, Zimbabwe	78	-	13.4 ± 2.25	-	-	Féron et al. (1998)
	Female	Ndzalama Wildlife Reserve, RSA	8	54.8 ± 1.2	30.5 ± 3.3	-	-	Theobald (2002)
		Selati Game Reserve, RSA	15	52.0 ± 2.7	23.8 ± 7.2	-	-	Theobald (2002)
		Mara Research Station, RSA	3	55.0 ± 2.4	24.0	-	-	Theobald (2002)
		Nyaminyami Rural District, Zimbabwe	63	-	13.4 ± 2.82	-	-	Féron et al. (1998)
		Nyaminyami Rural District, Zimbabwe	11	-	13.4 ± 2.82	-	-	Bourgarel et al. (2002)
18 months	Male	Kruger National Park, RSA	6	35.24 ± 4.33	-	-	-	Fairall & Braack (1976)
		Nyala Game Ranch, RSA	21	28.58 ± 3.01	-	-	-	Anderson (1982)
		Musina Experimental Farm, RSA	3	33.00 ± 3.50	18.83 ± 2.36	-	56.99 ± 1.19	Hoffman et al. (2005)
		Mara Research Station,RSA	9	48.32 ± 5.18	29.36 ± 3.29	-	60.75 ± 1.40	Hoffman et al. (2005)
		Overberg Test Range (Denel), RSA	2	26.3 ± 4.5	-	14.5 ± 2.2	63.5 ± 2.9	Van Zyl & Ferreira (2004)
	Female	Kruger National Park, RSA	-	31.89 ± 1.95	-	-	-	Fairall & Braack (1976)
		Nyala Game Ranch, RSA	1	23.6	-	-	-	Anderson (1982)
Sub-adult	Male	Nyaminyami Rural District, Zimbabwe	74	-	18.4 ± 3.27	-	-	Féron et al. (1998)
Sub-adult (6-18 months)	Male	Kruger National Park, RSA	16	33.3 ± 7.8	-	-	-	Bush et al. (2004)
Sub-adult	Female	Nyaminyami Rural District, Zimbabwe	43	-	16.5 ± 3.57	-	-	Féron et al. (1998)

Abbreviations: SE = standard error; CW = carcass weight; RSA = Republic of South Africa.

Table I Continued.

Age classification	Sex	Location	n	Live weight ± SE (kg)	Warm CW (kg)	Cold CW (kg)	Dressing %	Reference
Sub-adult (19-34 months)	Male	Mara Research Station, RSA	24	46.9 ± 1.3	-	28.5 ± 0.8	60.9 ± 0.8	Du Plessis et al. (2006)
		Messina Experimental Farm, RSA	55	38.1 ± 0.6	-	22.6 ± 0.4	59.2 ± 0.4	Du Plessis et al. (2006)
	Female	Mara Research Station, RSA	9	43.7 ± 1.2	-	26.1 ± 0.9	59.7 ± 0.9	Du Plessis et al. (2006)
		Messina Experimental Farm, RSA	32	33.3 ± 0.7	-	19.4 ± 0.5	58.5 ± 0.8	Du Plessis et al (2006)
Sub-adult (has not established permanent dentition)	Male	Mabula District, Limpopo, RSA	6	33.8 ± 10.71	-	20.2 ± 6.03	59.9 ± 1.44	Hoffman et al (2009)
	Female	Mabula District, Limpopo, RSA	8	41.8 ± 9.91	-	25.0 ± 5.22	60.0 ± 1.34	Hoffman et al (2009)
24 months	Male	Kruger National Park, RSA	-	36.72 ± 1.76	-	-	-	Fairall & Braack (1976)
		Kruger National Park, RSA	5	38.5	22.0	-	57.1	Fairall (1983)
		Nyala Game Ranch, RSA	10	32.37 ± 4.11	-	-	-	Anderson (1982)
		Lake Mburo region, Uganda	-	31.5	-	-	-	Averbeck (2002)
	Female	Kruger National Park, RSA	-	34.52 ± 1.33	-	-	-	Fairall & Braack (1976)
30 months	Male	Musina Experimental Farm, RSA	4	46.38 ± 0.39	25.62 ± 4.64	-	55.03 ± 2.48	Hoffman et al. (2005)
		Mara Research Station, RSA	1	55.50 ± 0.00	33.84 ± 0.00	-	60.97 ± 0.00	Hoffman et al. (2005)
	Female	Musina Experimental Farm, RSA	6	35.00 ± 3.52	20.25 ± 2.04	-	58.07 ± 5.32	Hoffman et al. (2005)
		Mara Research Station, RSA	6	43.85 ± 2.69	27.66 ± 1.54	-	63.16 ± 2.62	Hoffman et al. (2005)
Adult (>34 months)	Male	Mara Research station, RSA	41	61.8 ± 1.0	-	38.5 ± 0.9	62.3 ± 0.8	Du Plessis et al (2006)
		Messina Experimental Farm, RSA	159	52.9 ± 0.5	-	31.1 ± 0.3	58.8 ± 0.3	Du Plessis et al (2006)
	Female	Mara Research Station, RSA	27	48.4 ± 0.8	-	29.8 ± 0.6	61.6 ± 1.0	Du Plessis et al (2006)
		Messina Experimental Farm, RSA	11	41.2 ± 0.4	-	24.0 ± 0.3	57.9 ± 0.4	Du Plessis et al (2006)

Abbreviations: SE = standard error; CW = carcass weight; RSA = Republic of South Africa.

Table I Continued.

Age classification	Sex	Location	n	Live weight ± SE (kg)	Warm CW (kg)	Cold CW (kg)	Dressing %	Reference
36 months	Male	Kruger National Park, RSA	3	40.58 ± 2.21	-	-	-	Fairall & Braack (1976)
		Lake Mburo region, Uganda	-	45.1	-	-	-	Averbeck (2002)
	Female	Overberg Test Range (Denel), RSA	6	42.6 ± 1.8	-	24.8 ± 1.0	66.3 ± 1.2	Van Zyl & Ferreira (2004)
42 months	Male	Musina Experimental Farm, RSA	7	58.28 ± 3.74	35.21 ± 3.78	-	60.28 ± 3.17	Hoffman et al. (2005)
		Mara Research Station, RSA	9	61.75 ± 3.13	37.83 ± 2.32	-	61.27 ± 2.42	Hoffman et al. (2005)
	Female	Musina Experimental Farm, RSA	6	42.08 ± 2.06	24.75 ± 2.04	-	58.77 ± 3.29	Hoffman et al. (2005)
		Mara Research Station, RSA	10	46.89 ± 0.64	29.22 ± 1.64	-	62.33 ± 2.83	Hoffman et al. (2005)
48 months	Male	Lake Mburo region, Uganda	-	53.5	-	-	-	Averbeck (2002)
54 months	Male	Musina Experimental Farm, RSA	1	58.00 ± 0.00	32.50 ± 0.00	-	56.03 ± 0.00	Hoffman et al. (2005)
		Mara Research Station, RSA	2	65.80 ± 7.91	43.33 ± 7.95	-	65.60 ± 4.19	Hoffman et al. (2005)
Adult (permanent dentition)	Male	Mabula District, Limpopo, RSA	11	58.21 ± 8.30	-	37.89 ± 4.46	60.9 ± 1.18	Hoffman et al. (2009)
	Female	Mabula District, Limpopo, RSA	7	43.76 ± 8.74	-	25.44 ± 4.93	58.6 ± 1.18	Hoffman et al. (2009)
Mature/Adult	Male	Serengeti National Park, Tanzania	28	56.90	-	-	-	Sachs (1967)
		S.A. Lombard Nature Reserve, RSA	12	63.3 ± 2.2	-	-	-	Skinner (1971)
		Ranch near Lake Elmenteita, Kenya	22	63.5 ± 1.7	-	-	-	Bramley & Neaves (1972)
		Kruger National Park, RSA	-	49.22 ± 1.02	-	-	-	Fairall & Braack (1976)
		Northern Transvaal, RSA	9	57.2 ± 8.5	34.9 ± 5.9	-	-	Monro & Skinner (1979)
		Nyala Game Ranch, RSA	10	44.18 ± 6.86	-	-	-	Anderson (1982)
		Kruger National Park, RSA	5	49.4	28.1	-	56.9	Fairall (1983)

Abbreviations: SE = standard error; CW = carcass weight; RSA = Republic of South Africa.

