The effect of age and sex on meat quality characteristics of blue wildebeest (*Connochaetes taurinus*)

by

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DECLARATION

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SUMMARY

Selective culling has become a popular practice for intensive to semi-extensive wildlife farms. However, some game farmers remain hesitant to cull surplus, older cows and young heifers and bulls for meat production due to the uncertainties regarding the meat quality of these animals. Therefore, this research aimed to quantify the effect of age and sex on various carcass characteristics and meat quality parameters of blue wildebeest (*Connochaetes taurinus*) meat to provide baseline data for the Wildlife industry of South Africa. The latter was achieved by collecting data of the carcass characteristics, including muscle-, internal- and external offal yields, as well as the body condition score (BCS) of the dressed carcasses. The physical quality (ultimate pH (pH_U), drip- and cooking loss, colour and shear force) and chemical composition (moisture, protein, fat and ash content) of six muscles (*Longissimus thoracis et lumborum (*LTL), *biceps femoris* (BF), *semimembranosus* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS)) of blue wildebeest were also determined.

The study included a total of 32 blue wildebeest, comprising of two trials. The first trial consisted of 24 blue wildebeest females who were categorised into three age groups (1.5-, 4.5- and >6.5-years old). The trial included eight females of each age group which were culled from a semi-extensive production system in the Central Bushveld region located on the outskirts of the Modimolle region in the Limpopo, South Africa. When the effect of age on carcass yields was investigated, the 4.5-year old cows had the heaviest dead weights (203.63 ± 9.54 kg), total internal- (55.84 ± 2.87 kg) and total offal weights (88.83 ± 5.75 kg). However, no differences were recorded between the cold carcass weights (100.15 ± 10.01 kg >6.5-year old; 105.45 ± 6.82 kg 4.5-year old), dressing percentage (53.10 ± 3.55 % >6.5-year old; 51.78 ± 1.99 % 4.5-years old), total external offal weights (33.29 ± 2.26 kg >6.5-years old; 33.38 ± 2.84 kg 4.5-years old), individual muscle weights, as well as for the BCS of the two older age groups. The 1.5-year old heifers were associated with the lightest carcass yields and lower BCS in comparison to the older age groups. A significant age effect was also observed for the physical parameters measured for the six muscles of blue wildebeest females. The oldest age group was associated with the highest pH_U values for all six muscles, and for some muscles (LTL, ST and IS) the pH_U was higher than 5.9 which could result in dark-firm-dry (DFD) meat. Many of the muscles of the two older age groups showed tendencies of lower drip loss than the heifers, while the heifers exhibited higher cooking loss for the LTL, BF and ST muscles than the >6.5-year old cows. An age effect was observed for the shear force values of the six muscles. The heifers had significantly lower shear force values for the LTL, IS and SS muscles than the 4.5-year old cows. The muscles of the 4.5-year old cows exhibited more vivid colour (high chroma-, a* and b* values) than the other age groups, while the youngest animals had significantly lighter (high L* values) and less red (high hue-angle) muscles. Furthermore, age

had little effect on the basic chemical composition of the muscles investigated. The heifers had higher moisture content in the ST, IS and SS muscles than the older animals, but the differences were less than 1.5 %. Age had a negligible effect on the protein content and the ash content of the muscles of the blue wildebeest females. The oldest cows (>6.5-years old) had higher fat content in the LTL (1.7 ± 0.14 %), BF (1.7 ± 0.09 %) and SS (2.1 ± 0.15 %) muscles than the younger females, however, the differences were negligible (<0.5% differences).

The second trial included eight additional 1.5-year old blue wildebeest bulls that were compared to the 1.5-year old heifers from the first trial. Sexual dimorphism was observed for most of the carcass yields (dead-, cold carcass weight, dressing percentage, total offal yields, muscles weights and the BCS) for which the bulls recorded heavier weights than the heifers. Sex also had a significant effect on the physical quality of the six muscles investigated in this trial. The bulls had higher pH_U values for four of the muscles than the heifers for which two muscles (LTL and ST) exhibited pH_U >5.9 (DFD meat). The heifers had higher drip loss in three muscles (LTL (2.4 ± 0.61 %), SM (3.6 ± 1.05 %) and SS (1.5 ± 0.25 %)) than the bulls, while only two muscles (BF (42.0 ±1.25 %) and ST (42.1 ± 0.91 %)) of the heifers showed higher cooking loss than the bulls. Sex had little effect on the shear force values of the six muscles of the bulls and heifers. Furthermore, the muscles located in the hindquarters of the bulls were darker (low L* values and high myoglobin content (g/100g)) and redder (lower hue-angle values) than that of the heifers. The BF and ST muscles of the bulls were associated with lower metmyoglobin- (MMb) and higher oxymyoglobin (OMb) percentages than the heifers. With regards to the chemical composition of the six muscles of the bulls and heifers, the heifers exhibited higher moisture content and lower protein content in the SM and ST muscles (<1 % difference). Furthermore, sex had a negligible effect on the fat- and ash content of the muscles of bulls and heifers.

Therefore, it was concluded that the older surplus blue wildebeest cows and young blue wildebeest bulls can be harvested for meat production due to their high carcass yields and desired physical- and chemical meat quality of the six muscles (excluding those exhibiting DFD characteristics) investigated.

OPSOMMING

Intensiewe en semi-ekstensiewe wildplase beskou selektiewe uitskot as 'n waardevolle hulpmiddel om optimale opberengste van ‘n kudde te verseker. Wildboere huiwer egter om surplus, ouer koeie en jong bulle vir vleisproduksie te oes weens die onsekerhede met betrekking to die vleiskwaliteit van hierdie diere. Die doelwit van hierdie navorsing was om die invloed van ouderdom en geslag op verskillende karkaseienskappe en die vleiskwaliteit van blouwildebees (*Connochaetes taurinus*) te kwantifiseer om data vir die wildbedryf van Suid-Afrika te voorsien. Hierdie doel was bewerkstellig deur data van die karkaseienskappe te versamel, insluitend spier-, interne- en eksterne afvalopbrengste, sowel as die liggaamskondisie (BCS) van die karkasse. Die fisiese (finale pH (pH_U), drup- en kookverlies, kleur en skeurkrag) en chemiese samestelling (vog, proteïen, intramuskulêre vet (IMF) en asinhoud) van ses spiere (*Longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF)), *semimembranosus* (SM), *semitendinosus* (ST), *infraspinatus* (IS) en *supraspinatus* (SS)) van blouwildebeeste is ook bepaal.

Die studie het 32 blouwildebeeste ingesluit, wat in twee proewe verdeel is. Die eerste proef het 24 vroulike blouwildebeeste bevat, wat uit drie ouderdomsgroepe (1.5, 4.5 en >6.5 jaar oud) bestaan het. Elke ouderdomsgroep het agt vroulike diere bevat wat vanuit 'n semi-ekstensiewe produksiestelsel in die Sentraal-Bosveldstreek, aan die buitewyke van die Modimolle-streek in Limpopo, Suid-Afrika, geoes is. Die 4.5 jarige koeie het die swaarste dooiegwig (203.63 ± 9.54 kg), totale interne afval- (55.84 ± 2.87 kg) en totale afvalgewigte (88.83 ± 5.75 kg) gehad. Geen verskille is egter aangeteken tussen die koue karkasgewig (100.15 ± 10.01 kg > 6.5 jaar oud; 105.45 ± 6.82 kg 4.5-jaar oud), uitslagpersentasie (53.10 ± 3.55 % >6.5 jaar oud; 51.78 ± 1.99 % 4.5 jaar oud), totale eksterne afvalgewigte (33.29 ± 2.26 kg >6.5 jaar oud; 33.38 ± 2.84 kg 4.5 jaar oud), individuele spiergewigte, sowel as vir die BCS van die twee ouer ouderdomsgroepe nie. Die 1.5 jarige verse het die ligste karkasopbrengste en laagste BCS gehad in vergelyking met die twee ouer ouderdomsgroepe. 'n Beduidende ouderdomseffek was ook waargeneem vir die fisiese vleiskwaliteitskenmerke van die ses spiere van die vroulike blouwildebeeste. Die koeie van die oudste ouderdomsgroep het die hoogste pH_U waardes vir al ses spiere gehad, en vir sommige spiere (LTL, ST en IS) was die pH_U hoër as 5.9, wat kan lei tot donker, ferm, droë vleis (DFD-kenmerke). Die meerderheid van die spiere van die twee ouer ouderdomsgroepe het 'n neiging tot laer drupverliespersentasies as die verse getoon, terwyl die verse hoër kookverliespersentasies vir die LTL, BF en ST spiere as die >6.5 jarige koeie gehad het. Ouderdom het ‘n klein effek op die skeurkragwaardes van die ses spiere van die vroulike diere gehad. Die verse het egter laer skeurkragwaardes vir die LTL, IS en SS spiere as die 4.5 jarige koeie getoon. Die spiere van die 4.5 jarige koeie het ‘n meer helder kleur (hoë chroma-, a*- en b* waardes) gehad as

die ander ouderdomsgroepe, terwyl die spiere van jongste diere aansienlik ligter (hoë L* waardes), en minder rooi (hoë kleurtoon) was. Weining ouderdoms invloed was waargeneem vir die basiese chemiese samestelling van die ses spiere. Die verse het 'n hoër voginhoud in die ST, IS en SS spiere as die ouer diere gehad, nietemin, die verskille was minder as 1.5 %. Ouderdom het ‘n weglaatbare invloed op die proteïeninhoud en die asinhoud van die spiere van die vroulike blouwildebeeste gehad. Die oudste koeie (>6.5 jaar oud) het 'n hoër vetinhoud in die LTL (1.7 ± 0.14 %), BF (1.7 ± 0.09 %) en SS (2.1 ± 0.15 %) spiere as jonger ouderdomsgroepe gehad, die verskille was egter weglaatbaar (<0.5 % verskille).

Die tweede proef het agt bykoomende 1.5 jarige blouwildebees bulle ingesluit wat met die 1.5 jarige verse van die eerste proef vergelyk was. Seksuele dimorfisme was waargeneem vir meeste van karkasopbrengste (dooie, kouekarkasgewig, uitslagpersentasie, totale afvalopbrengste, spiergewigte en die BCS) waarvoor die bulle swaarder gewigte as die verse getoon het. Geslag het ook 'n beduidende invloed op die fisiese vleiskwaliteit van die ses spiere gehad. Die bulle het hoër pH_U waardes as die verse getoon in vier van die spiere, waarvoor twee spiere (LTL en ST) pH_U >5.9 (DFD-kenmerke) gehad het. Die verse het hoër drupverliespersentasies vir drie spiere (LTL (2.4 ± 0.61 %), SM (3.6 ± 1.05 %) en SS (1.5 ± 0.25 %)) as die bulle gehad, terwyl slegs twee spiere (BF (42.0 ± 1.25 %)) en ST (42.1 ± 0.91 %) van die verse hoër kookverliespersentasies as die bulle getoon het. ‘n Weglaatbare geslagseffek was opgemerk vir die skeurkragwaardes van die ses spiere van bulle en verse. Verder was die spiere in die agterkwartte van die bulle donkerder (lae L* waardes en hoë mioglobieninhoud (g/100 g)) en rooier (laer kleurtoon) as dié van die verse. Die BF en ST spiere van die bulle het laer metmioglobien (MMb) en hoër oksimioglobien (OMb) persentasies as die verse gehad. Met betrekking tot die chemiese samestelling van die ses speiere van die bulle en verse, het die verse hoër voginhoudpersentasies en laer proteïeninhoudpersentasies vir die SM en ST spiere (<1 % verskil) getoon. Verder het geslag 'n weglaatbare effek op die vet- en asinhoud van die spiere van die bulle en verse gehad.

Die navorsing het bevestig dat die ouer, surplus blouwildebees koeie en jong bulle geskik is vir vleisproduksie as gevolg van die hoë karkasopbrengste en die gewenste fisiese- en chemiesevleiskwaliteit van die ses spiere (uitgesonderd die wat DFD-kenmerke toon) wat in die studie ondersoek is.

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ABBREVIATIONS

Abbreviation	Expansion
˚C	Degree Celsius
3n	Omega-3 polyunsaturated fatty acid
6n	Omega-6 polyunsaturated fatty acid
%	Percentage
π	Pi
Φ	Diameter
ANOVA	Analysis of Variance
BF	*Biceps femoris* muscle
CIE	International Commission on Illumination
DMb	Deoxymyoglobin
DFD	Dark, firm and dry meat
FA	Fatty acid
g	Gram
GIT	Gastro-intestinal tract
hrs	Hours
ha	Hectare
IMF	Intramuscular fat
IS	*Infraspinatus* muscle
kg	Kilogram
LSMeans	Least squares means
LTL	*Longissimus thoracis et lumborum* muscle
m	Metre
Mb	Myoglobin
mg	Milligram
min	Minute
ml	Millilitre
mm	Millimetre
MMb	Metmyoglobin
MUFA	Monounsaturated fatty acids
N	Newton
n	Number
OMb	Oxymyoglobin
PUFA:SFA	Polyunsaturated to saturated fatty acid ratio
pH_U	Ultimate pH
PUFA	Polyunsaturated fatty acid
r	Pearson's correlation coefficient
SFA	Saturated fatty acids

SM	*Semimembranosus* muscle
SS	*Supraspinatus* muscle
ST	*Semitendinosus* muscle
v/v	Volume per volume
WHC	Water-holding capacity
WBSF	Warner-Bratzler shear force
µl	Microliter
µm	Micrometre

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CHAPTER 1
GENERAL INTRODUCTION

1.1 BACKGROUND

In recent years, South Africa has been experiencing climate change which has led to a decline in water resources and increased temperatures, consequently posing a challenge to food security (Dzama, 2016). It is reported that temperatures may rise by more than 6°C over the western central and northern parts of South Africa by the year 2100 (DEF, 2018). Climate change has a major effect on the agricultural sector for which a 9-21% decline in productivity has been predicted in developing countries by the year 2050 (Misselhorn et al., 2012). In South Africa, red meat production accounts for 45 % of agricultural entities which has been challenged especially by climate change as well as desertification, aggravated by overgrazing which results in increased bush encroachment (Otieno & Muchapondwa, 2015; Saayman, Rossouw & Krugell, 2012; AgriSeta, 2018). The latter poses a challenge for commercial beef production in regions such as the bushveld of South Africa (Van Der Merwe, Saayman & Krugell, 2010). As a result of the aforementioned challenges, reduced production performance may occur as well as increased parasites in areas where high temperatures and moisture are combined (Dzama, 2016). Beef production is the highest in provinces such as Free State (17 %), Eastern Cape (25 %), Kwazulu-Natal (19 %) and North West (12 %) whilst sheep are mostly farmed within the Eastern Cape (29%), Northern Cape (25 %), Free State (20 %) and Western Cape (12 %) (DAFF, 2018). South Africa can be classified as a semi-arid to an arid country with large parts of the country comprising of Grassland, Savanna and Nama-karoo biomes (Rutherford, Mucina, & Powrie, 2006). Most of the red meat producing provinces overlaps with these biomes. It is therefore necessary to investigate alternative, well-adapted red meat species that can utilise these vegetation types to aid in the addressing of food insecurity (Cawthorn & Hoffman, 2014).

A noticeable transformation from commercial livestock to farming with indigenous wildlife species has occurred in South Africa (2-2.5% conversion rate per annum during the past decade) (Patterson & Khosa, 2005). In the year 2016, 18.7 million ha of the land in South Africa (15.3% of land) was utilised for wildlife ranching (DEF, 2018). Large parts of the Limpopo province (3 325 652 ha) is used by game farming and the same tendency has been reported for the Northern Cape (4 852 053 ha) and Eastern Cape (881 633 ha) (Pasmans & Hebinck, 2017; Van der Merwe & Saayman, 2012). This transformation has been considered as one of the most successful agricultural transformations in Africa's recent history.