Table I Continued.

Age classification	Sex	Location	n	Live weight ± SE (kg)	Warm CW (kg)	Cold CW (kg)	Dressing %	Reference
Mature/Adult (Continued)	Male	Nyaminyami Rural District, Zimbabwe	19	-	25.5 ± 4.26	-	-	Féron et al. (1998)
		Ndzalama Wildlife Reserve, RSA	7	74.0 ± 4.1	42.0	-	-	Theobald (2002)
		Selati Game Reserve, RSA	3	60.0 ± 3.1	41.4	-	-	Theobald (2002)
		Mara Research Station, RSA	5	77.2 ± 3.7	38.2	-	-	Theobald (2002)
		Mara Research Station, RSA	20	55.5 ± 1.1	36.1 ± 0.8	32.0 ± 1.3	60.0 ± 0.6	Van den Berg (2009)
	Female	Serengeti National Park, Tanzania	12	42.08	-	-	-	Sachs (1967)
		Kruger National Park, RSA	-	38.30 ± 1.79	-	-	-	Fairall & Braack (1976)
		Nyala Game Ranch, RSA	9	40.48 ± 4.50	-	-	-	Anderson (1982)
		Nyaminyami Rural District, Zimbabwe	355	-	20.4 ± 2.94	-	-	Féron et al. (1998)
		Nyaminyami Rural District, Zimbabwe	346	-	20.4 ± 3.548	-	-	Bourgarel et al. (2002)
		Ndzalama Wildlife Reserve, RSA	1	73.0 ± 5.1	44.5	-	-	Theobald (2002)
		Selati Game Reserve, RSA	8	58.0 ± 3.2	39.5	-	-	Theobald (2002)
		Mara Research Station, RSA	20	46.4 ± 1.1	29.3 ± 0.8	27.0 ± 0.7	59.4 ± 0.6	Van den Berg (2009)
5 years and older	Male	Lake Mburo region, Uganda	-	58.7	-	-	-	Averbeck (2002)
Old	Male	Kruger National Park, RSA	-	47.80 ± 2.19	-	-	-	Fairall & Braack (1976)
	Female	Kruger National Park, RSA	-	41.83 ± 3.44	-	-	-	Fairall & Braack (1976)
10 months-4+ years	Male	Maneze Wildlife Conservancy, Zimbabwe	8	49.4 ± 4.606	28.3 ± 2.571	27.6 ± 2.6	57.5 ± 0.548	Hoffman (2000)
	Female	Maneze Wildlife Conservancy, Zimbabwe	8	33.5 ± 3.417	19.5 ± 2.0	19.0 ± 2.0	58.0 ± 0.621	Hoffman (2000)

Abbreviations: SE = standard error; CW = carcass weight; RSA = Republic of South Africa.

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ADDENDUM II

CORRELATION MATRIX

Table II Correlation matrix for the Pearson correlation coefficients (*r*) for the sensory characteristics and fatty acids obtained in impala meat. Values in bold are significant at a level of P ≤ 0.05.

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1	**1**	**<0.001**	**<0.001**	**0.001**	0.982	**<0.001**	**0.005**	**<0.001**	**<0.001**	**0.000**	**0.000**	**<0.001**
2	**0.782**	**1**	**<0.001**	**0.001**	0.872	**<0.001**	**0.004**	**0.001**	**0.000**	**0.004**	**0.008**	**<0.001**
3	**0.679**	**0.693**	**1**	**<0.001**	0.061	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
4	**-0.549**	**-0.517**	**-0.736**	**1**	**0.031**	**<0.001**	**0.006**	**0.001**	**0.009**	**0.000**	**<0.001**	**<0.001**
5	-0.004	-0.028	-0.315	**0.360**	**1**	0.259	0.192	0.635	0.231	**0.004**	**0.030**	**0.019**
6	**0.751**	**0.626**	**0.744**	**-0.691**	-0.193	**1**	**0.001**	**<0.001**	**0.001**	**0.001**	**<0.001**	**<0.001**
7	**-0.457**	**-0.467**	**-0.739**	**0.447**	0.222	**-0.513**	**1**	**0.001**	**<0.001**	**0.000**	**0.001**	**0.003**
8	**0.614**	**0.521**	**0.618**	**-0.540**	-0.082	**0.712**	**-0.551**	**1**	**0.001**	**0.005**	**0.000**	**0.000**
9	**0.603**	**0.567**	**0.716**	**-0.429**	-0.205	**0.515**	**-0.687**	**0.526**	**1**	**<0.001**	**<0.001**	**0.004**
10	**0.552**	**0.473**	**0.604**	**-0.554**	**-0.473**	**0.548**	**-0.567**	**0.461**	**0.680**	**1**	**0.001**	**0.003**
11	**0.580**	**0.432**	**0.781**	**-0.717**	**-0.362**	**0.697**	**-0.525**	**0.602**	**0.652**	**0.550**	**1**	**<0.001**
12	**-0.662**	**-0.622**	**-0.794**	**0.760**	**0.388**	**-0.686**	**0.481**	**-0.578**	**-0.468**	**-0.486**	**-0.742**	**1**
13	-0.198	-0.162	**-0.341**	0.284	-0.177	**-0.349**	0.186	-0.278	-0.218	0.127	**-0.468**	0.322
14	**0.737**	**0.689**	**0.866**	**-0.738**	**-0.333**	**0.818**	**-0.555**	**0.688**	**0.697**	**0.678**	**0.836**	**-0.764**
15	**-0.369**	**-0.372**	**-0.625**	**0.458**	**0.488**	**-0.495**	**0.664**	**-0.441**	**-0.564**	**-0.590**	**-0.605**	**0.581**
16	**0.579**	**0.561**	**0.799**	**-0.656**	**-0.417**	**0.675**	**-0.564**	**0.539**	**0.555**	**0.488**	**0.825**	**-0.860**
17	-0.034	0.123	0.051	-0.021	0.190	0.002	-0.038	-0.066	0.078	0.009	-0.024	-0.039
18	-0.044	0.139	-0.208	0.283	0.264	**-0.330**	0.084	-0.068	0.044	-0.078	**-0.427**	**0.405**
19	-0.042	0.097	-0.079	0.134	0.230	0.111	0.050	-0.040	-0.201	-0.101	-0.091	0.117
20	0.074	0.007	-0.080	0.005	-0.152	0.081	0.284	0.082	-0.086	0.055	-0.030	-0.087
21	0.019	0.012	-0.215	**0.374**	0.012	-0.142	0.090	-0.036	0.046	0.130	-0.322	0.191
22	-0.018	0.035	0.221	**-0.384**	-0.006	0.260	-0.095	0.106	-0.018	-0.084	**0.365**	-0.169
23	-0.072	-0.099	-0.256	**0.388**	0.091	**-0.334**	0.021	-0.245	0.048	0.122	**-0.439**	0.316
24	0.029	0.095	0.236	**-0.402**	0.087	0.194	-0.209	0.086	0.156	-0.002	0.326	-0.129
25	**-0.537**	**-0.377**	**-0.664**	**0.678**	0.220	**-0.796**	**0.401**	**-0.562**	**-0.339**	**-0.418**	**-0.656**	**0.712**
26	0.164	0.147	0.218	-0.014	-0.143	0.151	-0.136	-0.089	0.103	0.004	0.093	-0.059
27	-0.235	-0.265	-0.112	0.072	-0.147	-0.287	0.178	-0.184	-0.051	-0.166	-0.086	0.146
28	-0.302	**-0.384**	-0.283	0.201	0.214	**-0.374**	0.327	**-0.429**	**-0.425**	**-0.369**	-0.323	0.299
29	-0.238	**-0.366**	-0.227	0.216	0.243	-0.260	0.264	**-0.392**	**-0.415**	**-0.367**	-0.250	0.276
30	**-0.458**	**-0.576**	**-0.418**	0.280	**0.394**	**-0.470**	0.306	**-0.484**	**-0.502**	**-0.415**	**-0.435**	**0.476**
31	**-0.481**	**-0.587**	**-0.426**	0.258	**0.345**	**-0.567**	**0.362**	**-0.501**	**-0.471**	**-0.390**	**-0.447**	**0.473**
32	-0.142	-0.207	-0.048	-0.107	0.155	-0.116	0.129	0.045	-0.141	0.006	-0.104	0.168
33	-0.240	-0.199	-0.281	0.162	-0.023	-0.175	0.062	-0.322	-0.083	0.012	-0.300	0.296
34	-0.145	0.072	-0.101	-0.085	-0.066	0.016	0.053	0.060	0.135	0.068	0.028	-0.059
35	**-0.422**	**-0.527**	**-0.398**	0.219	**0.366**	**-0.531**	**0.337**	**-0.417**	**-0.418**	**-0.372**	**-0.380**	**0.400**
36	0.181	0.026	0.133	-0.249	0.254	0.117	0.087	0.198	0.019	0.122	0.172	-0.202
37	**-0.387**	-0.313	-0.260	0.132	0.002	**-0.461**	0.238	-0.256	-0.295	**-0.512**	-0.232	0.166
38	**-0.389**	**-0.523**	**-0.370**	0.164	**0.369**	**-0.462**	**0.344**	**-0.406**	**-0.432**	**-0.340**	**-0.355**	**0.395**
39	0.190	-0.010	0.031	-0.054	0.251	0.202	0.153	0.121	-0.138	0.004	0.158	-0.149
40	**-0.344**	**-0.454**	-0.322	0.164	0.312	**-0.405**	0.268	-0.299	**-0.338**	-0.292	**-0.332**	**0.356**
41	-0.284	-0.194	-0.098	-0.022	-0.021	-0.317	0.087	0.012	-0.138	-0.266	-0.156	0.101
42	0.138	0.155	0.081	-0.147	-0.250	0.261	-0.091	0.149	0.259	0.291	0.107	-0.123
43	-0.292	**-0.420**	-0.240	0.123	**0.388**	**-0.344**	0.190	**-0.330**	**-0.337**	-0.293	-0.239	0.284
44	0.128	0.115	0.017	0.018	0.153	0.033	0.207	0.272	-0.041	-0.038	0.005	-0.053
45	**-0.427**	**-0.476**	-0.327	0.140	0.263	**-0.503**	0.299	**-0.368**	**-0.359**	**-0.393**	-0.287	0.309
46	**0.469**	**0.370**	**0.499**	**-0.470**	0.088	**0.556**	**-0.373**	**0.633**	**0.403**	**0.453**	**0.386**	**-0.427**
47	0.171	0.275	0.183	0.045	-0.249	0.181	-0.196	0.091	0.164	0.152	0.166	-0.111
48	-0.285	**-0.401**	-0.220	0.126	0.158	**-0.377**	0.143	-0.176	-0.224	-0.325	-0.176	0.189
49	-0.323	-0.252	-0.307	0.289	-0.136	**-0.478**	0.232	-0.196	-0.171	**-0.340**	-0.267	0.263
50	**0.539**	**0.467**	**0.462**	-0.294	0.063	**0.553**	**-0.375**	0.322	0.292	0.275	**0.377**	**-0.428**
51	0.114	0.221	0.171	0.050	-0.281	0.125	-0.211	0.088	0.135	0.119	0.169	-0.098
52	-0.168	-0.278	-0.084	-0.055	0.191	-0.266	0.126	-0.081	-0.154	-0.183	-0.084	0.024
53	**-0.483**	-0.281	-0.281	0.180	0.214	**-0.336**	0.188	**-0.439**	**-0.348**	**-0.382**	**-0.378**	**0.343**
54	-0.223	-0.118	-0.131	0.046	0.180	-0.065	0.126	-0.191	-0.190	-0.200	-0.179	0.154
55	-0.193	0.039	0.012	0.117	0.097	-0.094	-0.029	-0.200	-0.159	-0.268	-0.138	0.102
56	**0.345**	**0.349**	**0.341**	-0.099	-0.174	0.291	-0.269	0.304	0.242	0.160	0.289	-0.288
57	-0.214	0.038	-0.032	0.201	-0.007	-0.121	0.006	-0.228	-0.164	-0.235	-0.140	0.155
58	-0.133	0.034	0.064	-0.006	0.207	-0.044	-0.067	-0.132	-0.126	-0.261	-0.111	0.021
59	-0.176	-0.007	-0.127	0.263	-0.253	-0.129	0.061	-0.161	-0.079	-0.020	-0.059	0.189
60	**-0.371**	-0.143	-0.158	0.153	0.184	-0.223	0.102	**-0.347**	-0.282	**-0.352**	-0.285	0.246
61	**-0.371**	-0.143	-0.158	0.153	0.184	-0.223	0.102	**-0.347**	-0.282	**-0.352**	-0.285	0.246

Numbers in the first column correspond to numbers in the first row; 1, overall aroma intensity; 2, gamey aroma; 3, beef-like aroma; 4, metallic aroma; 5, liver-like aroma; 6, herbaceous aroma; 7, off, sour, sweat-like aroma; 8, sweet-associated aroma; 9, overall flavour intensity; 10, gamey flavour; 11, beef-like flavour; 12, metallic flavour; 13, liver-like flavour; 14, herbaceous flavour; 15, off, sour, sweat-like flavour; 16, sweet associated taste; 17, salty taste; 18, sour taste; 19, initial juiciness; 20, sustained juiciness; 21, tenderness; 22, residue; 23, mealiness; 24, Warner-Bratzler shear force; 25, thaw loss percentage; 26, cooking loss percentage; 27, C6:0; 28, C8:0; 29, C10:0; 30, C12:0; 31, C14:0; 32, C15:0; 33, C16:0; 34, C18:0; 35, C20:0; 36, C22:0; 37, C24:0; 38, C14:1; 39, C15:1; 40, C16:1; 41, C17:1; 42, C18:1n9c; 43, C20:1; 44, C18:2n9c; 45, C18:3n6; 46, C18:3n3; 47, C20:2n6; 48, C20:3n6; 49, C20:3n3; 50, C20:5n3; 51, C22:2n6; 52, C22:6n3; 53, total SFA; 54, total MUFA; 55, total PUFA; 56, PUFA:SFA ratio; 57, n6; 58, n3; 59, n6:n3 ratio; 60, total fatty acids; 61, intramuscular fat content. The non-shaded area indicates Pearson correlation coefficients (*r*); area shaded in grey indicates corresponding P-values for Pearson correlation coefficients (*r*).

Table II Continued.