1.2 MOTIVATION FOR RESEARCH

The wildlife industry has evolved into a profitable sector generating R10.1 billion total revenue which is categorised into four main subsectors (live sales, hunting, ecotourism and processed game products). Currently, local hunting activities account for 30 % of the total revenue of the wildlife industry followed by processed meat products (12 %) and live sales (10 %) (DEA, 2018). Processed game meat products are generating a total of R1.2 billion per annum. The game meat producing sector has the potential to grow even further and should not only focus on producing similar products to domestic livestock, but to market a niche product (Slabbert & Saayman, 2018). Game meat could be considered as a suitable alternative to red meat derived form domestic livestock due to its low intramuscular fat (IMF) (< 3 %) and cholesterol (49.75-59.34 mg/g) contents and high protein content (20-24 %) which conforms to the health-conscious consumer's demands (Hoffman, 2000; Hoffman, Kroucamp & Manley, 2007; Hoffman, Kritzinger & Ferreira, 2005; Van Zyl & Ferreira, 2004). In addition, game meat can be marketed as "organic" due to the absence or limited use of chemical production enhancers such as growth stimulants (Hoffman & Wiklund 2006). Irrespective of how meat is marketed, the physical and chemical attributes thereof are essential factors that influence consumer choice. Both extrinsic and intrinsic factors affect these attributes for which various methods are used to measure the impact of these factors on meat quality. Physical quality parameters measured on meat include; colour, water-holding capacity (WHC), and tenderness. Previous studies have shown that the variability in both the chemical and physical characteristics of meat can be attributed to animal maturity, sex, diet and anatomical location of the muscle (Lawrie & Lenard, 2006). Numerous studies have been conducted to establish the optimum age at which to slaughter livestock species such as pigs, poultry, cattle and sheep. However, limited research is available on the optimum culling age of game species to produce quality meat products. Current research on the meat production potential of South African wildlife species has focused on providing baseline data by profiling and comparing the meat quality of specific species.

The blue wildebeest (*Connochaetes taurinus*) has been a popular game species sold at auctions. The species' popularity may be attributed to its high population growth (29-35 % annual increase), possibly as a result of its hardiness, adaptability, fertility as well as its resistance to most tropical diseases (Furstenburg, 2002). The golden- and king wildebeest are two colour variants of the blue wildebeest which has led to increased value of blue wildebeest split cows carrying the recessive genes responsible for the unique colours (F1 generation). F1 cows will hypothetically produce 10 % golden offspring, F2 and F3 cows will produce 30 % and 50 % golden calves respectively (Strauss & Willemse, 2015). In 2015, blue wildebeest bulls (1 669 animals sold) and cows (929 animals sold) were the most popular species sold at auctions. However the average price of blue wildebeest cows (R3 566) were far less than that received for species such as kudu (*Tragelaphus strepsiceros*) cows (R12 108), buffalo (*Syncerus caffer*) cows (R200 000), eland (*Taurotragus oryx*) cows (R8 673) and nyala (*Tragelaphus angasii*) ewes (R21 205) (DEA, 2018). In the year 2015, the price of blue wildebeest splits were considerably higher than that of the blue wildebeest. The average price paid for golden wildebeest F1 cows and heifers, F2 cows and heifers and F3 cows and heifers were R40 000, R60 000 and R80 000, respectively. However, the value of these colour variants has experienced a drastic drop in recent years, possibly due to colour variants becoming a common phenomenon. There is thus an increase in supply causing a decrease in price (Taylor, Lindsey & Davies-mostert, 2016).

Currently, the majority of game breeders have adequate numbers of colour variants and excess breeding stock which do not meet their high breeding selection criteria. Due to the extensive nature of the wildlife industry, as well as its dependence on natural vegetation as a food source, excess animals may limit the available vegetation. The latter requires that the excess animals be removed (sold as live animals or to hunters to be hunted) or harvested for meat. Selective harvesting has become a successful operation in the game farming industry as this allows the removal of specific underperforming animals. The focused breeding of particular animals, has led to farmers applying scientific based practices including individual tagging and record keeping. One such important measurement is the recording of an animal's age. Certain age groups are selected for harvesting for meat production, it is also recommended to cull young animals before the onset of winter months when food resources become limiting. Surplus males are also harvested to ensure more grazing for lactating and pregnant females. The implementation of selective culling maximizes the reproduction potential of a herd (Hoffman, 2013). Furthermore, these surplus animals enter the meat production chain at different ages which have led to farmers questioning the potential of these animals to produce quality meat products. Little research is available on the influence of age, as well as sex (of sub-adult blue wildebeest) on meat quality.

The aim of this study was to quantify the effect of age and sex on blue wildebeest carcass characteristics as well as on various physical and chemical parameters. The latter will be used to determine the quality of meat produced by blue wildebeest of various ages (1.5-, 4.5- and >6.5-years old) as well as young bulls (1.5-years old) culled in South Africa. The results may provide baseline data to farmers who have excess sub-standard breeding stock, which may include old and young females as well as young males, aspiring to cull these animals for meat production.

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CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

South Africa is regarded as a megadiverse country harbouring ±10 % of global plant, bird and freshwater fish diversity and ±6 % of global mammal and reptile diversity (Endangered Wildlife Trust, 2004). The latter has attracted international trophy hunters for whom approximately 65 species are available to be hunted (Saayman, van der Merwe & Saayman, 2018). Therefore, South Africa is the country which offers the highest number of wildlife species for trophy hunting. The industry has experienced tremendous growth, and at present 9000 commercial and private game farms cover approximately 20.5 million ha of land (±16.8 %) in South Africa (Taylor, Lindsey & Davies-Mostert, 2016). The wildlife industry is closely linked to conservation of wildlife species and contributes five million ha of non-protected areas towards conservation targets of the country. The industry is also experiencing a 3.5 % animal population net growth per year (DEA, 2018).

The game industry has further evolved into a specialized industry utilizing various management techniques to ensure sustainability, efficiency and ultimately, profitability. The implementation of intensive or semi-extensive production systems has become a widespread practice. These management systems enable wildlife farmers to selectively breed and feed their animals to ensure optimum growth and to increase profit generated from live sales (Taylor et al., 2016). Selective harvesting enables the farmer to cull surplus animals not complying with the breeding standards of the specific farm. Surplus males can be harvested to ensure an adequate amount of environmental recourses for lactating and pregnant females. Females not contributing to population growth may also be culled. The latter may also include a percentage of young animals before the onset of the dry winter months (Van Schalkwyk & Hoffman, 2010). The usage of supplementary feed, especially during the dry months, has also improved the production performance of these wildlife species. Some farms utilizing an intensive management system, improve the productivity of the animals by completely supplementing the pasture with a specially formulated diet (Taylor et al., 2016).

In addition to the increased animal productivity, the industry has also proven its profitability by generating R10.1 billion total revenue (DEA, 2018; Meissner, Scholtz, & Palmer, 2013). The industry generates profit from four sectors namely hunting, ecotourism, breeding and production (Van der Merwe, Saayman, & Krugell, 2010). The industry can further be divided into two primary forms of land use. Private nature reserves focus on ecotourism, while commercial game farms aim to produce wildlife for hunting and breeding purposes. The game farming industry utilizes wildlife species to produce meat, by-products, recreational activities and sport hunting (Kamuti, 2015). Fresh game meat offtakes are from trophy hunting, biltong hunting and culling. Taylor et al. (2016) have calculated the extrapolated carcass mass offtakes for all wildlife ranches in South Africa to be 11.52 million kg, 18.93 million kg and 9.70 million kg of meat from trophy-, biltong hunting and culling, respectively. Their study also concluded that R33/ha and R52/ha income were generated from game meat produced from trophy hunting and culling, respectively (Taylor et al., 2016). In the latest statistics, Saayman, van der Merwe & Saayman (2018) calculate that trophy hunting provides 17 000 work opportunities as well as contributing US$341 million to the South African economy. The study also showed that the average trophy hunter spends US$13 278.56 on game species, which accounts for 47 % of their spending (Table 2.1). The local hunting sector, meat processing and fresh game meat sub-sectors have generated R3.0 billion (3 % of the total revenue), R1.2 billion (1.2 % of the total revenue) and R200 million (0.2 % of the total revenue) total revenue, respectively (DEA, 2018). Slabbert and Saayman (2018) predicted the economic potential of processed and fresh game meat products for a scenario of 1 million consumers. Their predictions have shown that R2.4 billion and R2.8 billion could potentially be spent on processed and fresh meat products, respectively. The latter is equivalent to ±1 042.98 tons and ±1 644.33 tons of processed and fresh game meat that could potentially be sold (Slabbert & Saayman, 2018).

Table 2.1 The economic impact of trophy hunting on the South African economy.

Total spending by trophy hunters (US$)	214 850 926
Total impact on production (ZAR million)	5 389.516
Total impact on employment (total labour)	17 685
Total impact on income (ZAR million)	4 894.905

(Saayman, van der Merwe, & Saayman, 2018)

Currency exchange rate: 1 United States Dollar equals 14.48 South African Rand.

2.1.1 Harvesting of game meat

Due to the free-roaming nature of wild animals, live transport to formal abattoirs is impossible. Therefore, various methodologies have been developed to harvest wild species to minimize the stress experienced by the animals while increasing efficiency and profitability. The latter includes day harvesting, night harvesting, boma harvesting and helicopter harvesting (Hoffman, 2013). Wildlife farms utilize different harvesting methods to suit the terrain from which animals will be hunted. Helicopter harvesting has gained more attention due to the relatively quick and efficient nature thereof. The latter method allows farmers to access terrain where vegetation is dense which enables farmers to locate animals hiding in bushes. Helicopter harvesting is typically implemented on farms where selective harvesting or culling for meat production is the farmer's goals. Regardless of the efficiency, this method may inflict unnecessary high stress on the animals by forcing them into fences and/or bushes in an attempt to escape. Therefore, the meat of helicopter harvested animals is often associated with lower meat quality due to high ultimate pH (pH_U) after the adrenaline challenge resulting in dark-firm-dry (DFD) meat (Le Grange, 2006).

2.1.2 Challenges faced by the wildlife industry

Currently, expropriating farm land without compensation could pose challenges to the industry. If the expropriation without compensations is not executed correctly, investors may become reluctant to invest due to the higher risk levels. According to South Africa's Land and Agriculture Development Bank, the latter could cost the government R41 billion if it's forced to repay the state company's debt immediately. Ultimately, the latter may further contribute to a deterioration of the country's financial sustainability (Vollgraaff, 2018).

Illegal hunting for bush meat has emerged into a challenge for the wildlife industry of South Africa. The latter can confer a negative impact on the economic and social sectors of the country by threatening food security due to the loss of potentially sustainable supply of meat protein (Lindsey et al., 2015). Another challenge faced by wildlife framers is meat loss due to animals being wounded or not recovered during the harvesting process. Meat can also be wasted as a result of damage caused by the bullet and decreased meat quality (inedible) as caused by *ante-mortem* stress. As mentioned previously, fresh game meat comes from culling, trophy- and biltong hunting. Shooting of animals for trophies and biltong are generally conducted by hunters who prefer to aim for the animal's shoulder area since it gives the shooter a large, stationary target (Hoffman, 2013). Shot placement in the shoulder area will ensure that the head and neck of the animals stay intact for the hunter who desires to mount the heads of their trophies. However, the shot placement through the shoulders has proven to be very wasteful and could result in the weight-loss of one-fifth of the carcass (Von La Chavellerie & Van Zyl, 1971). The possibility of inexperienced hunters wounding animals exists and often results from aiming for the shoulder and hitting the gut or lower extremities of the animals. The latter will cause contamination of the carcass from the stomach and intestines, which is unacceptable for human consumptions, from a hygiene point of view (Van Schalkwyk & Hoffman, 2010). Proficient marksmen must operate the correct calibre rifle, which will ensure the correct shot placement (high neck or head) and consequently decrease meat losses. Hoffman (2000) has shown that no wastage occurred with a headshot while less than 2 % of meat is lost if the bullet hits the high neck area of an animal. Regardless of meat wastage through damage or contamination, various meat quality parameters must be investigated to ensure that the meat entering the food supply chain conforms to the high standards of the Meat Safety Act, No. 40 (South African Government, 2000).

2.2 MEAT QUALITY

Due to the drastic changes in the national and international meat market, 'meat quality' has become difficult to define as a result of its variability (Andersen, Oksbjerg, Young, & Therkildsen, 2005). Meat quality is often defined as the appearance-, eating satisfaction- and reliance traits associated with a specific product. The appearance quality traits refer to the colour, drip and purge, texture, as well as the amount and distribution of visible fat of the meat (Joo & Kim, 2011). The eating satisfaction traits include the tenderness, as well as the flavour, juiciness and aroma experienced while eating meat (Webb, Casey, & Simela, 2005; Joo & Kim, 2011). The appearance and eating quality traits are greatly influenced by intrinsic factors such as the species, age, sex, diet and anatomical location of the muscle of the animals.

Furthermore, reliance quality traits refer to the combination of the price, presentation and the origin of the meat products. The latter is predominantly influenced by extrinsic factors such as storage conditions and harvesting conditions (Andersen, Oksbjerg, Young, & Therkildsen, 2005; Joo & Kim, 2011). Meat quality is not solely based on the consumer's perception; several parameters can be measured to determine the quality of meat on a scientific basis (Webb et al., 2005). These parameters include carcass quality (carcass yield, body condition score (BCS) distribution of valuable cuts), physical measurements (water-holding capacity (WHC), colour and tenderness (Warner-Bratzler shear force)), the compositional quality (chemical composition) and the sensory profile of meat (juiciness, texture and aroma) (Mostert & Hoffman, 2007). A vast amount of research has investigated the intrinsic and extrinsic factors influencing the quality of meat of livestock. However, for this study, only the effect of age and sex on meat quality of the various game- and livestock species will be elaborated on.

2.2.1 Carcass characteristics

The carcass characteristics of an animal (carcass compositions and yield) need to be measured to determine meat production to calculate the value per animal. These characteristics include dead weight, carcass weight as well as internal- and external offal weights. The *post-mortem* BCS evaluation can aid in the estimation of the amount of fat visible on the carcass which ultimately affects the meat production potential of an animal (Pryce, Coffey & Simm, 2001). The BCS also functions as an indirect predictor of the intermuscular fat (IMF), the latter is known to have a high correlation with the eating (particularly flavour and juiciness) quality of the meat (North & Hoffman, 2014). The BCS is typically recorded on live animals and entails a visual or tactile method to measure the fat reserves in the back and pelvic regions of an animal (Ottom, Ferguson, Fox & Sniffen, 1991). However, the BCS can also be recorded after the dressing process is completed and consists of a scale from 1 to 5, where 1 indicates the lowest fatness level and a score of 5 is associated with the fattest animal (Pryce et al., 2001).

Generally, game carcasses are sold per animal or kilogram; therefore, the calculation of carcass yield should include most of the edible portions of the carcass. When beef carcasses are processed into wholesale cuts or primals, several muscles are included in these cuts. However, during the portioning and packaging of these cuts, the meat products may be derived from a single muscle (Lawrie & Ledward, 2006). These products that contain single muscles are regarded as economically valuable due to their better eating quality characteristics and high lean meat to bone ratio (Keane & Allen, 1998; Ledger, 1963). Therefore, individual muscles should also be investigated to determine the yield derived from specific muscles (Figure 2.1). The muscles located in the hindquarter of an animal (*biceps femoris* (BF) and *semimembranosus* (SM)) are known for exhibiting high growth rates as a result of high functional demands to provide maximum performance (Jones, 2004). The latter are of economic importance due to their high yields and quality attributes. According to Jones, Arnaud, Gouws, & Hoffman (2017), the *longissimus thoracis et lumborum* (LTL) muscle is popular for biltong production due to its elongated shape which allows for longer cuts along the muscle fibres. Whereas the *infraspinatus* (IS) and *supraspinatus* (SS) muscles, located in the shoulder of an animal, are classified as lower value cuts which are typically processed further into minced products (Berg & Butterfield, 1976). The yields of consumable internal - as well as external organs must also be included to fully utilize the carcass (Erasmus & Hoffman, 2017; Hoffman & Wiklund, 2006). The internal organs include the liver, kidneys, lungs and heart whereas the external organs include the head and horns, legs and skin (McCrindle, Siegmund-schultze, Heeb, Zarate, & Ramrajh, 2013; SANS, 2011). During commercial harvesting, these products remain undamaged and are sold as a low-cost protein source in South Africa (Erasmus & Hoffman, 2017).