Variable	13	14	15	16	17	18	19	20	21	22	23	24
1	0.247	**<0.001**	**0.027**	**0.000**	0.845	0.797	0.807	0.666	0.912	0.916	0.675	0.868
2	0.346	**<0.001**	**0.025**	**0.000**	0.476	0.418	0.573	0.967	0.943	0.842	0.564	0.580
3	**0.042**	**<0.001**	**<0.001**	**<0.001**	0.766	0.224	0.648	0.644	0.207	0.195	0.131	0.165
4	0.094	**<0.001**	**0.005**	**<0.001**	0.903	0.094	0.436	0.977	**0.025**	**0.021**	**0.019**	**0.015**
5	0.301	**0.047**	**0.003**	**0.011**	0.267	0.119	0.178	0.377	0.947	0.972	0.596	0.613
6	**0.037**	**<0.001**	**0.002**	**<0.001**	0.990	**0.049**	0.518	0.638	0.407	0.126	**0.046**	0.257
7	0.279	**0.000**	**<0.001**	**0.000**	0.827	0.624	0.773	0.093	0.602	0.582	0.903	0.221
8	0.100	**<0.001**	**0.007**	**0.001**	0.702	0.694	0.816	0.634	0.833	0.540	0.149	0.620
9	0.202	**<0.001**	**0.000**	**0.000**	0.651	0.801	0.240	0.619	0.789	0.915	0.781	0.364
10	0.460	**<0.001**	**0.000**	**0.003**	0.957	0.650	0.558	0.750	0.449	0.625	0.479	0.992
11	**0.004**	**<0.001**	**<0.001**	**<0.001**	0.888	**0.009**	0.599	0.863	0.055	**0.029**	**0.007**	0.053
12	0.056	**<0.001**	**0.000**	**<0.001**	0.822	**0.014**	0.497	0.612	0.266	0.323	0.060	0.453
13	**1**	0.076	0.734	**0.025**	1.000	0.174	0.941	0.171	**0.000**	**0.001**	**<0.001**	**0.005**
14	-0.300	**1**	**<0.001**	**<0.001**	0.885	0.063	0.743	0.679	0.587	0.309	0.131	0.370
15	0.059	**-0.611**	**1**	**<0.001**	0.480	**0.041**	0.995	0.950	0.652	0.861	0.838	0.713
16	**-0.374**	**0.799**	**-0.671**	**1**	0.656	**0.006**	0.569	0.766	0.138	0.126	**0.015**	0.266
17	0.000	0.025	-0.122	0.077	**1**	0.620	0.779	0.451	0.969	0.499	0.937	0.109
18	0.232	-0.314	**0.343**	**-0.447**	0.085	**1**	0.799	0.863	0.383	0.141	0.269	0.990
19	-0.013	0.056	-0.001	-0.098	-0.048	-0.044	**1**	0.411	0.712	0.858	0.676	0.808
20	0.233	0.071	0.011	-0.051	-0.130	0.030	0.141	**1**	**<0.001**	**0.000**	0.078	**0.007**
21	**0.569**	-0.094	-0.078	-0.252	0.007	0.150	0.064	**0.610**	**1**	**<0.001**	**<0.001**	**<0.001**
22	**-0.530**	0.174	0.030	0.260	0.116	-0.250	0.031	**-0.567**	**-0.916**	**1**	**<0.001**	**<0.001**
23	**0.692**	-0.256	-0.035	**-0.401**	0.014	0.189	-0.072	0.298	**0.838**	**-0.829**	**1**	**0.000**
24	**-0.460**	0.154	-0.063	0.190	0.272	0.002	-0.042	**-0.445**	**-0.745**	**0.779**	**-0.577**	**1**
25	**0.348**	**-0.658**	**0.400**	**-0.582**	0.041	**0.487**	-0.028	-0.289	0.131	-0.196	0.303	-0.142
26	-0.004	0.178	-0.151	0.156	0.096	-0.161	-0.124	**-0.534**	**-0.354**	**0.374**	-0.176	0.312
27	-0.115	-0.181	0.097	-0.114	0.078	**0.365**	-0.317	0.192	0.050	-0.190	-0.058	-0.109
28	0.251	**-0.388**	**0.382**	**-0.438**	-0.050	-0.140	-0.200	-0.204	-0.094	0.063	0.159	-0.145
29	0.177	-0.317	0.277	**-0.350**	-0.002	-0.224	-0.085	-0.283	-0.176	0.144	0.065	-0.038
30	0.210	**-0.522**	**0.412**	**-0.547**	0.008	-0.117	-0.083	-0.276	-0.101	0.044	0.214	-0.020
31	0.210	**-0.567**	**0.418**	**-0.565**	-0.019	0.038	-0.189	-0.119	-0.030	-0.100	0.245	-0.107
32	0.082	-0.058	0.247	-0.169	-0.048	-0.015	-0.159	-0.191	-0.173	0.269	-0.065	0.205
33	**0.412**	-0.175	0.061	-0.310	0.147	-0.064	-0.001	-0.138	0.234	-0.147	**0.427**	0.023
34	0.160	0.030	-0.094	0.012	0.246	-0.048	0.098	0.110	0.176	-0.045	0.178	-0.037
35	0.208	**-0.527**	**0.448**	**-0.551**	-0.092	-0.016	-0.191	-0.121	-0.051	-0.032	0.247	-0.122
36	-0.093	0.118	-0.002	0.025	-0.013	-0.108	-0.122	0.160	0.009	-0.037	0.021	-0.085
37	-0.045	**-0.424**	**0.329**	-0.305	-0.226	0.069	-0.269	0.008	-0.153	0.051	-0.041	-0.097
38	0.192	**-0.477**	**0.434**	**-0.516**	-0.061	-0.047	-0.185	-0.127	-0.068	-0.022	0.215	-0.086
39	-0.009	0.016	0.091	0.034	-0.104	-0.301	0.022	0.125	-0.073	0.091	-0.051	-0.156
40	0.285	**-0.446**	**0.366**	**-0.544**	-0.097	0.019	-0.209	0.050	0.081	-0.111	0.314	-0.167
41	0.049	-0.256	0.304	-0.172	-0.167	0.170	**-0.340**	0.005	-0.080	0.110	-0.064	0.003
42	**0.338**	0.222	-0.123	0.045	0.123	-0.024	-0.061	0.225	0.296	-0.125	0.283	-0.004
43	0.105	**-0.381**	0.323	**-0.382**	-0.126	-0.176	-0.125	-0.177	-0.132	0.075	0.189	-0.048
44	-0.213	0.046	0.289	-0.010	-0.288	0.231	-0.045	0.073	0.007	-0.041	-0.177	-0.266
45	0.098	**-0.472**	**0.383**	**-0.470**	-0.087	0.002	-0.263	-0.109	-0.109	0.029	0.154	-0.078
46	-0.144	**0.477**	-0.252	0.260	-0.037	0.032	0.023	0.228	0.145	-0.106	-0.031	0.013
47	-0.280	0.215	-0.302	0.310	0.125	0.126	0.246	0.006	-0.094	0.076	-0.323	0.163
48	0.018	**-0.400**	0.296	**-0.388**	-0.299	0.006	-0.249	0.048	-0.038	-0.081	0.130	-0.204
49	0.046	**-0.378**	0.211	-0.225	-0.223	0.324	-0.177	0.064	0.034	-0.148	-0.014	-0.263
50	-0.306	**0.525**	-0.325	**0.599**	0.004	-0.292	0.203	-0.170	-0.189	0.192	-0.236	0.258
51	-0.278	0.170	-0.279	0.276	0.051	0.138	0.230	0.028	-0.110	0.070	**-0.338**	0.152
52	0.063	-0.268	0.208	-0.274	-0.125	0.012	-0.262	0.068	0.010	-0.102	0.174	-0.199
53	0.254	**-0.340**	0.325	-0.303	0.277	-0.023	0.102	-0.321	-0.188	0.255	0.023	0.256
54	0.288	-0.154	0.280	-0.184	0.202	-0.072	0.056	-0.100	-0.088	0.219	0.052	0.186
55	-0.095	-0.079	0.101	0.082	0.221	0.059	0.252	-0.316	**-0.342**	**0.349**	**-0.333**	**0.331**
56	**-0.409**	0.303	-0.254	**0.419**	-0.119	0.130	0.133	0.077	-0.124	0.040	**-0.379**	0.053
57	-0.132	-0.097	0.064	0.044	0.234	0.134	0.286	-0.256	-0.308	0.315	**-0.370**	0.304
58	-0.034	-0.043	0.129	0.114	0.166	-0.043	0.167	**-0.333**	-0.324	**0.330**	-0.230	0.307
59	-0.153	-0.090	-0.056	-0.062	0.148	0.214	0.243	0.028	-0.072	0.083	-0.256	0.101
60	0.132	-0.234	0.259	-0.144	0.277	0.004	0.179	-0.326	-0.270	**0.330**	-0.136	0.316
61	0.132	-0.234	0.259	-0.144	0.277	0.004	0.179	-0.326	-0.270	**0.330**	-0.136	0.316

Numbers in the first column correspond to numbers in the first row; 1, overall aroma intensity; 2, gamey aroma; 3, beef-like aroma; 4, metallic aroma; 5, liver-like aroma; 6, herbaceous aroma; 7, off, sour, sweat-like aroma; 8, sweet-associated aroma; 9, overall flavour intensity; 10, gamey flavour; 11, beef-like flavour; 12, metallic flavour; 13, liver-like flavour; 14, herbaceous flavour; 15, off, sour, sweat-like flavour; 16, sweet associated taste; 17, salty taste; 18, sour taste; 19, initial juiciness; 20, sustained juiciness; 21, tenderness; 22, residue; 23, mealiness; 24, Warner-Bratzler shear force; 25, thaw loss percentage; 26, cooking loss percentage; 27, C6:0; 28, C8:0; 29, C10:0; 30, C12:0; 31, C14:0; 32, C15:0; 33, C16:0; 34, C18:0; 35, C20:0; 36, C22:0; 37, C24:0; 38, C14:1; 39, C15:1; 40, C16:1; 41, C17:1; 42, C18:1n9c; 43, C20:1; 44, C18:2n9c; 45, C18:3n6; 46, C18:3n3; 47, C20:2n6; 48, C20:3n6; 49, C20:3n3; 50, C20:5n3; 51, C22:2n6; 52, C22:6n3; 53, total SFA; 54, total MUFA; 55, total PUFA; 56, PUFA:SFA ratio; 57, n6; 58, n3; 59, n6:n3 ratio; 60, total fatty acids; 61, intramuscular fat content. The non-shaded area indicates Pearson correlation coefficients (*r*); area shaded in grey indicates corresponding P-values for Pearson correlation coefficients (*r*).

Table II Continued.

Variable	25	26	27	28	29	30	31	32	33	34	35	36
1	**0.001**	0.339	0.167	0.073	0.162	**0.005**	**0.003**	0.409	0.158	0.397	**0.010**	0.292
2	**0.024**	0.392	0.119	**0.021**	**0.028**	**0.000**	**0.000**	0.226	0.245	0.677	**0.001**	0.881
3	**<0.001**	0.202	0.516	0.094	0.183	**0.011**	**0.009**	0.783	0.097	0.560	**0.016**	0.438
4	**<0.001**	0.938	0.677	0.241	0.205	0.098	0.129	0.534	0.346	0.621	0.199	0.144
5	0.197	0.404	0.394	0.211	0.153	**0.017**	**0.040**	0.368	0.893	0.703	**0.028**	0.135
6	**<0.001**	0.379	0.089	**0.024**	0.125	**0.004**	**0.000**	0.499	0.308	0.928	**0.001**	0.497
7	**0.015**	0.429	0.298	0.052	0.119	0.069	**0.030**	0.453	0.720	0.759	**0.045**	0.614
8	**0.000**	0.605	0.282	**0.009**	**0.018**	**0.003**	**0.002**	0.795	0.055	0.730	**0.011**	0.248
9	**0.043**	0.551	0.766	**0.010**	**0.012**	**0.002**	**0.004**	0.413	0.629	0.432	**0.011**	0.914
10	**0.011**	0.981	0.333	**0.027**	**0.028**	**0.012**	**0.019**	0.974	0.946	0.692	**0.026**	0.478
11	**<0.001**	0.589	0.618	0.055	0.142	**0.008**	**0.006**	0.547	0.075	0.870	**0.022**	0.316
12	**<0.001**	0.735	0.394	0.076	0.103	**0.003**	**0.004**	0.328	0.080	0.731	**0.016**	0.237
13	**0.038**	0.983	0.502	0.140	0.301	0.219	0.219	0.636	**0.012**	0.351	0.224	0.589
14	**<0.001**	0.300	0.291	**0.019**	0.060	**0.001**	**0.000**	0.735	0.309	0.860	**0.001**	0.492
15	**0.016**	0.380	0.573	**0.022**	0.102	**0.013**	**0.011**	0.147	0.725	0.586	**0.006**	0.990
16	**0.000**	0.363	0.508	**0.008**	**0.036**	**0.001**	**0.000**	0.324	0.066	0.943	**0.000**	0.885
17	0.814	0.577	0.652	0.774	0.991	0.964	0.912	0.781	0.392	0.148	0.593	0.939
18	**0.003**	0.349	**0.028**	0.415	0.190	0.497	0.825	0.929	0.710	0.780	0.925	0.530
19	0.870	0.472	0.059	0.243	0.623	0.631	0.271	0.354	0.995	0.570	0.265	0.480
20	0.088	**0.001**	0.261	0.233	0.094	0.104	0.489	0.264	0.423	0.523	0.482	0.351
21	0.446	**0.034**	0.770	0.587	0.304	0.558	0.861	0.312	0.170	0.305	0.769	0.957
22	0.253	**0.024**	0.267	0.717	0.401	0.801	0.563	0.113	0.392	0.795	0.853	0.828
23	0.072	0.304	0.736	0.353	0.708	0.211	0.150	0.706	**0.009**	0.298	0.146	0.903
24	0.407	0.064	0.527	0.400	0.825	0.908	0.533	0.230	0.896	0.829	0.480	0.621
25	**1**	0.587	0.402	0.365	0.537	0.109	0.110	0.630	0.139	0.976	0.220	0.050
26	0.094	**1**	0.100	0.100	**0.004**	0.362	0.516	0.566	0.302	0.094	0.408	0.055
27	0.144	-0.279	**1**	0.921	0.782	0.895	0.094	0.706	**0.014**	0.134	0.560	0.548
28	0.156	0.279	0.017	**1**	**<0.001**	**<0.001**	**<0.001**	**0.030**	0.590	0.619	**<0.001**	**0.050**
29	0.106	**0.467**	-0.048	**0.939**	**1**	**<0.001**	**<0.001**	0.055	0.739	0.208	**<0.001**	0.136
30	0.272	0.156	0.023	**0.878**	**0.867**	**1**	**<0.001**	**0.006**	0.253	0.489	**<0.001**	0.067
31	0.271	-0.112	0.283	**0.791**	**0.707**	**0.906**	**1**	**0.014**	0.729	0.440	**<0.001**	**0.004**
32	0.083	0.099	0.065	**0.361**	0.323	**0.447**	**0.406**	**1**	0.276	0.282	**0.015**	**0.017**
33	0.252	0.177	**-0.404**	0.093	0.058	0.195	0.060	-0.187	**1**	**0.025**	0.648	**0.040**
34	0.005	-0.283	-0.254	-0.086	-0.215	-0.119	-0.133	-0.184	**0.373**	**1**	0.949	0.570
35	0.209	-0.142	0.101	**0.843**	**0.703**	**0.875**	**0.930**	**0.401**	0.079	0.011	**1**	**0.001**
36	-0.329	-0.323	0.103	**0.330**	0.253	0.308	**0.474**	**0.394**	**-0.344**	0.098	**0.527**	**1**
37	0.191	-0.123	0.313	**0.508**	**0.337**	**0.342**	**0.427**	0.092	-0.269	0.030	**0.539**	0.081
38	0.176	-0.077	0.139	**0.856**	**0.759**	**0.928**	**0.965**	**0.471**	0.055	-0.049	**0.971**	**0.549**
39	**-0.353**	-0.117	-0.311	**0.431**	**0.410**	0.302	0.276	0.029	-0.218	0.057	**0.428**	**0.564**
40	0.093	-0.189	0.048	**0.808**	**0.647**	**0.788**	**0.844**	0.313	0.178	0.102	**0.928**	**0.513**
41	0.176	-0.131	0.265	**0.341**	0.149	0.237	0.267	**0.562**	-0.280	-0.015	**0.372**	0.074
42	-0.179	-0.007	**-0.385**	-0.154	-0.246	-0.266	**-0.353**	-0.273	**0.664**	**0.633**	-0.218	-0.207
43	0.078	-0.044	-0.065	**0.810**	**0.720**	**0.869**	**0.861**	**0.407**	0.056	-0.020	**0.939**	**0.549**
44	0.029	-0.292	0.258	-0.126	-0.216	-0.199	-0.064	0.269	**-0.550**	-0.279	-0.010	0.269
45	0.182	-0.140	0.226	**0.834**	**0.669**	**0.806**	**0.876**	**0.372**	-0.019	0.087	**0.958**	**0.520**
46	**-0.559**	**-0.330**	-0.120	-0.327	**-0.350**	-0.303	-0.215	0.037	-0.088	-0.003	-0.164	**0.414**
47	0.013	0.177	0.162	**-0.660**	**-0.469**	**-0.618**	**-0.606**	**-0.352**	-0.273	**-0.381**	**-0.786**	**-0.522**
48	0.015	-0.270	0.229	**0.653**	**0.487**	**0.559**	**0.667**	0.142	-0.191	-0.011	**0.800**	**0.435**
49	**0.422**	-0.140	**0.561**	0.076	-0.014	-0.028	0.100	0.068	**-0.479**	-0.161	0.086	-0.186
50	-0.291	0.296	**-0.356**	**-0.499**	-0.292	**-0.360**	**-0.487**	-0.053	-0.086	-0.297	**-0.563**	-0.145
51	0.006	0.138	0.208	**-0.605**	**-0.429**	**-0.579**	**-0.554**	**-0.357**	-0.317	**-0.433**	**-0.722**	**-0.530**
52	-0.082	**-0.352**	0.236	**0.622**	**0.432**	**0.535**	**0.675**	0.267	-0.229	0.097	**0.810**	**0.650**
53	0.256	0.283	-0.081	**0.509**	**0.512**	**0.579**	**0.405**	0.318	**0.340**	0.160	**0.399**	-0.148
54	-0.021	0.164	-0.282	**0.457**	**0.410**	**0.407**	0.229	0.199	**0.350**	0.315	**0.338**	-0.038
55	0.158	**0.363**	0.096	-0.016	0.129	0.054	-0.081	0.156	-0.211	-0.323	-0.191	**-0.415**
56	-0.149	0.006	0.275	**-0.640**	**-0.500**	**-0.640**	**-0.562**	-0.227	**-0.615**	**-0.563**	**-0.683**	-0.304
57	0.201	**0.360**	0.173	-0.125	0.038	-0.080	-0.182	0.005	-0.222	**-0.373**	**-0.330**	**-0.522**
58	0.078	0.304	-0.015	0.120	0.217	0.209	0.057	0.315	-0.161	-0.204	0.012	-0.212
59	0.185	0.097	0.228	**-0.350**	-0.244	**-0.360**	**-0.333**	**-0.349**	-0.104	-0.228	**-0.472**	**-0.504**
60	0.198	**0.341**	-0.045	0.326	**0.388**	**0.385**	0.204	0.267	0.131	-0.017	0.168	-0.276
61	0.198	**0.341**	-0.045	0.326	**0.388**	**0.385**	0.204	0.267	0.131	-0.017	0.168	-0.276