Furthermore, carcass classification systems have been developed to characterize the yield and carcass traits of an animal (Polkinghorne & Thompson, 2010). Differences exist between the carcass processing techniques utilized in domestic and game species. It is, therefore, challenging to compare beef cuts to excised muscles used for quality analysis in game species. Beef carcasses in South Africa are classed into four age groups which are determined by the number of permanent incisors the animal possesses. These age groups include A (0 incisors), AB (1-2 incisors), B (2-6 incisors) and C (>6 incisors) (DAFF, 2015). Age group C carcasses are typically cull cows which were produced on the veld with the addition of supplementary feed to achieve optimal fatness (Hall, Schönfeldt, & Pretorius, 2016). In contrast to the latter, game species are typically classified into only adult and sub-adult categories due to the challenges of estimating age from phenotypic characteristics such as body size, horn (when present) size, tooth eruption, etc., however, with the intensive breeding of stud animals, these are individually marked and thus the age of the specific animal is now known. Adult animals represent reproductive animals (sexually mature) where sub-adult animals have not yet reached reproductive maturity. The age at which sexual maturity is reached varies among the different species within the game industry (Bothma, Van Rooyen & Du Toit, 2010). The latter often causes variability at which stage of the growth curve (at what age) the effect of sex is observed.

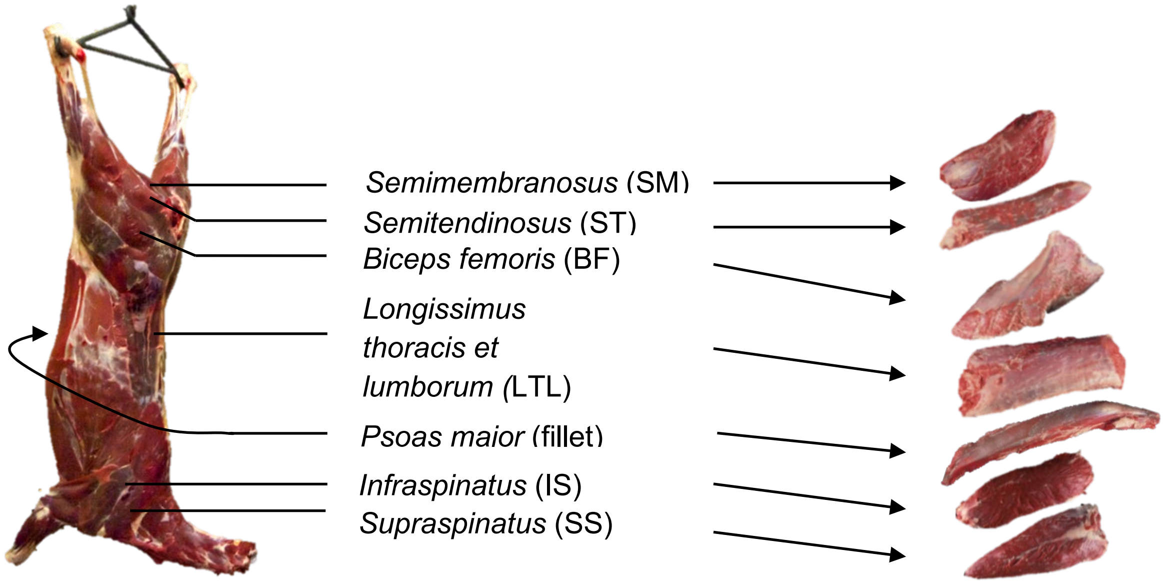

Figure 2.1 Lateral view of a dressed carcass as well the anatomical location and illustration of the seven muscles removed for analyses in this investigation (adapted from Jones, Guru, Singh, Carpenter, Calkins & Johnson (2004) and Raines (2011)).

2.2.1.1 The effect of age and sex on carcass characteristics

Older animals are generally associated with heavier carcass-, muscle-, internal- and external offal weights and exhibit increased proportion of fat and decreased proportions of muscle. The latter can be attributed to the change in morphology of the animal body at the different stages of the growth curve (Berg & Butterfield, 1976; Jones, 2004). Studies have also shown that the BCS of the animal changes with age (Renquist, Oltjen, Sainz, & Calvert, 2006). In mammals, large herbivore females only start producing offspring at two or three years of age (Flajšman, Jerina, & Pokorny, 2017). The low body condition of younger animals could thus be attributed to the relative proportional increase in growth at different times, as described by Berg & Butterfield (1976).

Research on beef reported heavier mean live weights, cold carcass weights and dressing percentages for 30-month old steers than 18-24-month old steers (du Plessis & Hoffman, 2004). Similar results were reported for the cold carcass weight of 18- and 22-month old Angus heifers (Lundesjö, Hessle, Johansson, Hunt, & Lundstrom, 2012). Studies on various game species also observed heavier dead weights and carcass weights for adults than sub-adults (Hoffman, Mostert, & Laubscher, 2009; Smit, Hoffman, & Muller, 2004; Van Heerden & Hoffman, 2018; Van Schalkwyk, Hoffman, & Muller, 2004; Żochowska-Kujawska, Kotowicz, Sobczak, Lachowicz, & Wójcik, 2019). A study on adult and sub-adult black- (*Connochaetes gnou*) and blue wildebeest (*Connochaetes taurinus*) attributed the differences in carcass weights to the differences observed in the carcass measurements such as carcass length, carcass depth and chest circumference (Van Schalkwyk et al., 2004). In most of the studies mentioned, age had a significant effect on the carcass weight of animals. However, few studies concluded differences between the dressing percentages of different age groups. It is, therefore, crucial to consider the various factors influencing the dressing percentage of an animal. These factors include the dressing techniques used, gut fill, fatness level and muscle conformation of an animal (Hoffman, 2000). Literature has also reported a significant age effect on head, skin and leg weights of various game species (Mostert & Hoffman, 2007; Van Heerden & Hoffman, 2018; Żochowska-Kujawska et al., 2019). Similar results were observed when the weights of the liver, kidneys, GIT (gastrointestinal tracts), lungs and heart (Attwell, 1982) of adult and sub-adult game species were compared (Hoffman et al., 2009; Van Heerden & Hoffman, 2018).

As depicted in Table 2.2, the majority of the studies on the game species mentioned above, only included two groups (adults and sub-adults). Thus, large age variation exists within the adult and sub-adult age groups which make it challenging to compare the results of different studies conducted on game species.

The body weight of an animal at the different stages of the growth curve is also affected by hormonal and environmental factors (Owens, Dubeski, & Hanson, 1993). Due to the extensive nature of the wildlife industry, males and females develop differently to fulfil their distinctive roles in their social organizations (Estes, 1991). As expected, and widely discussed in the literature, mammalian males are larger than females. Sexual dimorphism plays a prominent role in the development of an animal which refers to the morphological differentiation between sexually mature males and females (Fairbairn, 1997; Georgiadis, 1985). Males of dimorphic species tend to reach an asymptotic weight at a later stage than monomorphic species (Georgiadis, 1985). According to Clutton-brock, Tim, Albon & Guinness, (1986), sexual selection for increased body size and growth rate is a result of increased specific metabolism rates in males in comparison to females. For example, blue wildebeest cows continue to grow until five years of age, while bulls will continue to grow after the cow growth has reached a plateau (Furstenburg, 2013).

Table 2.2 Age classifications used in various studies conducted on game species to categorise animals into different age groups.

Species	Age classification			Source
	Lambs	Sub-adult	Adult	
Blue Wildebeest (*Connochaetes taurinus*)	-	16- to 28-months old	40-months to >4-years old	#1
Black Wildebeest *(Connochaetes gnou)*	-	Non reproductive	reproductive	#2
Blesbok *(Damaliscus dorcas phillipsi)*	No horns/ straight horns	Horns of intermediate size	Fully developed horns	#3
Kudu (*Tragelaphus strepsiceros*)	-	< 34-months old	> 34-months old	#4
Impala *(Aepyceros melampus)*	-	Animals that have not yet established permanent dentition	Permanent dentition	#4
Springbok *(Antidorcas marsupialis)*	0 to 1-year	1- to 2-years old	2- to 5-years old	#5
Warthog *(Phacochoerus africanus)*	-	< 35 kg without tusk protrusion past the flanges of the lip	all the other animals	#6

#1Van Heerden & Hoffman, 2018, #2Van Schalkwyk et al., 2004, #3Smit et al., 2004, #4Mostert & Hoffman, 2007, #5Hoffman et al., 2007, #6Swanepoel et al., 2016.

According to Hossner (2005), males and females have different levels of various types of sex hormones which play a crucial role in the growth rate and patterns of the animal. The level of testosterone and growth hormone present in males and females also have different effects on the average daily gain (ADG) and feed conversion ratio (Hossner, 2005). Furthermore, the difference in growth rate and feed usage result in the production of carcasses with different fatness levels. Males can utilize feed better when compared to females, resulting in better performance in terms of growth (Crouse, Busboom, Field, & Ferrell, 1981; Seideman & Crouse, 1986). Females typically have a lower growth rate (kg/year) than males.

Literature investigating the effect of sex on adult game species such as the kudu (*Tragelaphus strepsiceros)* (Mostert & Hoffman, 2007), blesbok *(Damaliscus dorcas phillipsi)* (Smit et al., 2004), warthog (*Phacochoerus africanus*) (Swanepoel, Leslie, Rijst, &

Hoffman, 2016) and fallow deer (*Dama Dama L.*) (Fitzhenry, Hoffman, Cawthorn, & Muchenje, 2016) reported heavier dead- and carcass weights for males than females. Males also typically have heavier internal and external offal weights that are attributed to their larger body size (Renecker, Renecker & Mallor, 1998). Sexually mature males also exhibited bulkier muscles in the neck and thoracic region to assists them during the mating season (Jones, 2004), while sexually mature females tend to have higher muscle percentages in the more valuable hindquarters (Ledger, 1963).

2.2.2 Physical quality and sensory attributes of meat

Meat quality parameters can be measured using standardized methodologies to determine the acidity (pH), surface colour, water-holding capacity (WHC) and tenderness of meat (Honikel, 1998). The standardization of these methodologies enables meat producers to compare meat quality of animals from different species, origin, slaughter ages, sexes and production systems. These parameters will be elaborated on in the following section (2.2.2.1).

Sensory attributes, also known as eating quality traits of meat, can be directly linked to human senses such as appearance, smell, taste and mouth feel (Joo & Kim, 2011). The consumer's initial impression of meat includes the appearance of the meat (raw and cooked), after that cooked attributes such as texture, juiciness, aroma and flavour are experienced (Roberts & Acree, 1995). During the consumption of meat, the aroma could be experienced in two ways, namely retronasal aroma and orthonasal aroma. The retronasal aroma refers to the movement of flavorous molecules from the mouth area to the nasal cavity while orthonasal aroma can only be experienced through the nasal cavity through the external nostrils (Roberts & Acree, 1995). Therefore, meat aroma only includes orthonasal aroma, whereas flavour is described as the combined effect of taste and retronasal aroma (James & Calkins, 2008; Resconi, Campo, Montossi, Ferreira, Sanudo, & Escudero, 2012). Meat aromas include grassy, metallic, farm smell, woolly, fatty, sour, sweaty, earthy aromas. Meat flavours can be described as gamey, beef-like, sweet oily, metallic, liver-like, sour, salty and barnyard flavour (Van Heerden & Hoffman, 2018). The texture of meat refers to the disintegration of the muscle fibre into very small particles retained on the tongue within the first chews (Lawrie & Ledward, 2006). Meat texture can be characterized as mealiness, tenderness, chewiness, fattiness, fibrousness, stickiness, juiciness and residue (Gkarane, Allen, Gravador, Diskin, Claffy, Fahey, & Monahan, 2017). Juiciness can further be described as initial juiciness and sustained juiciness. Meat with higher IMF content tends to be juicier as a result of salivary production in the mouth (Joo & Kim, 2011). The aroma, flavour and juiciness of the meat directly intertwine with the aftertaste of the meat. The aftertaste of meat can be characterized as soapy, metallic, bloody, fatty, dry or astringent (Gkarane et al., 2017; Legako, Brooks, O'Quinn, Hagan, Polkinghorne, Farmer & Miller, 2015).

2.2.2.1 Effect of age on the physiological composition of muscles

Animal age affects muscle characteristics such as proportions of muscle fibre types and its cross-sectional area, IMF and connective tissue characteristics which are key factors influencing the physical quality of meat (Lawrie & Ledward, 2006). The variations in meat quality of different aged animals is also partly attributed to the difference in the degree at which muscles are influenced by physical activity at different stages of growth (Wegner et al., 2000).

Lefaucheur (2010) reported that age affects the proportion and functional characteristics of fibres of specific muscles. A study on fallow deer reported an increase in Type I- and a decrease in Type IIB muscle fibres in the BF, SM and LTL muscles with increased animal age (Table 2.3) (Żochowska-Kujawska et al., 2019). The differences in muscle fibre composition were attributed to the continual alteration that muscle fibres undergo, which reflects the constitution of the fibre at a particular age. Muscles of younger animals are generally associated with a more substantial proportion of white muscle fibres, possibly due to the increase in muscular size during the development stage (Ashmore & Addis, 1972; Schiaffino & Reggiani, 2011). Dreyer, Naudé, Henning & Rossouw (1977) also concluded a sharp increase in fibre diameter up to 12-months of age, after which it tapers off. The muscle fibre diameter of the SM muscle of beef increased from 25 μm at birth to 64 μm at 24-months of age. A similar trend was also observed for the change in the percentage of white fibres (Dreyer et al., 1977). A study on young (18-months) and spent (>10- years) water buffalo (*Bubalus bubalis*) males also confirmed a larger muscle fibre diameter in older buffaloes. Another study on male Binlangjang buffaloes of different ages reported larger muscle fibre diameter in the LTL muscle of older animals. The largest muscle fibre diameter was observed for the animals between 24- and 36-months of age (30.83 μm) when compared to the 3-month old buffaloes (11.06 μm).

In addition to muscle fibre composition, the connective tissue structure influences the tenderness (shear force) of meat (Purslow, 2005). Connective tissue is present in three layers in the muscle (epimysium, perimysium and endomysium). The endomysium surrounds each muscle fibre and is regarded as the most delicate layer of connective tissue (Shimokomaki et al., 1972). As depicted in Table 2.3, the thickness of the peri- and endomysium increases with animal age (Żochowska-Kujawska, Kotowicz, Sobczak, Lachowicz, & Wójcik, 2019).

Table 2.3 Mean percentage of muscle fibre type and structure elements of the *biceps femoris* (BF) and *Longissimus thoracis et lumborum* (LTL) muscle of fallow deer (*Dama Dama L.*) bucks as influenced by age (Żochowska-Kujawska et al., 2019).

Muscle	**Age (months)**	**Type I %**	**Type IIB %**	**Muscle fibre area** (μm^2)	**Perimysium thickness** (μm)	**Endomysium thickness** (μm)
BF	18	21.42[a]	59.01[c]	414.19[a]	11.60[a]	0.94[a]
	30	27.63[b]	59.8[c]	420.15[a]	11.89[a]	0.96[a]
	42	34.82[c]	53.71[b]	706.73[b]	14.14[b]	1.37[b]
	54	37.62[d]	51.90[a]	672.90[b]	15.02[b]	1.38[b]
LD	18	12.45[a]	67.44[b]	359.46[a]	9.62[a]	0.79[a]
	30	16.78[b]	67.51[b]	369.50[a]	9.84[a]	0.93[b]
	42	23.64[c]	62.51[a]	517.30[b]	12.80[b]	1.30[c]
	54	25.87[c]	63.31[a]	588.14[b]	12.94[b]	1.32[c]

[a,b,c] Different superscripts within a column for a specific parameter indicate significant differences ($p \leq 0.05$) between age groups.

Collagen is the most prominent protein found in connective tissue which makes up 1-15 % of the muscle tissue (Purslow, 2005). It has been reported that the growth of an animal influences the strength of connective tissue in the muscle. Changes may occur in the collagen fibril diameter as well as in the nature of the cross-linking bonds that bind the alpha chains (Lawrie & Ledward, 2006). These changes are attributed to the increase in the number of covalent cross-links between collagen molecules in the fibre with increasing animal age (Bailey, 1968; Bentley, 1979; Shimokomaki, Elsden, & Bailey, 1972). Shimokomaki et al. (1972) contributed valuable data to support this statement. Their study proposed that as the rate of synthesis of new collagen slows down, the collagen has time to stabilize; resulting in the formation of permanent, thermally stable cross-links producing insoluble collagen (Bailey, 1989; Hoffman, Mostert, Kidd, & Laubscher, 2009; Lepetit, 2007; Shimokomaki et al., 1972). Research on water buffaloes reported that older animals had lower collagen solubility and larger muscle fibre diameter than younger animals (Kandeepan, Anjaneyulu, Kondaiah, Mendiratta, & Lakshmanan, 2009). Another study on the change in collagen characteristics as the animal ages reported that 19-24 % of the total collagen is soluble in calves, whereas only 7-8 % solubility in 2-year old steers and noticeably lower solubility in old cows (2-3 %) were noted (Sharp, 1963). This phenomenon could be attributed to the higher activity of the inhibitor possibly caused by lower myofibril proteolysis in older animals (Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003).