Numbers in the first column correspond to numbers in the first row; 1, overall aroma intensity; 2, gamey aroma; 3, beef-like aroma; 4, metallic aroma; 5, liver-like aroma; 6, herbaceous aroma; 7, off, sour, sweat-like aroma; 8, sweet-associated aroma; 9, overall flavour intensity; 10, gamey flavour; 11, beef-like flavour; 12, metallic flavour; 13, liver-like flavour; 14, herbaceous flavour; 15, off, sour, sweat-like flavour; 16, sweet associated taste; 17, salty taste; 18, sour taste; 19, initial juiciness; 20, sustained juiciness; 21, tenderness; 22, residue; 23, mealiness; 24, Warner-Bratzler shear force; 25, thaw loss percentage; 26, cooking loss percentage; 27, C6:0; 28, C8:0; 29, C10:0; 30, C12:0; 31, C14:0; 32, C15:0; 33, C16:0; 34, C18:0; 35, C20:0; 36, C22:0; 37, C24:0; 38, C14:1; 39, C15:1; 40, C16:1; 41, C17:1; 42, C18:1n9c; 43, C20:1; 44, C18:2n9c; 45, C18:3n6; 46, C18:3n3; 47, C20:2n6; 48, C20:3n6; 49, C20:3n3; 50, C20:5n3; 51, C22:2n6; 52, C22:6n3; 53, total SFA; 54, total MUFA; 55, total PUFA; 56, PUFA:SFA ratio; 57, n6; 58, n3; 59, n6:n3 ratio; 60, total fatty acids; 61, intramuscular fat content. The non-shaded area indicates Pearson correlation coefficients (*r*); area shaded in grey indicates corresponding P-values for Pearson correlation coefficients (*r*).

Table II Continued.

Variable	37	38	39	40	41	42	43	44	45	46	47	48
1	**0.020**	**0.019**	0.268	**0.040**	0.093	0.424	0.084	0.455	**0.009**	**0.004**	0.318	0.092
2	0.063	**0.001**	0.952	**0.005**	0.257	0.366	**0.011**	0.503	**0.003**	**0.027**	0.104	**0.015**
3	0.126	**0.026**	0.858	0.056	0.571	0.641	0.158	0.923	0.051	**0.002**	0.287	0.198
4	0.442	0.340	0.753	0.340	0.897	0.392	0.474	0.918	0.415	**0.004**	0.796	0.464
5	0.991	**0.027**	0.140	0.064	0.904	0.141	**0.019**	0.373	0.121	0.610	0.143	0.356
6	**0.005**	**0.005**	0.237	**0.014**	0.059	0.125	**0.040**	0.848	**0.002**	**0.000**	0.292	**0.024**
7	0.163	**0.040**	0.373	0.114	0.615	0.598	0.268	0.225	0.076	**0.025**	0.252	0.404
8	0.131	**0.014**	0.482	0.077	0.943	0.386	**0.049**	0.108	**0.027**	**<0.001**	0.598	0.304
9	0.081	**0.009**	0.422	**0.044**	0.422	0.127	**0.044**	0.814	**0.032**	**0.015**	0.340	0.188
10	**0.001**	**0.042**	0.981	0.084	0.117	0.085	0.083	0.824	**0.018**	**0.006**	0.377	0.053
11	0.173	**0.033**	0.358	**0.048**	0.363	0.534	0.161	0.977	0.090	**0.020**	0.333	0.304
12	0.333	**0.017**	0.386	**0.033**	0.556	0.475	0.093	0.758	0.067	**0.009**	0.520	0.269
13	0.792	0.263	0.957	0.091	0.776	**0.044**	0.541	0.211	0.569	0.402	0.098	0.918
14	**0.010**	**0.003**	0.926	**0.006**	0.132	0.194	**0.022**	0.790	**0.004**	**0.003**	0.209	**0.016**
15	**0.050**	**0.008**	0.598	**0.028**	0.071	0.474	0.055	0.087	**0.021**	0.137	0.074	0.080
16	0.071	**0.001**	0.844	**0.001**	0.317	0.795	**0.022**	0.955	**0.004**	0.125	0.065	**0.019**
17	0.184	0.725	0.547	0.572	0.329	0.476	0.464	0.088	0.613	0.830	0.469	0.076
18	0.688	0.787	0.074	0.914	0.323	0.890	0.305	0.176	0.989	0.854	0.465	0.971
19	0.113	0.280	0.900	0.220	**0.043**	0.722	0.467	0.794	0.121	0.895	0.149	0.143
20	0.961	0.461	0.469	0.771	0.976	0.187	0.302	0.673	0.528	0.181	0.970	0.781
21	0.374	0.692	0.673	0.637	0.642	0.079	0.444	0.966	0.526	0.398	0.586	0.825
22	0.770	0.900	0.599	0.518	0.522	0.467	0.662	0.812	0.866	0.538	0.661	0.639
23	0.813	0.209	0.767	0.063	0.709	0.095	0.269	0.301	0.370	0.860	0.055	0.450
24	0.572	0.617	0.362	0.329	0.988	0.983	0.779	0.116	0.651	0.939	0.343	0.233
25	0.264	0.303	**0.035**	0.590	0.305	0.297	0.649	0.868	0.288	**0.000**	0.940	0.932
26	0.473	0.655	0.495	0.269	0.447	0.968	0.800	0.084	0.416	**0.049**	0.303	0.112
27	0.063	0.419	0.065	0.782	0.118	**0.020**	0.708	0.129	0.185	0.486	0.346	0.179
28	**0.002**	**<0.001**	**0.009**	**<0.001**	**0.042**	0.369	**<0.001**	0.463	**<0.001**	0.052	**<0.001**	**<0.001**
29	**0.045**	**<0.001**	**0.013**	**<0.001**	0.385	0.149	**<0.001**	0.205	**<0.001**	**0.036**	**0.004**	**0.003**
30	**0.041**	**<0.001**	0.074	**<0.001**	0.165	0.116	**<0.001**	0.245	**<0.001**	0.072	**<0.001**	**0.000**
31	**0.009**	**<0.001**	0.103	**<0.001**	0.115	**0.035**	**<0.001**	0.711	**<0.001**	0.207	**<0.001**	**<0.001**
32	0.594	**0.004**	0.869	0.063	**0.000**	0.107	**0.014**	0.112	**0.025**	0.830	**0.035**	0.407
33	0.112	0.748	0.202	0.300	0.098	**<0.001**	0.744	**0.001**	0.913	0.611	0.107	0.264
34	0.861	0.778	0.741	0.555	0.933	**<0.001**	0.906	0.100	0.612	0.987	**0.022**	0.949
35	**0.001**	**<0.001**	**0.009**	**<0.001**	**0.025**	0.201	**<0.001**	0.953	**<0.001**	0.338	**<0.001**	**<0.001**
36	0.637	**0.001**	**0.000**	**0.001**	0.669	0.227	**0.001**	0.113	**0.001**	**0.012**	**0.001**	**0.008**
37	**1**	**0.006**	0.830	**0.004**	**<0.001**	0.168	**0.016**	0.395	**<0.001**	**0.036**	**0.012**	**<0.001**
38	**0.453**	**1**	**0.014**	**<0.001**	0.055	0.108	**<0.001**	0.840	**<0.001**	0.331	**<0.001**	**<0.001**
39	0.037	**0.406**	**1**	**0.003**	0.817	0.972	**0.001**	0.685	**0.024**	0.354	**0.006**	**0.021**
40	**0.470**	**0.889**	**0.482**	**1**	**0.024**	0.895	**<0.001**	0.472	**<0.001**	0.964	**<0.001**	**<0.001**
41	**0.656**	0.322	-0.040	**0.376**	**1**	0.418	0.120	0.124	**0.003**	0.674	**0.019**	**0.002**
42	-0.235	-0.273	0.006	0.023	-0.139	**1**	0.161	**0.014**	0.215	0.257	0.115	0.232
43	**0.399**	**0.928**	**0.532**	**0.871**	0.264	-0.239	**1**	0.684	**<0.001**	0.367	**<0.001**	**<0.001**
44	0.146	-0.035	0.070	-0.124	0.261	**-0.408**	-0.070	**1**	0.943	0.170	0.999	0.651
45	**0.673**	**0.922**	**0.375**	**0.900**	**0.489**	-0.212	**0.889**	0.012	**1**	0.207	**<0.001**	**<0.001**
46	**-0.350**	-0.167	0.159	-0.008	-0.073	0.194	-0.155	0.234	-0.216	**1**	0.471	0.813
47	**-0.416**	**-0.741**	**-0.448**	**-0.819**	**-0.389**	-0.268	**-0.750**	0.000	**-0.767**	-0.124	**1**	**<0.001**
48	**0.798**	**0.716**	**0.383**	**0.776**	**0.500**	-0.204	**0.697**	0.078	**0.844**	-0.041	**-0.653**	**1**
49	**0.709**	0.044	-0.322	-0.035	**0.545**	**-0.431**	-0.100	**0.390**	0.205	**-0.401**	0.100	**0.375**
50	**-0.632**	**-0.480**	-0.107	**-0.637**	**-0.486**	-0.138	-0.321	-0.003	**-0.649**	0.184	**0.459**	**-0.663**
51	-0.314	**-0.691**	**-0.428**	**-0.752**	-0.296	-0.317	**-0.708**	0.018	**-0.692**	-0.129	**0.979**	**-0.536**
52	**0.676**	**0.746**	**0.446**	**0.783**	**0.495**	-0.165	**0.708**	0.206	**0.852**	0.154	**-0.761**	**0.903**
53	0.154	**0.421**	0.001	**0.342**	0.270	0.081	**0.379**	**-0.434**	**0.370**	**-0.338**	**-0.340**	0.108
54	0.073	0.321	**0.349**	**0.415**	0.252	**0.423**	**0.351**	**-0.420**	0.310	-0.100	**-0.486**	0.143
55	-0.049	-0.142	-0.230	-0.329	0.114	**-0.371**	-0.154	-0.130	-0.200	-0.315	**0.411**	-0.286
56	-0.202	**-0.657**	-0.313	**-0.752**	-0.160	**-0.477**	**-0.645**	**0.378**	**-0.650**	0.106	**0.844**	**-0.401**
57	-0.119	-0.284	-0.298	**-0.442**	-0.005	**-0.380**	-0.317	-0.125	-0.321	**-0.385**	**0.639**	**-0.383**
58	0.045	0.058	-0.106	-0.132	0.240	-0.295	0.074	-0.114	-0.016	-0.174	0.059	-0.118
59	-0.211	**-0.468**	-0.315	**-0.473**	-0.261	-0.173	**-0.520**	-0.067	**-0.428**	**-0.346**	**0.811**	**-0.397**
60	0.066	0.200	-0.046	0.089	0.232	-0.060	0.178	**-0.352**	0.145	**-0.335**	-0.061	-0.056
61	0.066	0.200	-0.046	0.089	0.232	-0.060	0.178	**-0.352**	0.145	**-0.335**	-0.061	-0.056