2.2.2.2 The effect of age on physical quality and sensory attributes of meat

The physiology of a muscle influences the ultimate pH (pH_U) of that muscle/meat which in turn, affects the WHC, tenderness, colour as well as the shelf-life and eating satisfaction of fresh meat products (Hughes et al., 2014). The pH_U of meat is directly linked to the muscle glycogen levels at slaughter and provides valuable information on the physical qualities thereof (Hughes, Oiseth, Purslow, & Warner, 2014). Studies have shown an inverse relationship between the pH_U and the WHC of meat (Lawrie & Ledward, 2006). Furthermore, a tendency of a curvilinear relationship between the pH_U and shear force values (tenderness) of meat has been reported (Purchas & Aungsupakorn, 1993). It has been reported that tenderness decreases as the pH_U increases from 5.5 to 6.1, thereafter the shear force values decreases as the pH_U rise up to 7.0. There are speculations that latter could be attributed to the reduced activity of proteolytic enzymes between pH_U of 5.8-6.3, while the activity of calpains peak from a pH_U of 6.0-7.0 (Purchas & Aungsupakorn, 1993).

Muscles containing a higher proportion slow twitch, oxidative muscles (Type I) fibres, exhibit higher *post-mortem* pH for a longer period which could result in higher pH_U values (Lawrie & Ledward, 2006). White muscles with higher activity of glycolytic enzymes have higher *ante-mortem* glycogen content which leads to lower muscle pH_U (Klont et al., 1998). Muscles exhibiting high pH_U (>5.8) can lead to the occurrence of DFD meat (Viljoen, De Kock, & Webb, 2002). Game meat is often associated with DFD as a result of the stressful manner in which animals are hunted (Shange, Gouws, & Hoffman, 2019).

Various studies have reported a significant age effect on the pH_U of meat. Hopkins, Stanley, Martin, Toohey & Gilmour (2007) reported higher pH_U (6.0) values for the ST muscle of older sheep. They attributed the higher pH_U values to the decreased ability of older animals to withstand stress (Hopkins et al., 2007). In a study on Arabian camel (*Camelus dromedaries*) of different ages (1-3-years, 3-5-years and 6-8-years old), it was concluded that the proportion of red muscle fibres with low glycogen content increased with animal age which could explain the differences in pH_U (Kadim, Mahgoub, Al-Marzooqi, Al-Zadjali, Annamalai & Mansour, 2006). Muscles predominantly consisting of Type I (slow twitch, oxidative) fibres are more prone to glycogen depletion when stress is applied to the animal. Older cattle also tend to have reduced muscle glycogen concentration after an adrenaline challenge, such as being chased (Gardner, Martin, McGilchrist, & Thompson, 2005).

In contrast, Żochowska-Kujawska et al. (2019) reported significantly lower pH_U values of the BF and SM muscles of 54-month old animals in comparison to the 18- and 30-month old animals. They attributed the age differences to the manner in which the muscles are affected by physical activity, and thus by the fibre type distribution within the muscle.

Furthermore, studies on sub-adult and adult wildebeest bulls (Van Heerden & Hoffman, 2018), kudu (*Tragelaphus strepsiceros*), impala (*Aepyceros melampus*) (Mostert & Hoffman, 2007), blesbok (*Damaliscus pygargus phillipsi*) (Smit et al., 2004) and yearling and adult free-ranging white-tailed deer (*Odocoileus virginianus*) (Hewitt, Hellickson, Wester, & Bryant, 2014) also showed no differences between age groups when the pH_U was investigated.

As mentioned previously, animal age affects the proportion and functional characteristics of fibres of specific muscles (Lefaucheur, 2010). The latter could lead to increased WHC due to the muscle structure becoming less susceptible to post-slaughter changes as the age of the animal increases. The WHC of raw meat is influenced by the extent of sarcomere shortening, which refers to the shrinkage induced by *rigor* (Brewer, 2004; Ertbjerg & Puolanne, 2017). Ertbjerg & Puolanne (2017) described two possible reasons for the reduction in WHC; a reduction in WHC at a shorter sarcomere length could be attributed to the stronger pull created by the higher number of cross-bridges or because of longer distances between longitudinal filaments. As the age of an animal increase, the sarcomere also grows in length, but does not exceed 20 % of the length at birth (Ertbjerg & Puolanne, 2017; Ono, 2010). A study on 9-, 16-, 27- and 42-month old beef steers showed a linear increase in the sarcomere lengths of the LTL muscle as the animal age increased and concluded that the sarcomere lengths increased by 0.004μm with each month of age (Bouton, Ford, Harris, Shorthose, Ratclift & Morgan,1978). The latter also reported a linear decrease in cooking loss with increasing animal age (Bouton et al., 1978). The study did not report the pH_U values of the muscles of the different age groups, however it was reported that all the muscles had pH_U <5.8. Furthermore, an age effect was also observed in the drip loss and cooking loss of various muscles of game species such as blue wildebeest bulls (Van Heerden & Hoffman, 2018) and springbok (Hoffman, Kroucamp, & Manley, 2007b). The WHC of meat can also be influenced by the percentages of different fibre types present in the muscles, as well as the fibre area. According to Hwang, Kim, Jeong, Hur, & Joo (2010), an increase in type IIB muscle fibres which is generally higher in young animals, results in lower WHC of the muscle (Żochowska-Kujawska et al., 2019).

The meat from older animals tends to be less tender than that from younger animals. The change in shear force values as the animals grow older is highly correlated to different rates of myofibrillar protein degradation, muscle fibre bundle size, collagen heat stability, and the number of cross-links between collagen molecules and fibrils (Offer, Knight, Jeacocke, Almond, Cousins, Elsey & Purslow, 1989; Troy & Kerry, 2010; Dransfield, 1993). Volpelli et al. (2003) reported a negative correlation between collagen solubility and Warner-Bratzler shear force (WBSF) values measured in muscles of fallow deer. This phenomenon was confirmed by a study on the LTL muscle of 18- and 30-month old fallow deer. The study reported decreased collagen solubility as the animals grew older (30-months), which coincide with higher WBSF values resulting in less tender meat (Volpelli et al., 2003). Research on young and spent buffalo males also confirmed the latter; the collagen solubility of meat derived from young males was higher than that of the older males and as expected, the young animals exhibited lower shear force values indicating more tender meat (Kandeepan et al., 2009). A study on beef steers also confirmed lower tenderness scores on muscles of older animals than younger ones (du Plessis & Hoffman, 2007; Bouton & Harris, 1972).

The IMF predominantly found within the perimysium, also affects the physical quality and sensory attributes of meat. An increase in fat content may lead to the separation and reduction of the integrity of the perimysium connective tissue which increases the juiciness of meat (Fiems et al., 2000; Fortin, Robertson, & Tong, 2005). Older animals are often associated with a higher amount of IMF present in the muscles due to it being the last tissue to mature in the animal body (Hocquette et al., 2010; Lawrie & Ledward, 2006). It has been established that a positive correlation exists between intramuscular lipid (IML) and juiciness and tenderness of meat (Corbin et al., 2015). Meat from older animals tends to contain higher percentages of IML and typically higher concentrations of saturated fatty acids (SFA) (Lawrie & Ledward, 2006). Studies on game species such as fallow deer and springbok (*Antidorcas marsupialis*) reported an increase in intramuscular fat (IMF) as the age of an animal increased (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012; Hoffman, Kroucamp, & Manley, 2007). However, no differences in juiciness were reported between adult and sub-adult springbok. Similar results were reported for Binlangjang buffalo of different ages (0-3-, 4-6-, 12-18- and 24-36-months of age). An increase in marbling and backfat thickness of the carcass and IMF content were observed for the buffalo, which stabilized after 12-months of age (Li et al., 2018).

The fatty acid profile of meat is influenced by animal age, which also affects the meat flavour (Calkins & Hodgen, 2007; Farmer & Mottram, 1990; Wood et al., 1999, 2003). Sink & Caporaso (1977) noted that the flavour intensity of meat tends to increase as the animals get older. The age-related changes in IML content of muscle tissue may result in differences in fatty acid profiles, causing a possible increase in meat flavour as animal age increases (Fisher et al., 2000; Lawrie & Ledward, 2006; Ramanzin et al., 2016). Van Schalkwyk et al. (2004) investigated the effect of age on the fatty acid composition of black wildebeest and observed a decrease in myristic (C14:0) and palmitic (C16:0) acids after weaning, while stearic (C18:0) and oleic acid (C18:1) acids increased. Camfield, Brown, Lewis, Rakes and Johnson (1997) concluded a negative correlation between myristic and palmitic acids and the juiciness and taste characteristics of meat. Increases in SFA and PUFA can cause changes in the flavour of meat; PUFA provide better flavour which improves overall acceptance of the product. The muscles from younger animals typically contain higher concentrations of polyunsaturated fatty acid (PUFA) as well as higher PUFA: SFA (saturated fatty acid) ratios (Rule & Mccormick, 1998; Mostert & Hoffman, 2007). Other studies reported a higher percentage of MUFA and significantly lower omega-3 and omega-6 PUFA percentages in older fallow deer (Volpelli et al., 2003). In contrast, no age effect was observed for the PUFA, SFA, MUFA and PUFA: SFA or sub-adult and adult springbok and blue wildebeest (Kroucamp et al., 2004; Van Heerden & Hoffman, 2018).

Meat colour is one of the most important appearance traits, which is also regarded as an essential tool when evaluating and comparing meat products. Meat colour is often used as a guideline when determining the freshness of the meat (Hoffman, Kroucamp, & Manley, 2007; Risvik, 1994; Yin, Faustman, Tatiyaborworntham, Ramanathan, Maheswarappa, Mancini & Sun, 2011; Kropf, 1980). Consumers favour a bright red meat colour as they perceive it as more wholesome and fresh and therefore, tend to discriminate against brown or tan discolouration of meat. (Kropf, 1980; Mancini & Hunt, 2005). This misperception has led to consumers previewing darker meat as lower quality meat, although dark appearance does not necessarily influence the meat quality (Corcoran, Bernués, Manrique, Pacchioli, Baines & Boutonnet, 2001). Meat colour can be measured with a colour meter (Van Schalkwyk et al., 2004), which utilize a three-component equation to calculate the colour (Setser, 1984). It is evaluated using an objective method using CIElab values with the L* values indicating lightness, a* the red-green range and b* the blue-yellow range (Stevenson, Seman, Weatherall, & LIltlejohn, 1989). High a* and b* values cause muscles to appear bright with greater purity resulting from higher saturation (Onyango, Izumimoto, & Kutima, 1998). The chroma and hue angle of meat can be calculated according to the following equations:

Chroma= √ (a*2+b*2) and Hue angle (˚) = tan-1 (b*/a*) (Onyango et al., 1998).

A higher hue angle value is associated with more significant discolouration, whereas a low chroma value indicates less vivid colour (Liu et al., 2003).

The concentration of the protein myoglobin (Mb) is one of the primary factors influencing the colour of meat (Neethling et al., 2016; Yin et al., 2011; Faustman & Cassens, 1990). Myoglobin is a monomeric protein globular protein present in the sarcoplasmic fraction of the cardiac and skeletal muscle (Renerre & Labas, 1987; Livingston & Brown, 1981). It is made up of 153 amino acids (Renerre & Labas, 1987) and consists of eight right-handed alpha-helices with a central hydrophobic core (AMSA, 2012; Mancini & Hunt, 2005). Inside the core, there is a prosthetic heme group which consists of a porphyrin ring with a central iron atom which can form six bonds (Renerre & Labas, 1987). The latter is due to six available valence electrons of the central iron atom. Four of these electrons are bound to the porphyrin ring via the nitrogens from the pyrroles. A distal histidine-64 is also located within the porphyrin ring, which is available to interact with oxygen, promoting the binding thereof (Livingston & Brown, 1981) (Figure 2.2).

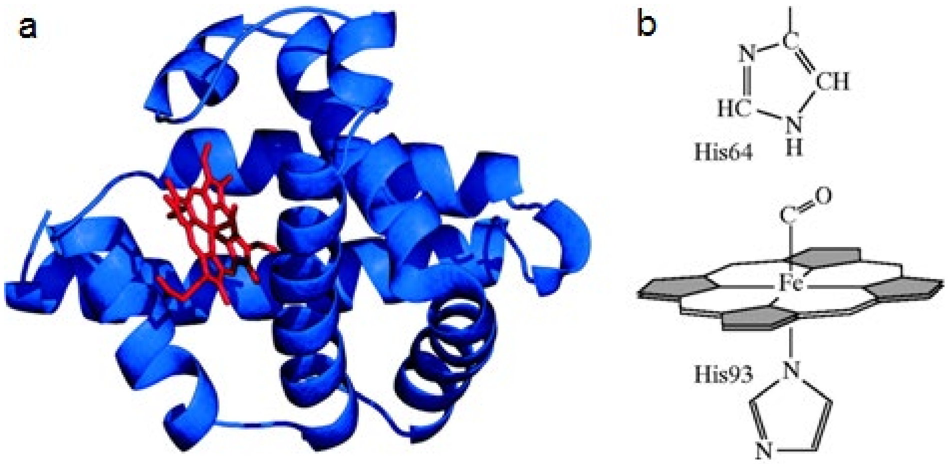

Figure 2.2 Myoglobin structure. (a) The backbone of myoglobin consists of eight α-helices (blue) that wrap around a central pocket containing a heme group (red). (b) The prosthetic heme group is bracketed or stabilized by histidine residues above (His64) and below (His93) (Ordway & Garry, 2004).

Myoglobin has higher binding capacity to oxygen compared to haemoglobin allowing the exchange of oxygen and carbon dioxide (Kim & Hunt, 2011). During exsanguination at slaughter, most of the muscle haemoglobin is removed. However, 6-25 % haemoglobin are retained in some muscles depending on the muscle's anatomical location, sex, age and species (Rickansrud & Henrickson, 1967).

The chemical state of myoglobin is another crucial determinant contributing to the changes in meat colour. There are three primary redox forms of Mb which include deoxymyoglobin (DMb), oxymyoglobin (OMb) and metmyoglobin (MMb) (Bekhit & Faustman, 2005). DMb is the native meat pigment containing iron in the ferrous state (Fe^{2+}) where the sixth binding sight is not bound to any ligands. A purplish-red colour of freshly cut meat is observed (Faustman & Cassens, 1990). When the sixth ligand is bound to oxygen, DMb is oxygenated, resulting in a bright red colour known as OMb (Faustman & Cassens, 1990). As the oxidation continuous to progress on the surface of the muscle, the exposure to oxygen increases resulting in discolouration of meat. Brown colour is observed a known as MMb, in this state the iron is oxidized (Fe^{3+}) with no ligand bound to iron. Instead, the binding site is occupied by water (Faustman & Cassens, 1990). The discolouration of meat is mainly influenced by pH, water-holding capacity and light scattering properties (Kim and Hunt, 2011).

The quantity of myoglobin is influenced by muscular activity which differs among species, breeds, sex, age, and type of muscle, as well as the level of activity (Lawrie & Ledward, 2006). A positive relationship exists between the age of an animal and myoglobin content in meat. However, a negative relationship exists between animal age and affinity of oxygen for myoglobin (Humada, Sañudo, & Serrano, 2014; Kim, Stuart, Black, & Rosenvold, 2012; Onyango et al., 1998). This phenomenon leads to a darker (lower L* values) and redder (higher a* values) meat colour in older animals as a result of higher concentration of myoglobin in the muscles (Insausti et al., 1999; Kim & Hunt, 2011). This phenomenon was also observed in beef where mature beef exhibited a higher myoglobin concentration (16-20 mg/g) than veal (1-3 mg/g) and young beef (4-10 mg/g) (Clydesdale & Francis, 1971). The quantity of IMF also affects the perceived muscle colour of an animal. Fat deposits tend to become more yellow as a result of increased carotenoid deposits (Lawrie & Ledward, 2006).

2.2.2.3 Effect of sex on the physiological composition of muscles

The effect of sex is most pronounced once sexual dimorphism has occurred. At this stage, the steroid hormones from the testes and ovaries have a more significant effect on growth than the pituitary growth hormones (Lawrie & Ledward, 2006). Sex influences the function of the muscle which affects the proportion of muscle fibres as well as the diameter thereof (Lefaucheur, 2010). As a result of sexual maturity, differences in muscle function and size occur between males and females (Lawrie & Ledward, 2006; Purslow, 2005). It has been reported that muscle fibre bundles are larger in males than females, possibly as a result of larger body size (Purslow, 2005).

2.2.2.4 Effect of sex on physical quality and sensory attributes of meat

According to Lewis, Pinchin & Kestin (1997), males are more susceptible to environmental disturbance than females. Hoffman (2000) reported higher pH_{36} (36 hours *post-mortem*) for the LTL muscle of male impala than females. Rutting season is an important factor to consider when comparing the meat quality of males and females. During the mating season, the forequarter muscles of males tend to be utilised more when showing dominance to lure females. Rutting behaviour includes clashing with other bulls and exchange of horn thrusts. During these actions, the testosterone levels of bulls increase to accommodate the rutting activities (Van Heerden & Hoffman, 2018). During the end of the rutting season, males are more excitable, which could also lead to decreased glycogen in muscles as a result of increased activity (Hoffman, 2000). The latter could lead to the depletion of glycogen stores in the muscles of males and consequently, higher pH_U values. Weglarz (2010) reported that males are more sensitive to extreme temperature changes than in females. The study reported that the pH_U of the LTL muscle of young bulls was 5.94 in winter, while in summer the pH_U

was 6.1. Furthermore, the pH_U in the muscles of cows was unaffected by season (change in temperature) (Węglarz, 2010). Generally, males are more prone to DFD meat as a result of low glycogen content in oxidative fibres which increases the risk of glycogen depletion (Dingboom & Weijs 2004).

It is well-known that the extent of pH fall, as well as the pH_U influences the WHC of meat. Drip- and cooking loss are both functions of WHC of meat and should be taken into account when measuring meat quality. When the pH_U of meat is low, possibly due to a rapid pH decline, the fibres will be thicker and consequently more water will be lost (Schäfer, Knight, Wess & Purslow, 2000).

Studies on common eland (*Taurotragus oryx*), also reported higher drip loss in female animals (Needham, Laubser, Kotrba, Bureš, & Hoffman, 2019). However, Araujo, Lorenzo, Cerqueira, Vazquez, Pores, Cantalapiedra & Franco (2016), Craigie, Lambe, Richardson, Haresign, Maltin, Rehfeldf & Bunger (2012), and Zhang, Zan, Wang, Xin, Adoligbe & Ujan (2010), reported a higher cooking loss in muscles of males. Although significant sex effects were reported for these studies, the biological differences were negligible. Furthermore, no differences were reported for drip loss and cooking loss of muscles between male and female fallow deer (Fitzhenry et al., 2016), kudu, impala (Hoffman, Mostert, Kidd, et al., 2009) and mountain reedbuck (Hoffman et al., 2008).

Research has reported a sex effect on the tenderness (shear force) of meat in species such as warthog (Swanepoel et al., 2016), roe deer (*Capreolus capreolus L.*) (Daszkiewicz et al., 2012) and Quinchuan cattle (Zhang et al., 2010). The studies showed lower shear force values in muscles of females than that of males. Higher hydroxyproline content in the collagen in connective tissue is closely related to meat tenderness. According to Boccard, Naudé, Cronje, Smit, Venter & Rossouw (1979), males have higher hydroxyproline content which was attributed to the anabolic effect of testosterone on collagen synthesis (Zhang et al., 2010). In contrast, no sex effect was observed for the meat tenderness of various muscles of species such as the mountain reedbuck (Hoffman et al., 2008), fallow deer (Fitzhenry et al., 2016), kudu, impala (Hoffman, Mostert, Kidd, et al., 2009), black wildebeest (Van Schalkwyk et al., 2004) and blue wildebeest (Van Heerden & Hoffman, 2018).

The difference between sensory- and physical meat quality of males and females could be attributed to the intramuscular fat (IMF) content and muscle fibre diameter. It has also been reported that the muscle fibre diameter significantly affects the tenderness of meat. It is expected muscles with a finer texture (smaller muscle fibres) would result in tougher meat as a result of higher ratio of connective tissue to fibre area (Lawrie & Ledward, 2006). Many studies have shown contradicting results where increasing cross-sectional area of muscle fibres negatively impacts the sensory quality of meat; therefore, fine-grained meats are more preferred (Purslow, 2005; Lefaucheur, 2010). Generally, male muscles are associated with greater cross-section area than females as a result of the hypertrophy-stimulating effect of testosterone (Choi & Kim, 2009). According to North & Hoffman (2014), female springbok exhibited larger muscle fibres for all the muscle fibre types in the BF and LTL muscles. However, the average fibre cross-sectional areas reported in the latter study was within the range of that reported for domesticated species and was unlikely to affect consumer's acceptance. Another study on spent male and female water buffalo also reported larger fibre diameter in the LTL muscle of females (Kandeepan et al., 2009). Furthermore, muscles with a larger proportion of Type IIB muscle fibres are associated with tougher meat as a result of larger fibres (Boccard et al., 1979). According to Taylor (2004), muscles which contain a higher percentage of Type I fibres exhibit higher lipid content resulting in more juicy meat with increased flavour (Klont et al., 1998). North & Hoffman (2017) reported higher Type IIX (fast-twitch glycolytic fibres) in the muscles of mature female springbok, which was also reported for sheep (Greenwood, Harden, & Hopkins, 2007). North & Hoffman, (2017), as well as in earlier study conducted on male and female springbok (Hoffman et al., 2007), found that females were associated with more residual tissue, although no differences occurred between the shear force values. A study on water buffalo also reported lower tenderness as well as lower connective tissue residue scores for spent females when compared to spent males (Kandeepan et al., 2009). Females are often associated with higher IMF content than males (Lawrie & Ledward, 2006). Terrel, Suess & Bray (1969) reported a higher percentage of oleic acid in the fat of bovine females than males. A study on adult warthogs also reported higher percentage of oleic acid in the *Longissimus thoracis et lumborum* (LTL) muscle of females which is one of the major fatty acids found in animal meat influencing the flavour thereof (Enser, Hallett, Hewitt, Fursey, & Wood, 1996; Arshad et al., 2018). This study also concluded higher SFA and MUFA in the LTL muscles of female warthog than males and attributed the difference to the higher fat content in meat of females (Swanepoel et al., 2016). However, studies on other game species such as mountain reedbuck (*Redunca fulvorufula*) (Van Schalkwyk et al., 2004), kudu, impala (Hoffman et al., 2008) and juvenile warthog (Swanepoel et al., 2016) reported no difference between the PUFS, MUFA and SFA content for meat of males and females

As mentioned, the colour of meat is influenced by muscle fibre types which affect the myoglobin present as well as the oxidative capacity of a muscle. The *post-mortem* pH decline also influences the colour of meat (Hunt & Hedrick, 1977; Neethling, Suman, Sigge, Hoffman, & Hunt, 2017). A muscle that contains larger proportions of Type I muscle fibres will appear red while muscle consisting of a larger proportion of Type II muscle fibres will appear more white (Lawrie & Ledward, 2006). North & Hoffman (2017) reported a higher proportion of Type I muscles fibres and less IIX muscle fibres in the muscles of male springbok, which also confirms the darker colour of meat from males. Males exhibit more significant levels of physical activity which have resulted in a higher concentration of myoglobin in the muscles causing the meat of males to appear darker (Seideman, Cross, Oltjen, & Schanbacher, 1982). Research on Minhota cattle also confirmed higher a* values in muscles of males than females (Franco, 2016). However, Fitzhenry et al. (2016), Hoffman et al. (2007) and Swanepoel et al. (2016) reported higher a* values in the muscles of female fallow deer, springbok and warthog respectively. Furthermore, no differences occurred between the colour coordinated when female and male mountain reedbuck (Hoffman et al., 2008), impala, kudu (Hoffman, Mostert, Kidd, et al., 2009) and black wildebeest were compared (Van Schalkwyk et al., 2004). It is evident that the studies conducted on the effect of sex on meat colour are inconclusive and therefore requires further investigation.

2.2.3 Chemical composition of muscles

The chemical composition of meat provides information on the nutritional value thereof. The basic chemical composition of meat includes moisture, protein, IMF and ash content (Ang, Young, & Wilson, 1984). Muscle tissue consists of 75-80 % moisture, 20-24 % protein, 1-10 % fat and ±1 % ash. Game meat is associated with low IMF content (<3 %) and cholesterol (49.75-59.34 mg/g) and high protein content (Hoffman & Cawthorn, 2013; North & Hoffman, 2014; Sebranek, 2014). The meat of wild ungulates also contains a higher proportion of PUFA and lower SFA content than domestic animals. PUFA can modulate the health risk factors associated with SFA's (Eckel, Jakicic, Ard, De Jesus, Miller, Hubbard & Millen, 2014). The PUFA/SFA ratio is another important factor determining the health risk associated with meat. In species such as water buffalo (Kadim et al., 2006), blesbok (Smit et al., 2004), black wildebeest (Van Schalkwyk et al., 2004) and springbok (Hoffman et al., 2007) desirable PUFA/SFA ratios (>0.7) were reported, which are considered healthy (Hoffman & Wiklund, 2006; WHO, 2003). The latter could be attributed to the diet of wild animals (Ramanzin et al., 2016). The variation between wild species also exists, where muscle fat of browsers exhibit higher percentages of PUFA than grazers or intermediate feeders (Meyer, Rowell, Streich, Stoffel, & Hofmann, 1998). It is evident that factors such as animal age and sex affect the chemical composition of meat and should thus be investigated when determining the nutritional properties of meat.

2.2.3.1 Effect of age on chemical composition of muscles

As illustrated in Figure 2.3, body weight (positively correlated with animal age) influences the basic chemical composition of meat (Haecker, 1920). The water in meat is structurally arranged in layers around polar molecules as well as between layers of cellular materials (Brewer, 2004; Pospiech & Montowska, 2011). Moisture in meat is extremely variable and greatly influenced by species' maturity, anatomical location and fat content (Keeton & Edd, 2004). A negative relation exists between the moisture content and fatness of muscle tissue, as the IMF content of meat increases, the moisture content decrease (Kandeepan et al., 2009; Lawrie & Ledward, 2006; Pflanzer & de Felício, 2011). Research on game species such as the blue wildebeest (Van Heerden & Hoffman, 2018), black wildebeest (Van Schalkwyk et al., 2004), kudu and impala (Mostert & Hoffman, 2007) found no differences in the moisture content of the LTL muscle of sub-adult and adults. However, lower moisture content was reported in the ST muscle of 30-month old fallow deer than 18-months old animals (Duranti, 1986).

Muscle tissue of game species generally comprises of 20-24 % protein which is higher than of domestic livestock comprising of ±19 % protein; the latter being lower due to their higher IMF contents (Lawrie & Ledward, 2006; Needham et al., 2019; Webb et al., 2005). In adult mammalian muscles, the total protein typically comprises of 11.5 % myofibrillar protein, 5.5 % sarcoplasmic protein and 2 % connective tissue (Greaser, Wang, & Lemanski, 1981). As a result of the lower IMF content in game meat, a stronger negative correlation exists between moisture and protein content (Keeton & Eddy, 2004; Smit, Hoffman, & Muller, 2004). Studies on game species such as buffalo (Kandeepan et al., 2009), kudu, impala (Mostert & Hoffman, 2007), blesbok (Smit et al., 2004) and black wildebeest (Van Schalkwyk et al., 2004) reported no difference in the protein content of the LTL muscles of sub-adults and adults. However, Hoffman et al. (2007) and Kadim et al. (2006) reported lower protein content in the muscles of adult springbok and Arabian camel, respectively. Furthermore Cho, Kang, Seong, Kang, Sun, Jang & Hwang (2017), reported higher protein content in the 3.5- to 4.5-year old Hanwoo cows in comparison to the seven-year old cows.

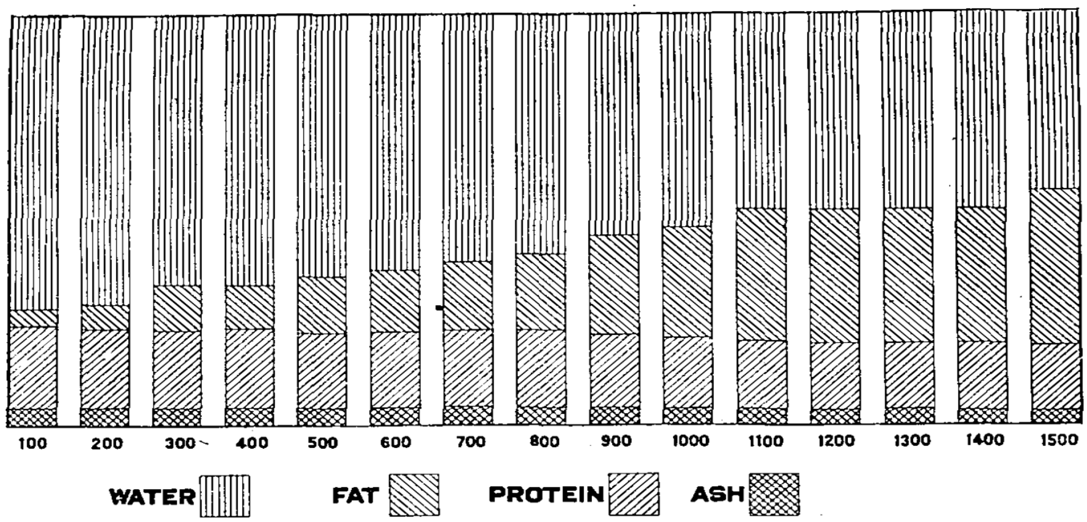

Figure 2.3 Change in chemical composition of the muscles of beef steers from 100 to 1,500 Pounds (Haecker, 1920).

Fat (adipose tissue) is the last tissue to reach maturity, typically coinciding with the onset of puberty and is influenced by various factors including animal age. Fat is also the first tissue to be utilised during certain circumstances. Fat in animals comprises of neutral and phospholipids that range from 1.5-13 % in muscle tissue (Lawrie & Ledward, 2006). Various forms of the latter serve as a source of energy for the cells as well as the structural and functional components of their walls. As mentioned, muscle fibres are classified according to their metabolism. Type I muscle fibres (red muscle fibres) are mainly located in muscles used in continuous motion that require slow-twitch contractions (Opern Stax, 2013). The latter contain large amounts of mitochondria, low glycogen and high fat contents which serve as the main source of energy during these prolonged activities (Lawrie & Ledward, 2006). Furthermore, Type IIB muscle fibres (white muscle fibres) are located in muscles which require fast rates of contraction particularly during rapid movement (Cassens & Cooper, 1971). These muscle fibres are characterised by higher glycogen and protein contents and lower lipid content (Lawrie & Ledward, 2006). A study on fallow deer confirms the above by reporting an increase in Type I fibres in the LTL, BF and SM muscles; in the study, 18-month old bucks had the lowest proportion, followed by the 30-, 42- and 54-month old animals (Żochowska-Kujawska et al., 2019). A study on Arabian camel reported higher fat content in the LTL muscles of 6-8-year old cows than 1-3-year old females (Kadim et al., 2006). In contrast, research on game species such as kudu, impala (Hoffman, Mostert & Kidd, 2009), blue wildebeest (Van Heerden & Hoffman, 2018), blesbok (Smit et al., 2004), black wildebeest (Van

Schalkwyk et al., 2004) and springbok (Hoffman et al., 2007) observed similar (and low) fat contents in the muscles of sub-adults and adults.

The ash content of meat represents the inorganic material which is used to determine the mineral content of meat. The latter occurs in the forms of oxides, sulphates phosphates, nitrates and chlorides. The low percentage (±2 %) of inorganic elements in muscles does not minimize the importance thereof. Minerals serve various purposes in the body which include the provision of rigidity and support for soft tissues as they constitute in the skeletal structure, they maintain and regulate tissue functions, regulate acid-base equilibrium and serve as constituents in enzymes and other body regulatory systems (Pearson & Young, 1989). As depicted in Table 2.4, specific minerals serve specific purposes in the human body.