Numbers in the first column correspond to numbers in the first row; 1, overall aroma intensity; 2, gamey aroma; 3, beef-like aroma; 4, metallic aroma; 5, liver-like aroma; 6, herbaceous aroma; 7, off, sour, sweat-like aroma; 8, sweet-associated aroma; 9, overall flavour intensity; 10, gamey flavour; 11, beef-like flavour; 12, metallic flavour; 13, liver-like flavour; 14, herbaceous flavour; 15, off, sour, sweat-like flavour; 16, sweet associated taste; 17, salty taste; 18, sour taste; 19, initial juiciness; 20, sustained juiciness; 21, tenderness; 22, residue; 23, mealiness; 24, Warner-Bratzler shear force; 25, thaw loss percentage; 26, cooking loss percentage; 27, C6:0; 28, C8:0; 29, C10:0; 30, C12:0; 31, C14:0; 32, C15:0; 33, C16:0; 34, C18:0; 35, C20:0; 36, C22:0; 37, C24:0; 38, C14:1; 39, C15:1; 40, C16:1; 41, C17:1; 42, C18:1n9c; 43, C20:1; 44, C18:2n9c; 45, C18:3n6; 46, C18:3n3; 47, C20:2n6; 48, C20:3n6; 49, C20:3n3; 50, C20:5n3; 51, C22:2n6; 52, C22:6n3; 53, total SFA; 54, total MUFA; 55, total PUFA; 56, PUFA:SFA ratio; 57, n6; 58, n3; 59, n6:n3 ratio; 60, total fatty acids; 61, intramuscular fat content. The non-shaded area indicates Pearson correlation coefficients (*r*); area shaded in grey indicates corresponding P-values for Pearson correlation coefficients (*r*).

Table II Continued.