According to research on various game species, age has no effect on the ash content of various muscles (Hoffman, Mostert, & Laubscher, 2009; Hoffman, Kroucamp, & Manley, 2007a; Kadim et al., 2006; Smit et al., 2004; Van Heerden & Hoffman, 2018). However, Doornebal & Murray (1981) and Lin et al. (1989) reported an increase in iron and sodium and a decrease in potassium as the age of the animal increases. They attributed the difference to nutritional status as well as the management system utilised.

Table 2.4 Functions and recommended daily intake of important minerals for the human body.

Mineral	Function	Recommended daily intake	
		Male	Female
Iron	Oxygen transport, enzyme synthesis, energy production and regulation of immune functions[#1]	8 mg[#6]	18-27 mg[#6]
Selenium	Redox regulation via neutralizing and removing free radicals. Key component in antioxidative defence, metabolism of thyroid hormones, male reproduction[#2]	55 µg (19-50-year old male and females)[#7]	
Calcium	Muscle function, nerve transmission, intracellular transmission, vasoconstriction and vasodilatation[#3]	1000-1200mg[#8]	
Magnesium	Acts as a cofactor for various enzyme systems, energy metabolism and protein- and nucleotide synthesis[#4]	320-420 mg[#8]	
Zinc	Catalytic functions, as over 100 enzymes are zinc-dependent, the maintenance of protein and cell membranes as well as the regulation of gene expression in cells[#5]	36-59 µg/ kg body weight (18-60+ years)[#9]	43-72 µg/ kg body weight (18-60+ years)[#9]

Adapted from Pogorzelska-Nowicka, Atanasov, Horbanczuk & Wierzbicka, 2018.
[#1]Beard, 2001; Radlowski & Johnson, 2013, [#2]Riaz & Mehmood, 2012, [#3]Beto, 2015, [#4]De Baaij, Hoenderop & Bindels, 2015,[#5]Pogorzelska-Nowicka, Atanasov, Horbanczuk & Wierzbicka, 2018,

[#6]Ganz & Nemeth, 2012, [#7]Peter, 2017, [#8]Moshfegh, Goldman, Ahuja, Rhodes & Lacomb, 2009, [#9]AO/IAEA/WHO, 1996.

2.2.3.2 Effect of sex on chemical composition of muscles

Research on various game species reported negligible differences between the moisture content of muscles of males and females. It has been reported that as the moisture and lipid content is meat increases, the protein content decreases in game meat (Swanepoel, Leslie, & Hoffman, 2014). According to literature, sex had little effect on the moisture content of meat of various game species (Hoffman et al., 2007; Hoffman, Mostert, & Laubscher, 2009; Hoffman et al., 2008; Kandeepan et al., 2009; Needham et al., 2019; Smit et al., 2004; Van Schalkwyk et al., 2004; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003). Furthermore, studies on species such as mountain reedbuck (Hoffman et al., 2008), warthog (Swanepoel et al., 2014), black wildebeest (Van Schalkwyk et al., 2004) and roe deer (Daszkiewics et al., 2012) reported higher protein content in some muscles of females than males. In contrast, no differences in the protein content of meat from males and female common eland (Needham et al., 2019), kudu, impala (Mostert & Hoffman, 2007), fallow deer (Volpelli et al., 2003), blesbok (Smit et al., 2004) and springbok (Hoffman et al., 2007) were recorded.

According to Berg & Butterfield (1976), fat is the tissue which alters the carcass composition most between males and females. The rate of fat accumulation in males is slower than in females. Studies have also reported higher fat content in female than in male springbok, blesbok and impala (Van Zyl & Ferreira, 2004); this is attributed to females reaching maturity at an earlier stage than males. Furthermore, the IMF metabolism is subject to hormonal regulation which causes changes in fat and muscle tissue metabolism. Oestrogen stimulates adipocyte growth and fat deposition, while testosterone decreases fat deposition (Mersmann & Smith, 2004). In game species, increased intramuscular fat content can be attributed to increased planes of nutrition. Males also tend to lose condition during the rutting season because of strenuous activities such as clashing with other males (Anderson, 1965). Female game species build up fat stores for reproduction which results is increased subcutaneous and intramuscular fat deposition (Swanepoel, Leslie, Rijst, & Hoffman, 2016). Research conducted on kudu and impala (Mostert & Hoffman, 2007), warthog (Swanepoel et al., 2016), blesbok (Smit et al., 2004), buffalo (Kadim et al., 2006), springbok (Hoffman et al., 2007) and roe deer (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012), reported higher fat content in the muscles of females than males. However, no differences were reported between the fat content of muscles of male and female game species such as the common eland, mountain reedbuck, fallow deer and black wildebeest (Table 2.5).

Table 2.5 Means of the proximate composition (%) of the *longissimus thoracis et lumborum* (LTL) muscles of various game species as influenced by sex.

Species	Muscle	Sex	Moisture	Protein	Fat	Ash	Source
Common Eland (*Taurotragus oryx*)	LTL	♂	76.0	22.7	1.2	1.1	#1
		♀	75.2	23.2	1.3	1.1	
Mountain Reedbuck (*Redunca fulvorufula*)	LTL	♂	72.76	23.68	2.94	1.23	#2
		♀	72.59	24.51	2.43	1.22	
Impala (Musina) (*Aepyceros melampus*)	LTL	♂	72.51	24.89	1.43	1.23	#3
		♀	72.50	24.87	1.98	1.22	
Kudu (*Tragelaphus strepsiceros*)	LTL	♂	75.66	22.77	1.48	1.22	#4
		♀	75.77	22.25	1.49	1.19	
Blue wildebeest (*Connochaetes taurinus*)	LTL	♂	75.55	23.31	1.26	1.26	#5
		♀	75.99	22.83	1.38	1.38	
Blesbok (*Damaliscus pygargus phillipsi*)	LTL	♂	75.08	23.34	4.69	1.16	#6
		♀	74.75	23.10	2.81	1.22	
Black wildebeest (*Connochaetes gnou*)	LTL	♂	74.69	19.42	0.97	1.29	#5
		♀	75.21	20.73	1.13	1.25	
Water buffalo	LTL	♂	73.42	21.61	2.76	-	#7
		♀	72.63	20.70	3.98	-	
Springbok (*Antidorcas marsupialis*)	LTL	♂	74.24	-	1.35	1.24	#8
		♀	73.39	-	3.13	1.28	

[#1]Needham et al., 2019, [#2]Hoffman et al., 2008, [#3]Hoffman, 2000, [#4]Hoffman, Mostert, Kidd, et al., 2009, [#5]Van Schalkwyk et al., 2004, [#6]Smit et al., 2004, [#7]Kandeepan et al., 2009, [#8]Hoffman et al., 2007.

♂: Male; ♀: Female

2.3 THE BLUE WILDEBEEST *(Connochaetes taurinus)*

The blue wildebeest (also known as the brindles gnu) has successfully been introduced into marginal grassland habitats and is currently distributed across most of South Africa (Furstenburg, 2018). They thrive in the grassland biome which covers a large part of the land in South Africa. The blue wildebeest is selective, short-grass grazer, preferring sweetveld grass species as *Panicum spp, Digitaria spp, Themeda triandra, Cynodon dactylon, Stipagrostis ciliata and S. obtuse* (Furstenburg, 2018). However, 13 % of their diet can consist of browse and forbs. (Bothma, Van Rooyen & Du Toit, 2010). Based on the diet an average blue wildebeest (180 kg), it is equivalent to 0.87 Grazer Units and 0.13 Browser Units, respectively. The popularity of the species can be attributed to its high population growth of 29-38 % increase, annually. They are also known to be resistant to diseases and parasites as well as for their lower nutritional requirements than domestic species. Their high reproductive potential also has a positive contribution on their population growth (Hoffman et al., 2011; Von la Chevallerie & Van Zyl, 1971). Many farmers wish to enter the game farming industry, however they do not have access to large ranches (500 ha) required by large game species such as buffalo (Bothma, Suich & Spenceley, 2009). Therefore, alternative antelope species such as blue wildebeest received more attention due to their smaller land (50 ha) requirements, which creates opportunities for farmers with limited access to land (Weavind, 2014).

The blue wildebeest has become a popular game species for biltong hunting as well as for trophy hunting (possibly due to its colour variants). In the year 2015, the blue wildebeest contributed 6 % and 6.13 % to the total game species hunted for biltong and trophies, respectively. The golden wildebeest and king blue wildebeest are the two major colour variants of the blue wildebeest (Taylor et al., 2016). The light colour observed in the golden wildebeest is caused by the expression of a recessive gene where the blue colour is the expression of the gene in its dominant form (Van Heerden & Hoffman, 2018). The king wildebeest has a grey-blue body colour with a white tail, main and beard. The most aesthetic feature, though uncommon, of the king wildebeest, is the light spot on both sides of the flank (Gouws, 2014). To further evolve the trophy market for hunters, game ranchers started breeding colour variants and split animals to generate more profit from this species (Cloete, 2018). Blue wildebeest splits are individuals that carry genes for the recessive colour and have the genetic potential of producing offspring with a more valuable colour phenotype. They are also known as hybrids between golden bulls and blue cows (Bezuidenhout, 2012). Hypothetically, F1 cows will produce 10 % golden offspring, F2 and F3 cows will produce 30 % and 50 % golden calves, respectively (Strauss & Willemse, 2015). In the year 2015, the price paid for golden wildebeest F1 cows and heifers, F2 cows and heifers and F3 cows and heifers were R40 000, R60 000 and R80 000, respectively (Strauss & Willemse, 2015). The average price of a purebred golden wildebeest adult bull and a pregnant cow was R 1 033 421 and R 531 538, respectively (Strauss & Willemse, 2015). However, the price of the colour variants has experienced a drastic decrease from the year 2015 onwards; in 2016 and 2017, the price of golden blue wildebeest dropped from R400 000 in 2015 to R200 000 and R100 000, respectively (Cloete, 2018). The average price received for a trophy golden wildebeest and king wildebeest bull in the year 2019, ranged from R30 000-R40 000 and R90 000, respectively (R. Davey, personal communication, April, 2019).

As illustrated in Figure 2.4, the potential future market is saturated for colour variants, which could explain the decline of these animals once the demand from breeders decreased. Concerns about these colour variants have raised and caused divisions between the different parties associated with the game industry. The South African National Biodiversity Institute (SANBI) suggested that the breeding of colour variants should be discouraged as well as the other role-players such as the South African Hunters and Game Conservation Association (SAHGCA), the National Council of the SPCA's and the International Council for Game and Wildlife Conservation (CIC) (Olivier & Butler, 2015). Some local and international hunters also oppose to the manipulation of wildlife and believe that coloured animals will not pose the same hunting challenge as normal coloured animals. The concerns regarding the colour variants have led to farmers shifting their focus towards the selection of animals with exceptional horn characteristics and body size. Therefore, farmers have adequate numbers of colour variants, particularly older females with decreased production and young stock unsuitable for their breeding programmes. Semi-intensive management practices include the regular culling of surplus or sub-standard stock, not meeting the breeding criteria. The latter are harvested for meat production and typically culled before puberty and the onset of the winter months. Additionally, game farmers evaluate young blue wildebeest bulls to determine their breeding potential. According to game breeders, the potential of a young bull, in terms of body size and horn characteristics can be established at an age as early as 18 months. These sub-standard bulls are often culled to enter for meat production.

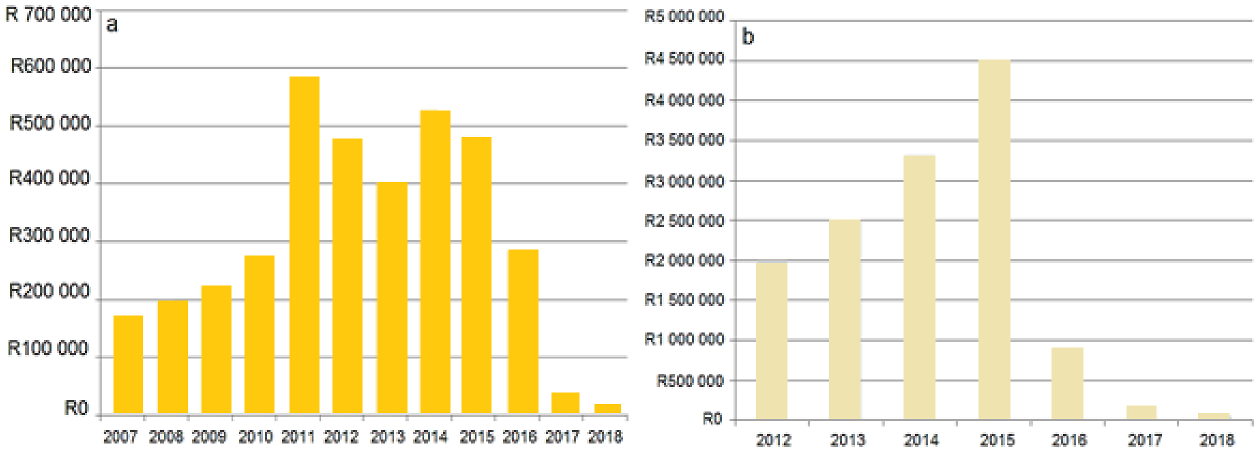

Figure 2.4 Decrease in average price per animal per year of a) Golden wildebeest and b) King wildebeest (AWA, 2018).

2.3.1 The meat production potential of the blue wildebeest

Studies on blue wildebeest have reported high meat production potential and meat quality of various muscles of the species. According to Van Heerden & Hoffman (2018), the mean undressed carcass weight, carcass weight and dressing percentage of an adult blue wildebeest bulls was 211.2 kg, 111.3 kg and 52.6 %, respectively. Sub-adult bulls had significantly lower mean undressed carcass weight (165.9 kg), carcass weight (85.7 kg) and dressing percentage (51.5 %). The mean pH_U, drip loss %, cooking loss % and shear force (N) of the LTL muscle of blue wildebeest bulls were 5.7, 1.6 %, 34.6 % and 37.8 N, respectively. The latter coincides with results reported in beef cattle farmed with in South Africa (Muchenje, Dzama, Chimonyo, Raats, & Strydom, 2008). The results obtained by Van Heerden & Hoffman (2018) are comparable to the meat production potential of various cattle breeds such as Nguni, Bonsmara & Aberdeen Angus farmed with in South Africa (Muchenje et al., 2008). The undressed carcass weight (205 kg), carcass weight (107 kg) and dressing percentage (52.1 %) of Nguni cattle is similar to that recorded for the blue wildebeest. In general the forelimb of the blue wildebeest is well developed, followed by the hind limb and the back extensors (Grand, 1991). High nutritional value of blue wildebeest muscles has been reported and coincide with that of Nguni muscles. Higher protein content was reported for the LTL muscle of blue wildebeest (22.28 %) than for Nguni (21.0 %), Bonsmara (20.6 %) and Aberdeen Angus cattle (20.0 %) (Muchenje et al., 2008). The LTL muscle of blue wildebeest is also associated with low IMF content (1.1–1.7 %) with a tendency to be lower than that recorded in the LTL muscle of Angus (3.23 %), Simmental (3.25 %) and Charolais cattle (3.25 %) (Chambaz, Scheeder, Kreuzer, & Dufey, 2003). The blue wildebeest is therefore a game species with high meat production potential whilst exhibiting good physical meat quality. The muscles of blue wildebeest are also high in protein and low in fat which makes it an appropriate alternative for meat from domesticated species.

It can thus be concluded that the blue wildebeest is an appropriate and sustainable wildlife species for the production of meat due to the high carcass yields and good physical meat quality. Additionally, the blue wildebeest produce lean meat (low in IMF) with high protein content which is favoured by the modern consumer.

2.4 CONCLUSION

According to research, various factors influence game meat quality, in terms of carcass-, physical- and chemical parameters. It has been shown that age and sex significantly affect the meat quality parameters of game species and should receive attention before harvesting for meat production. Different anatomical muscle locations also affect the meat quality due to the variation in function and consequently muscle fibre and structural composition. Many of the studies on blue wildebeest only investigated primal or included only one muscle (*Longissimus thoracis et lumborum* (LTL)). It would, therefore, be recommended that more muscles (e.g. LTL, BF, SM, ST, IS and SS) should be investigated further to determine the effect of age on the meat quality of blue wildebeest. The majority of these studies grouped the animals into sub-adults (16-28-months old) and adults (40-months to >4-years old) by using tooth eruption and horn characteristics as guidelines. By including only two age groups with significant age variations, it becomes difficult to distinguish at which specific age changes in carcass yields and meat quality will start to occur. Furthermore, previous studies investigating the effect of sex on meat quality did not always compare animals of the same age (i.e. in some studies where males and females were compared, the animals were not grouped according to age). Thus, it is challenging to establish the actual effect of sex due to different ages at which of male and female game species reach maturity.

The wildlife industry has become more intensive by implementing selective culling of specific age groups and sexes. Many of the game farms have started to tag their animals according to their ages and sex. Based on available research, it will be beneficial to compare more distinct age groups with the same aged animals per group. The latter will lower the variability within each age group and provide more detailed conclusions. With the inclusion of more age groups, the results may be more comparable to that reported for livestock species which key focus is on age at slaughter. Therefore, the study aimed to investigate and quantify the effect of age (1.5-, 4.5- and >6.5-year old females) and sex (1.5-year old bulls and heifers) on the carcass yields, as well as for the physical- and chemical meat quality of six muscles (LTL, BF, SM, ST, IS and SS) of blue wildebeest.

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CHAPTER 3
QUANTIFYING THE EFFECT OF AGE AND SEX ON CARCASS CHARACTERISTICS OF BLUE WILDEBEEST (*Connochaetes taurinus*)

ABSTRACT

The aim of this trial was to provide baseline data of the influence of age and sex on the meat production, particularly carcass yields of blue wildebeest. A total of 32 blue wildebeest were harvested from a semi-intensive production system. The study was sub-divided into two trials. The first trial comprised of 24 females divided into three age groups (1.5-, 4.5- and >6.5-years old) and included eight animals per group. The second trial included eight additional 1.5-year old bulls which were compared to the 1.5-year old heifers culled in the first trial. The 4.5-year old cows were associated with the heaviest dead weights (203.63 ± 9.54 kg) and total internal organ weights (88.83 ± 5.75 kg). The 4.5- and >6.5-year old blue wildebeest cows exhibited the heaviest cold carcass weights (100.15 ± 10.01 kg >6.5-year old; 105.45 ± 6.82 kg 4.5-year old), total external offal weights (33.29 ± 2.26 kg >6.5-years old; 33.38 ± 2.84 kg 4.5-years old), the highest dressing percentage (53.10 ± 3.55 % >6.5-year old; 51.78 ± 1.99 % 4.5-years old), body condition score as well as individual muscle weights. Furthermore, the 1.5-year old bulls exhibited heavier dead weight (174.25 ± 16.73 kg), cold carcass weight (94.05 ± 9.65 kg) as well as higher dressing percentage (53.95 ± 0.92 %) when compared to the young heifers. The young bulls were also associated with heavier external (37.31 ± 3.37 kg) and internal offal weights (33.76 ± 2.50 kg) and exhibited heavier muscle weights when compared to the heifers. The results obtained in the study indicate that older cows (>6.5-years old) and young sub-standard bulls have the potential to produce high carcass yields. The latter is beneficial to farmers in the game breeding industry, wanting to cull their older breeding stock, while producing high carcass yields.

Keywords: Carcass yields. Game species, Selective culling, Surplus animals

3.1 INTRODUCTION

In recent years, a significant shift has occurred in the perceptions of livestock and game farming as these industries are presently known for efficient livestock production under conditions of climate change. Extensive dry periods triggered by the El Niño Southern Oscillation (ENSO) (Dzama, 2016) are often experienced in South Africa. The El Niño phenomenon is described as a quasi-periodic invasion of warm sea surface water into the eastern tropical Pacific Ocean resulting in these dry conditions and warmer temperatures (Gibberd, Rook, Seear, & Williams, 1996; Rouault & Richard, 2003). As the global temperatures continue to increase, a downward trend is experienced in rainfall which leads to a reduction in quantity and quality of pastures, fodder crops and grain production (Dzama, 2016).

The livestock and game farming sectors of South Africa utilise different species and breeds distributed throughout the country based on grazing requirements, environmental differences, and type of production system utilized in the specific region (Meissner, Scholtz, & Palmer, 2013). Due to the warmer temperatures as a result of global warming, livestock species such as beef and dairy cattle are increasingly exposed to heat stress conditions and pests. This leads to reduced production performance and mortalities (Dzama, 2016). Furthermore, with the continuous deterioration of grazing capacity associated with climate change, alternative livestock such as wildlife species can be utilized to a greater extent (Otieno & Muchapondwa, 2016).

Nell (2003) regarded wildlife utilization as one of the greatest agricultural transformations in Africa's recent history. Game animals have developed physiological as well as behavioural mechanisms to assist in the conservation of water in arid regions. They have lower nutritional requirements that enable them to utilize natural vegetation more effectively than livestock species (Cole, 1990). Game species exhibit diverse feeding habits, which also allow them to utilize vegetation in diverse regions as the seasons change (Cole, 1990). When the average daily gain of domestic cattle, sheep and game species such as blue wildebeest, eland, impala and hartebeest were compared, most of the game species exhibited higher average daily gains (Ntiamoa-Baidu, 1997) under challenging environmental conditions. In support, Steyn (2012) found that profit generated per hectare per month from commercial game farming (R220) exceeds that generated by livestock (R80) under certain conditions. The latter may have increased the popularity of conversion from livestock production to game farming in South Africa (Chiyangwa & Hoffman, 2018). Patterson & Khosa (2005) have reported a conversion rate of 2-2.5 % from cattle to game farming on a national basis (Patterson & Khosa, 2005). In the Eastern Cape, ~12 % of the land has been converted from commercial livestock production to game farming since 1996 (Pasmans & Hebinck, 2017) whilst in the Limpopo Province, ~32 % of the land area has been converted to game farming (Van der Merwe & Saayman, 2012). Currently, Limpopo province represents ~50 % of the national commercial wildlife ranching (Otieno & Muchapondwa, 2016) .

The wildlife industry is supported by four main economic pillars comprising of the breeding and live sales of the game, hunting, ecotourism and processed game products (Van Der Merwe, Saayman, & Krugell, 2010, Taylor, Lindsey & Davies-mostert, 2016). For the purpose of this chapter only the meat processing pillar will be elaborated on. The game meat production industry has developed into a species-specific industry; with substantial differences occurring between species. There are also differences within species regarding carcass yields as well as live weights; mostly attributed to different regions in the country (Hoffman, 2007). Researchers have reported differences in meat yield and carcass characteristics of animals of differing ages subjected to changes experienced during the animal's natural growth curve (Hoffman, Mostert, Kidd, & Laubscher, 2009; Smit, Hoffman, & Muller, 2004; Van Heerden & Hoffman, 2018; Van Schalkwyk, Hoffman, & Muller, 2004).

The current study investigated the meat quality in terms of carcass characteristics of blue wildebeest due to their abundance in South Africa (it is a common species occurring on most game ranches) and their high adaptability, disease resistance and fertility during unfavourable conditions (Furstenburg, 2002). The blue wildebeest is a large antelope species with adults bulls reaching 250 kg mass and a shoulder height of 1.5 m (Attwell, 1982; Van Heerden & Hoffman, 2018). The golden wildebeest and king wildebeest are two colour variants of the blue wildebeest that have great commercial value and has contributed to the distribution of this species (Olivier & Butler, 2015; Taylor et al., 2016). In the past, game breeders utilized blue wildebeest splits (F1 generation) which carry the recessive genes responsible for the colour variants as breeding stock. Currently, the majority of game breeders have adequate numbers of colour variants and excess breeding stock, i.e. F1 as well as females that do not meet the high breeding criteria and are therefore destined for meat. Additionally, game ranchers regularly inspect the breeding potential of young bulls. The selection is normally linked to horn size/shape and skin colour and only the bulls exhibiting favourable characteristics will be kept for further breeding purposes. Wildlife farmers are able to establish the potential, in terms of body and horn size, of blue wildebeest males and females at the age of ± 18-months (± 1.5-years old). The sub-standard young bulls and above-mentioned older cows will consequently enter the meat production system. However, these surplus animals may enter the meat production sector at different ages (Bezuidenhout, 2012). Limited research is available on the influence of age and sex on carcass characteristics of blue wildebeest. Both male and female blue wildebeest reach sexual maturity at the age of 16-months, therefore; it is also important to investigate the extent at which sexual dimorphism influences the body characteristics of male and female blue wildebeest (Bothma, Van Rooyen & Du Toit, 2010). The aim of this study is to provide baseline data on blue wildebeest of different ages and sexes for the specialized game meat industry of South Africa.

3.2 MATERIALS AND METHODS

3.2.1 Animals and study location

Ethical clearance has been granted for this study (ACU-2018-6598). The experiment was conducted on Romaco Ranch (S24” 26’ 43.73” E28” 31’ 25.86”) situated in the valley of the Waterberg Mountains, located on the outskirts of the Modimolle region in the Limpopo province, South Africa in April (late summer/early autumn) 2018. The 7000 ha ranch boasts with a variety of wildlife including game species such as blue wildebeest (as well as various colour variants such as Gold, Kings, etc.), black wildebeest, impala, nyala, buffalo, sable antelope and roan antelope. The study location forms part of the central Bushveld bioregion, defined by Rutherford, Mucina, & Powrie (2006) as consisting of approximately 81 % grassland biome and 19 % of the savanna biome. The Northern Highveld Region falls under the early summer to midsummer rainfall region and has an annual rainfall of 400-1000 mm. The region has an elevation that varies from 630 mm and primary production potential of 4-8 tonne/ha/yr (Trytsman, Westfall, Breytenbach, Calitz, & van Wyk, 2016). This area boasts with sourveld and mixed veld groups which are veld types adapted to low phosphorus non-sodic soils with a low pH (<6.4) (Trytsman et al., 2016; Steenkamp, Van Wyk, Smith & Steyn, 2005) The habitats range from broad-leaved bushveld dominated by *Diplorhynchus condylocarpon* to open grassland with a well-developed grass layer as well as mountain slopes and marshland (Mucina & Rutherford, 2006).

Table 3.1 illustrates the experimental layout of the animals harvested for this study according to age and sex to quantify the effect on carcass yields. The eight sub-adult blue wildebeest cows (1.5-years old) that were culled, have not yet reached reproductive maturity (Bothma, Van Rooyen & Du Toit, 2010), whereas the cows from the 4.5- and >6.5-year old groups were classified as sexually mature animals (Estes, 1991).

Table 3.1 Distribution of animals harvested according to age and sex to determine the effect on carcass yields.

		Age (years)	Sex	Animals per group	Total
Trial 1		>6.5	Female	8	32
		4.5	Female	8	
	Trial 2	1.5	Female	8	
		1.5	Male	8	

The study included a total of 32 blue wildebeest (*Connochaetes taurinus)* comprising of two trials. The first trial investigated the effect of age on carcass characteristics of blue wildebeest cows. The animals from the first trail were categorized into three age groups (1.5-, 4.5- and >6.5-years old); each group included eight female blue wildebeest. The second trial investigated the effect of sex on carcass characteristics of blue wildebeest at the age of 1.5-years. Eight additional blue wildebeest bulls were culled and compared to the 1.5-year old heifers harvested during the first trial to quantify the effect of sex on carcass characteristics. All the animals were culled from a semi-extensive production system over a 7-day period. All the animals culled for the study were maintained in large breeding camps (150-200 ha) and received a supplementary feed during winter, formulated by Wildswinkel (protein (120 g/kg), energy (8.2 MJ/kg), moisture (120 g/kg), fat (25 g/kg), fibre (190 g/kg), Ca (7 g/kg), P (2 g/kg), K (1 g/kg), Mg (1 g/kg) & Na (1 g/kg)). It was expected that each animal will consume 2.8-3.2 % of their bodyweight of feed per day. The >6.5-year old cows only received supplementary feeding once they arrived on the farm two years prior to the study. The remaining trial animals were bred on the farm and had access to supplementary feed throughout their growth period.

3.2.2 Harvesting and dressing

Harvesting of the animals took place in April 2018 over a period of seven days and was part of the Ranch's annual cull. The animals were either culled early in the mornings or late in the afternoons from a helicopter and euthanized with a headshot from an appropriate calibre shotgun operated by an experienced huntsman. Van Schalkwyk & Hoffman (2010) reported that a headshot is an important requirement for game production destined to be exported or sold commercially, due to minimum damage, wastage and contamination of the carcasses associated with headshots. Each animal was immediately exsanguinated by severing after being shot. Thereafter, the animals were loaded on the back of a culling vehicle and transported to a registered abattoir (Certificate number 2/4G) on Romaco Ranch where they were processed further.

At the abattoir the dead weight (total weight excluding exsanguinated blood) was recorded using a calibrated hanging scale. The carcasses were skinned, eviscerated and cleaned within two hours *post-mortem* (PM) according to the standard operating procedure described by Van Schalkwyk & Hoffman (2010). In previous studies conducted on game species, the animals' age was determined by either using tooth eruption or horn measurements (Mostert & Hoffman, 2007; Van Heerden & Hoffman, 2018). In the current trial, the animals' ages were established from their ear tags before any shots were fired, thus no tooth or horn evaluation was necessary. The animals were tagged at eight months of age in August, each tag indicates the year of birth, as well as the sex of the animal.

The external (head, legs, skin and udders/testicles) and internal offal (lungs, full gastrointestinal tract (GIT), spleen, kidneys, liver and heart) were weighed and expressed as a percentage of the dead weight. The dressed warm carcass weight was also recorded prior to storage in a chiller at 4˚C to undergo rigor. To avoid unequal contraction of muscles going into rigor, the whole carcass was suspended by both Achilles' tendons in the cold room. After carcass dressing, body condition scores (BCS) were recorded. The BCS is a clear indication of the body reserves of an animal (Lowman, Scott & Somerville, 1976). A visual and palpation method was used to evaluate the body fat reserves in the back and pelvic regions of the carcasses (Ottom, Ferguson, Fox, & Sniffen, 1991). This method is based on the principle of BCS used in the beef cattle industry. The latter consists of a scale ranging 1 to 5 with 1 indicating no visible subcutaneous fat and 5 indicating excessive fat (Figure 3.1).

After a 24-hour *post-mortem* period in the chiller, the cold carcass weight was recorded where after the dressing percentage was calculated by expressing the dressed carcass weight as a percentage of the dead weight. Seven muscles were removed from the left side of the carcass for further analysis. The *infraspinatus* (IS) and *supraspinatus* (SS) muscles were removed from the shoulder and the *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST) muscles were removed from the hind limb. The *longissimus thoracis et lumborum* (LTL) muscle was removed from between the last lumbar vertebra and the cervical vertebra and the *psoas major* (fillet) muscle was removed from the ventral surface of the lumbar vertebrae and the last rib as demonstrated in Figure 3.2. After removal of the seven muscles, ultimate pH (pH_U) was measured with a calibrated Crison PH25 pH meter (Crison Instruments, Barcelona, Spain) in each muscle and the weights of the individual muscles were recorded. Thereafter, a fresh meat sample was cut for physical analyses (Chapter 4) and another sample was vacuum packed and stored at -20 ˚C for further chemical analysis (Chapter 5) at the University of Stellenbosch laboratories.