Variable	49	50	51	52	53	54	55	56	57	58	59	60	61
1	0.054	**0.001**	0.507	0.328	**0.003**	0.191	0.260	**0.040**	0.210	0.440	0.306	**0.026**	**0.026**
2	0.138	**0.004**	0.196	0.101	0.096	0.492	0.820	**0.037**	0.828	0.842	0.968	0.407	0.407
3	0.069	**0.005**	0.319	0.627	0.097	0.445	0.945	**0.042**	0.851	0.709	0.461	0.358	0.358
4	0.088	0.082	0.772	0.749	0.294	0.788	0.495	0.564	0.239	0.972	0.122	0.373	0.373
5	0.430	0.716	0.096	0.263	0.211	0.294	0.575	0.310	0.968	0.225	0.137	0.284	0.284
6	**0.003**	**0.000**	0.468	0.116	**0.045**	0.709	0.586	0.085	0.483	0.797	0.454	0.192	0.192
7	0.174	**0.024**	0.217	0.466	0.273	0.463	0.866	0.112	0.972	0.697	0.724	0.554	0.554
8	0.252	0.055	0.610	0.638	**0.007**	0.264	0.241	0.072	0.181	0.444	0.348	**0.038**	**0.038**
9	0.319	0.084	0.431	0.369	**0.037**	0.266	0.353	0.156	0.339	0.464	0.646	0.095	0.095
10	**0.042**	0.104	0.489	0.286	**0.021**	0.243	0.114	0.350	0.167	0.125	0.909	**0.035**	**0.035**
11	0.115	**0.024**	0.325	0.625	**0.023**	0.297	0.423	0.087	0.414	0.520	0.732	0.092	0.092
12	0.122	**0.009**	0.570	0.891	**0.041**	0.370	0.552	0.089	0.368	0.905	0.271	0.148	0.148
13	0.789	0.070	0.101	0.717	0.136	0.089	0.580	**0.013**	0.444	0.844	0.374	0.443	0.443
14	**0.023**	**0.001**	0.322	0.114	**0.042**	0.369	0.646	0.072	0.572	0.802	0.600	0.170	0.170
15	0.216	0.053	0.100	0.224	0.053	0.098	0.557	0.135	0.710	0.454	0.746	0.128	0.128
16	0.188	**0.000**	0.103	0.106	0.073	0.284	0.634	**0.011**	0.797	0.507	0.720	0.401	0.401
17	0.190	0.982	0.768	0.469	0.102	0.239	0.196	0.491	0.169	0.335	0.388	0.102	0.102
18	0.054	0.084	0.422	0.943	0.894	0.678	0.734	0.449	0.437	0.801	0.210	0.983	0.983
19	0.302	0.234	0.176	0.122	0.554	0.747	0.138	0.440	0.091	0.331	0.153	0.295	0.295
20	0.710	0.322	0.873	0.693	0.056	0.561	0.061	0.654	0.131	**0.047**	0.870	0.052	0.052
21	0.846	0.271	0.523	0.956	0.273	0.611	**0.041**	0.470	0.067	0.054	0.675	0.111	0.111
22	0.390	0.261	0.685	0.555	0.134	0.198	**0.037**	0.817	0.062	**0.049**	0.629	**0.049**	**0.049**
23	0.936	0.166	**0.044**	0.309	0.893	0.762	**0.047**	**0.023**	**0.027**	0.178	0.131	0.429	0.429
24	0.121	0.128	0.378	0.243	0.132	0.277	**0.049**	0.760	0.072	0.069	0.558	0.060	0.060
25	**0.010**	0.085	0.970	0.635	0.132	0.902	0.357	0.384	0.239	0.652	0.280	0.246	0.246
26	0.416	0.079	0.420	**0.035**	0.095	0.338	**0.029**	0.972	**0.031**	0.071	0.574	**0.042**	**0.042**
27	**0.000**	**0.033**	0.222	0.166	0.640	0.095	0.577	0.104	0.312	0.930	0.181	0.796	0.796
28	0.658	**0.002**	**<0.001**	**<0.001**	**0.002**	**0.005**	0.925	**<0.001**	0.467	0.485	**0.037**	0.052	0.052
29	0.936	0.084	**0.009**	**0.008**	**0.001**	**0.013**	0.455	**0.002**	0.824	0.204	0.151	**0.019**	**0.019**
30	0.870	**0.031**	**0.000**	**0.001**	**0.000**	**0.014**	0.755	**<0.001**	0.643	0.222	**0.031**	**0.020**	**0.020**
31	0.563	**0.003**	**0.000**	**<0.001**	**0.014**	0.180	0.637	**0.000**	0.287	0.742	**0.047**	0.233	0.233
32	0.695	0.757	**0.033**	0.115	0.059	0.245	0.364	0.184	0.979	0.061	**0.037**	0.116	0.116
33	**0.003**	0.616	0.060	0.179	**0.043**	**0.037**	0.216	**<0.001**	0.193	0.349	0.545	0.445	0.445
34	0.348	0.079	**0.008**	0.575	0.351	0.061	0.055	**0.000**	**0.025**	0.232	0.181	0.923	0.923
35	0.616	**0.000**	**<0.001**	**<0.001**	**0.016**	**0.044**	0.263	**<0.001**	**0.049**	0.945	**0.004**	0.327	0.327
36	0.278	0.398	**0.001**	**<0.001**	0.389	0.826	**0.012**	0.072	**0.001**	0.215	**0.002**	0.103	0.103
37	**<0.001**	**<0.001**	0.062	**<0.001**	0.370	0.673	0.777	0.237	0.491	0.794	0.217	0.700	0.700
38	0.797	**0.003**	**<0.001**	**<0.001**	**0.011**	0.056	0.410	**<0.001**	0.093	0.738	**0.004**	0.243	0.243
39	0.056	0.535	**0.009**	**0.006**	0.996	**0.037**	0.177	0.063	0.077	0.536	0.062	0.788	0.788
40	0.838	**<0.001**	**<0.001**	**<0.001**	**0.041**	**0.012**	0.050	**<0.001**	**0.007**	0.442	**0.004**	0.607	0.607
41	**0.001**	**0.003**	0.079	**0.002**	0.112	0.138	0.508	0.351	0.978	0.159	0.124	0.172	0.172
42	**0.009**	0.423	0.060	0.336	0.638	**0.010**	**0.026**	**0.003**	**0.022**	0.081	0.313	0.728	0.728
43	0.563	0.056	**<0.001**	**<0.001**	**0.023**	**0.036**	0.371	**<0.001**	0.060	0.669	**0.001**	0.299	0.299
44	**0.019**	0.985	0.919	0.229	**0.008**	**0.011**	0.448	**0.023**	0.466	0.508	0.700	**0.036**	**0.036**
45	0.231	**<0.001**	**<0.001**	**<0.001**	**0.027**	0.066	0.243	**<0.001**	0.056	0.925	**0.009**	0.400	0.400
46	**0.015**	0.282	0.452	0.370	**0.044**	0.560	0.061	0.537	**0.020**	0.311	**0.039**	**0.046**	**0.046**
47	0.563	**0.005**	**<0.001**	**<0.001**	**0.043**	**0.003**	**0.013**	**<0.001**	**<0.001**	0.734	**<0.001**	0.723	0.723
48	**0.024**	**<0.001**	**0.001**	**<0.001**	0.529	0.406	0.090	**0.015**	**0.021**	0.491	**0.017**	0.746	0.746
49	**1**	**0.007**	0.309	0.110	0.533	0.065	0.456	0.077	0.346	0.707	0.393	0.782	0.782
50	**-0.443**	**1**	**0.031**	**<0.001**	0.360	0.261	0.052	**0.002**	0.121	**0.038**	0.856	0.809	0.809
51	0.174	**0.359**	**1**	**<0.001**	**0.040**	**0.002**	**0.015**	**<0.001**	**<0.001**	0.833	**<0.001**	0.694	0.694
52	0.271	**-0.624**	**-0.678**	**1**	0.641	0.394	**0.029**	**0.004**	**0.002**	0.473	**0.000**	0.540	0.540
53	-0.107	-0.157	**-0.344**	0.080	**1**	**<0.001**	**<0.001**	**0.001**	**0.006**	**<0.001**	0.264	**<0.001**	**<0.001**
54	-0.311	-0.192	**-0.490**	0.146	**0.845**	**1**	**0.028**	**<0.001**	0.264	**0.001**	0.062	**<0.001**	**<0.001**
55	0.128	0.326	**0.403**	**-0.364**	**0.618**	**0.366**	**1**	**0.043**	**<0.001**	**<0.001**	0.112	**<0.001**	**<0.001**
56	0.298	**0.495**	**0.854**	**-0.465**	**-0.520**	**-0.612**	**0.340**	**1**	**0.003**	0.520	**0.001**	0.227	0.227
57	0.162	0.263	**0.644**	**-0.508**	**0.446**	0.191	**0.937**	**0.478**	**1**	**<0.001**	**0.000**	**<0.001**	**<0.001**
58	0.065	**0.347**	0.036	-0.124	**0.722**	**0.517**	**0.903**	0.111	**0.697**	**1**	0.335	**<0.001**	**<0.001**
59	0.147	-0.031	**0.847**	**-0.565**	-0.191	-0.314	0.269	**0.521**	**0.585**	-0.166	**1**	0.891	0.891
60	-0.048	0.042	-0.068	-0.106	**0.938**	**0.769**	**0.843**	-0.207	**0.697**	**0.876**	-0.024	**1**	**<0.001**
61	-0.048	0.042	-0.068	-0.106	**0.938**	**0.769**	**0.843**	-0.207	**0.697**	**0.876**	-0.024	**1.000**	**1**

Numbers in the first column correspond to numbers in the first row; 1, overall aroma intensity; 2, gamey aroma; 3, beef-like aroma; 4, metallic aroma; 5, liver-like aroma; 6, herbaceous aroma; 7, off, sour, sweat-like aroma; 8, sweet-associated aroma; 9, overall flavour intensity; 10, gamey flavour; 11, beef-like flavour; 12, metallic flavour; 13, liver-like flavour; 14, herbaceous flavour; 15, off, sour, sweat-like flavour; 16, sweet associated taste; 17, salty taste; 18, sour taste; 19, initial juiciness; 20, sustained juiciness; 21, tenderness; 22, residue; 23, mealiness; 24, Warner-Bratzler shear force; 25, thaw loss percentage; 26, cooking loss percentage; 27, C6:0; 28, C8:0; 29, C10:0; 30, C12:0; 31, C14:0; 32, C15:0; 33, C16:0; 34, C18:0; 35, C20:0; 36, C22:0; 37, C24:0; 38, C14:1; 39, C15:1; 40, C16:1; 41, C17:1; 42, C18:1n9c; 43, C20:1; 44, C18:2n9c; 45, C18:3n6; 46, C18:3n3; 47, C20:2n6; 48, C20:3n6; 49, C20:3n3; 50, C20:5n3; 51, C22:2n6; 52, C22:6n3; 53, total SFA; 54, total MUFA; 55, total PUFA; 56, PUFA:SFA ratio; 57, n6; 58, n3; 59, n6:n3 ratio; 60, total fatty acids; 61, intramuscular fat content. The non-shaded area indicates Pearson correlation coefficients (*r*); area shaded in grey indicates corresponding P-values for Pearson correlation coefficients (*r*).