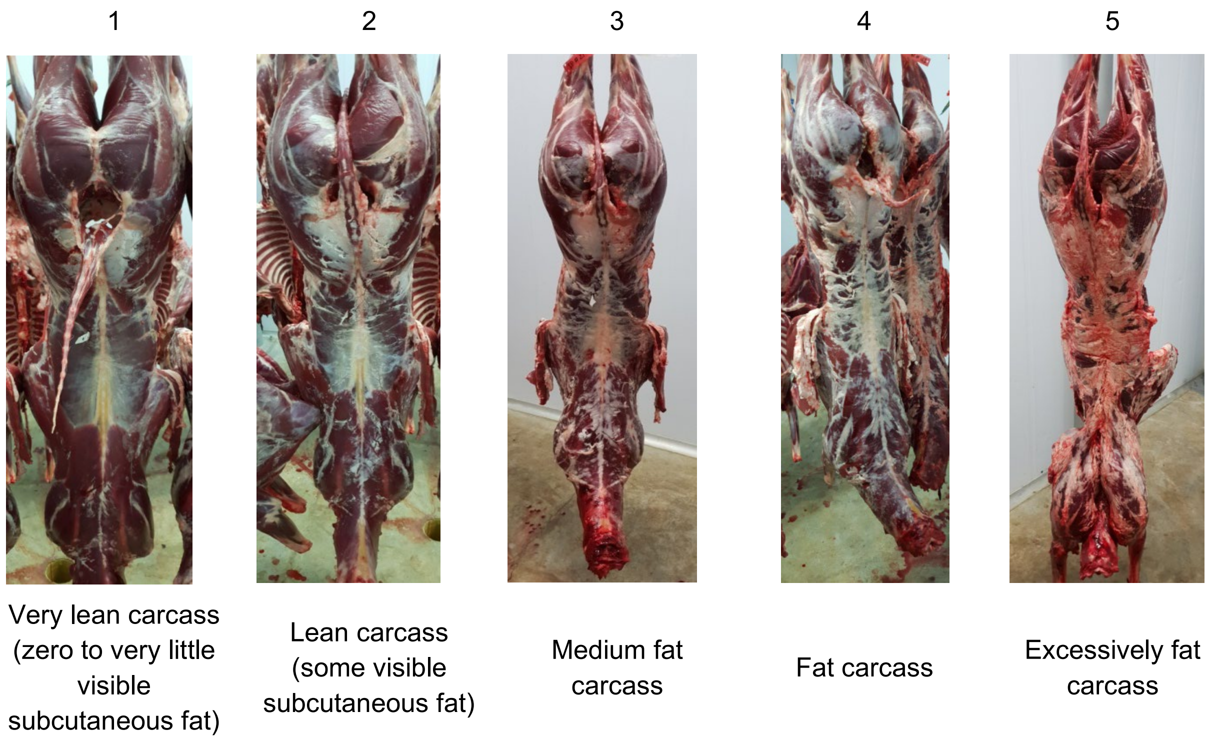

Figure 3.1 Visual representation of BCS (1-5) of Impala used as a guideline to classify the carcasses.

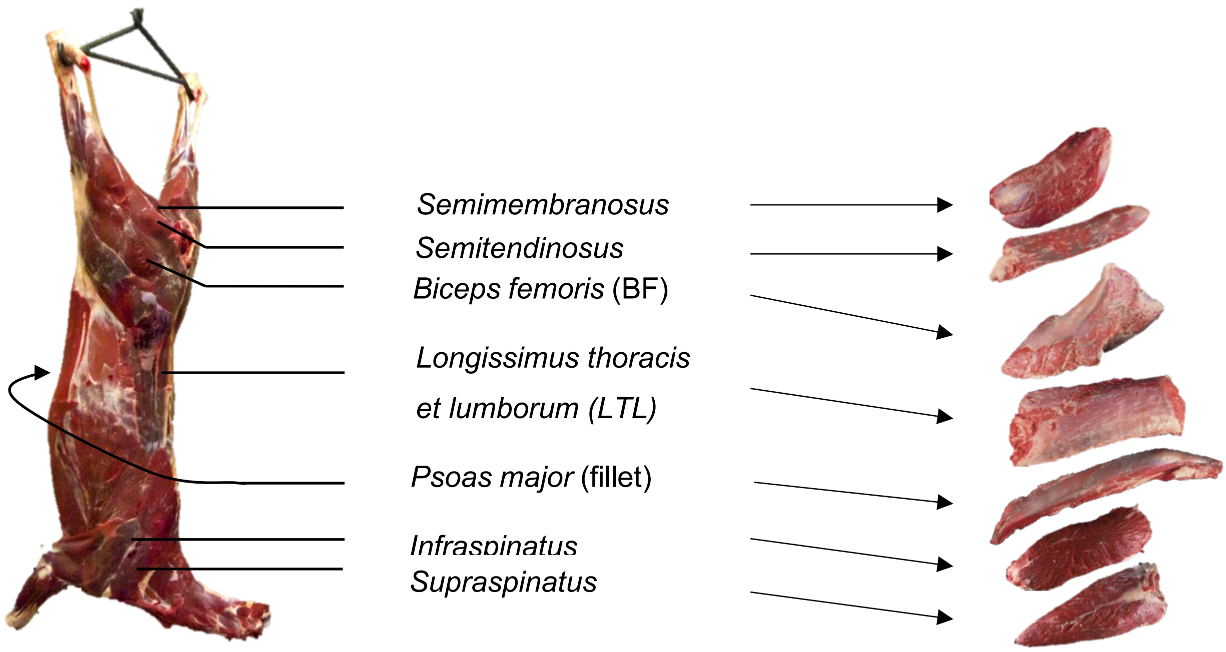

Figure 3.2 Lateral view of a dressed carcass as well the anatomical location and illustration of the seven muscles removed for analyses, adapted from Jones, Guru, Singh, Carpenter, Calkins & Johnson (2004) and Raines (2011).

3.2.3 Statistical analysis

The trial had a completely randomized design where age (1.5-, 4.5- and >6.5-years old) and sex (1.5-year old bulls and heifers) were the fixed effects tested independently and the animals as random repetitions. Eight animals were harvested for each age group. Statistica (version 13.5, Statsoft inc. 2013) was used to analyse the data collected on the trial. Normal probability plots were inspected to check normality assumptions, and were found to be acceptable. If an observation's standardized residual diverged from the model value (deviating significantly from normality), it was identified as an outlier and removed. The effects of age and sex on the carcass, offal and muscle weights were analysed by performing a mixed model repeated measures of analysis of variance (ANOVA's) on the data to determine the significant differences between the age groups and sex. A 5 % significant level was set as a guideline for determining significant age and sex effects. Where significant differences occurred, a post hoc test (Fisher's least significant differences) was run (on the age data) and the values reported as the Least Square Means and standard deviation.

3.3 RESULTS

The effects of age and sex on carcass yields of male and female blue wildebeest are presented in Table 3.2. The 1.5-year old heifers had the lightest mean dead weight (112.03 ± 4.03 kg) and cold carcass weight (56.35 ± 6.75 kg) in comparison to the 4.5- and >6.5-year old cows. The 4.5-year old cows had the heaviest dead weight (203.63 ± 9.54 kg) however, the cold carcass weights did not differ significantly from that of the >6.5-year old cows. The >6.5-year old cows exhibited a higher dressing percentage than that of the 1.5-year old heifers. When the carcass yields of the 1.5-year old bulls and heifers were compared, the bulls exhibited significantly heavier mean dead weight, cold carcass weight, as well as dressing percentage (Table 3.2).

Table 3.2 Least squares means for carcass yields (± Standard deviation (SD) of the mean) and p-values indicating the effect of age and sex on carcass characteristics of blue wildebeest.

Parameter		Age		Sex		p-values	
				Female	Male		
		>6.5-years (n=8)	4.5-years (n=8)	1.5-years (n=8)	1.5-years (n=8)	Age	Sex
Dead weight	kg	188.55^{b} ± 12.56	203.63^{a} ± 9.54	112.03^{c} ± 11.88	174.25 ± 16.73	**<0.01**	**<0.01**
Cold carcass weight	kg	100.15^{a} ± 10.01	105.45^{a} ± 6.82	56.35^{b} ± 6.75	94.05 ± 9.65	**<0.01**	**<0.01**
Dressing percentage	%	53.10^{a} ± 3.55	51.78^{ab} ± 1.99	50.24^{b} ± 1.00	53.95 ± 0.92	0.08	**<0.01**

^{a,b,c} Different superscripts within a row for a specific parameter indicate significant differences between age groups. Significant differences are highlighted in bold ($p \leq 0.05$).

As depicted in Table 3.3, the cows from the two older age groups exhibited heavier head, legs and skin weights as well as total external offal weights than the 1.5-year old heifers. However, the 4.5-year old cows exhibited a lower total external offal percentage than the two other age groups. The heaviest heart, GIT and udder weights were associated with the 4.5-year old cows. The 4.5- and >6.5-year old cows had similar weights for the lungs and trachea, liver and kidneys. Furthermore, the 1.5-year old heifers had the lowest weights for all the components contributing to the total internal offal weight (Table 3.3). The oldest cows had significantly lower percentage contributions of the liver, kidneys and GIT than the 1.5-year old heifers. The 4.5-year old cows also exhibited the heaviest total internal organ weights in comparison to the two other age groups. When the total internal offal weight was expressed as a percentage of the dead weight, the >6.5-year old animals exhibited a significantly lower percentage than the females from the other two younger age groups. Furthermore, the 4.5-year old cows had the heaviest total offal weight (88.83 ± 5.75 kg) as well as relative yields whilst the youngest animals had the lightest weight (51.75 ± 5.39 kg). The highest percentage of total offal was observed in the 1.5-year old heifers (46.21 ± 0.94 %) and the lowest percentage was associated with the oldest cows (40.14 ± 1.81 %).

Table 3.3 demonstrates further that the 1.5-year old bulls were associated with significantly heavier total external offal and internal offal weights (33.76 ± 2.50 kg; 37.31 ± 3.37kg, respectively) compared to the heifers (20.09 ± 2.14 kg; 31.66 ± 3.53 kg, respectively). Furthermore, the bulls had a higher percentage contribution of the total external offal and a lower contribution of the total internal offal than the heifers. The bulls also exhibited heavier head, legs, skin, heart, lungs and trachea, liver, kidneys and GIT weights than the heifers. When the different components of the external and internal offal weights were expressed as a percentage contribution of the dead weight, significant differences were only noted for the head, skin, lungs and trachea, GIT and kidney percentages (Table 3.3). The bulls exhibited higher head, skin and lungs and trachea percentages and lower GIT and kidney percentages than the heifers. The bulls had significantly heavier total offal and lower percentage total offal contribution than the heifers.

As illustrated in Figure 3.3a, the two older age groups exhibited a higher BCS than the youngest females. The bulls exhibited a significantly higher BCS when compared to the heifers (Figure 3.3b). Figure 3.4 further demonstrates that 1.5-year old heifers exhibited BCS of 1 (four heifers) and 2 (four heifers). The latter was lower that observed for the older cows. The 4.5-year old age group had four cows with BCS of 3, two cows exhibiting BCS of 4 and another two cows with a BCS of 5. It was also noted that the >6.5-year old cows exhibited a BCS ranging from 3 (three cows) to 4 (three cows), however some animals had a BCS of 2 (two cows). Furthermore, most of the bulls exhibited a BCS ranging of 3 (five bulls), whilst some bulls had a lower BCS of 2 (three bulls).

To compare muscle yields between different age groups and sexes, two muscles from the shoulder (forequarter), the entire back muscle and three muscles in the hindquarter and the fillet were weighed. The results gained from the data collected on the muscle yields are depicted in Table 3.4.

The cows from the two older age groups exhibited significantly heavier muscles weights than the 1.5-year old heifers; however, the percentage contribution of most of the muscles was similar to that recorded for the muscles of the heifers.

Furthermore, the >6.5-year old cows exhibited the highest percentage contribution of the LTL muscle. The 1.5-year old heifers exhibited lower percentage contribution of the BF muscle and the highest percentage for the SM muscle. When the effect of sex on the muscle yields of young blue wildebeest were compared, the bulls were associated with the heaviest muscle weights. However, no differences between the bulls and heifers were noted for the percentage contributions all the muscles except for the SM.

Table 3.3 The effect of age and sex on least squares means (± SD of the mean) of offal contributors (kg and %) and p-values of blue wildebeest.

Parameter		**Age**				**p-values**	
				Sex			
				Female	**Male**		
		>6.5-years (n=8)	**4.5-years** (n=8)	**1.5-years** (n=8)	**1.5-years** (n=8)	**Age**	**Sex**
Dead weight	kg	188.55[b] ± 12.56	203.63[a] ± 9.54	112.03[c] ± 11.88	174.25 ± 16.73	**<0.01**	**<0.01**
Head[1]	kg	12.619[a] ± 0.73	12.79[a] ± 0.75	7.97[b] ± 0.56	12.68 ± 1.30	**<0.01**	**<0.01**
	%	6.71[b] ± 0.37	6.28[c] ± 0.30	7.15[a] ± 0.44	7.28 ± 0.42	**<0.01**	**0.53**
Legs	kg	3.74[a] ± 0.26	3.86[a] ± 0.29	2.79[b] ± 0.30	4.31 ± 0.38	**<0.01**	**0.00**
	%	1.98[b] ± 0.10	1.90[b] ± 0.06	2.50[a] ± 0.11	2.48 ± 0.19	**<0.01**	0.88
Skin	kg	16.94[a] ± 1.77	16.73[a] ± 1.95	9.33[b] ± 1.36	16.78 ± 1.55	**<0.01**	**<0.01**
	%	8.99 ± 0.79	8.20 ± 0.69	8.31 ± 0.55	9.66 ± 0.73	0.64	**<0.01**
Total external offal	kg	33.29[a] ± 2.26	33.38[a] ± 2.84	20.09[b] ± 2.14	33.76 ± 2.50	**<0.01**	**<0.01**
	%	17.68[a] ± 0.92	16.18[b] ± 1.08	17.94[a] ± 0.71	19.42 ± 0.69	**<0.01**	**<0.01**
Heart	kg	1.20[b] ± 0.19	1.45[a] ± 0.22	0.70[c] ± 0.14	1.09 ± 0.12	**<0.01**	**<0.01**
	%	0.63 ± 0.08	0.72 ± 0.12	0.63 ± 0.12	0.63 ± 0.08	0.22	0.98
Lungs & trachea	kg	1.94[a] ± 0.35	2.11[a] ± 0.22	1.28[b] ± 0.18	2.06 ± 0.24	**<0.01**	**<0.01**
	%	1.03 ± 0.20	1.03 ± 0.09	1.15 ± 0.10	1.18 ± 0.12	0.19	**0.51**
Liver	kg	2.07[a] ± 0.26	2.17[a] ± 0.14	1.35[b] ± 0.11	2.08 ± 0.22	**<0.01**	**<0.01**
	%	1.10[b] ± 0.08	1.07[b] ± 0.08	1.21[a] ± 0.09	1.19 ± 0.09	**<0.01**	0.64
Kidneys	kg	0.38[a] ± 0.04	0.38[a] ± 0.01	0.25[b] ± 0.02	0.36 ± 0.03	**<0.01**	**<0.01**
	%	0.20[b] ± 0.02	0.19[b] ± 0.01	0.23[a] ± 0.02	0.21 ± 0.02	**<0.01**	**0.04**
Spleen	kg	0.51 ± 0.16	0.53 ± 0.06	0.40 ± 0.16	0.57 ± 0.18	0.13	0.07
	%	0.27 ± 0.07	0.26 ± 0.04	0.35 ± 0.12	0.33 ± 0.09	0.07	0.58
GIT[2]	kg	36.13[b] ± 2.52	49.21[a] ± 2.86	27.68[c] ± 3.16	31.16 ± 2.91	**<0.01**	**0.04**
	%	19.24[b] ± 1.79	24.16[a] ± 0.74	24.70[a] ± 1.06	17.91 ± 0.95	**<0.01**	**<0.01**
Udder	kg	1.03[b] ± 0.53	1.85[a] ± 0.31	0.15[c] ± 0.03		**<0.01**	
	%	0.55[b] ± 0.29	0.91[a] ± 0.14	0.14[c] ± 0.04		**<0.01**	
Total internal offal	kg	42.22[b] ± 2.63	55.84[a] ± 2.87	31.66[c] ± 3.53	37.31 ± 3.37	**<0.01**	**<0.01**
	%	22.46[b] ± 1.76	27.43[a] ± 0.71	28.27[a] ± 1.19	21.44 ± 1.03	**<0.01**	**<0.01**
Total offal	kg	75.51[b] ± 2.86	88.83[a] ± 5.75	51.75[c] ± 5.39	71.07 ± 5.75	**<0.01**	**<0.01**
	%	40.14[c] ± 1.81	43.60[b] ± 1.34	46.21[a] ± 0.94	40.86 ± 1.60	**<0.01**	**<0.01**

Head[1] = includes tongue and horns. GIT[2] = Gastro-intestinal tract includes stomach and intestines.
[a,b,c] Different superscripts within a row for a specific parameter indicate significant differences between age groups. Significant differences are highlighted in bold ($p \leq 0.05$).

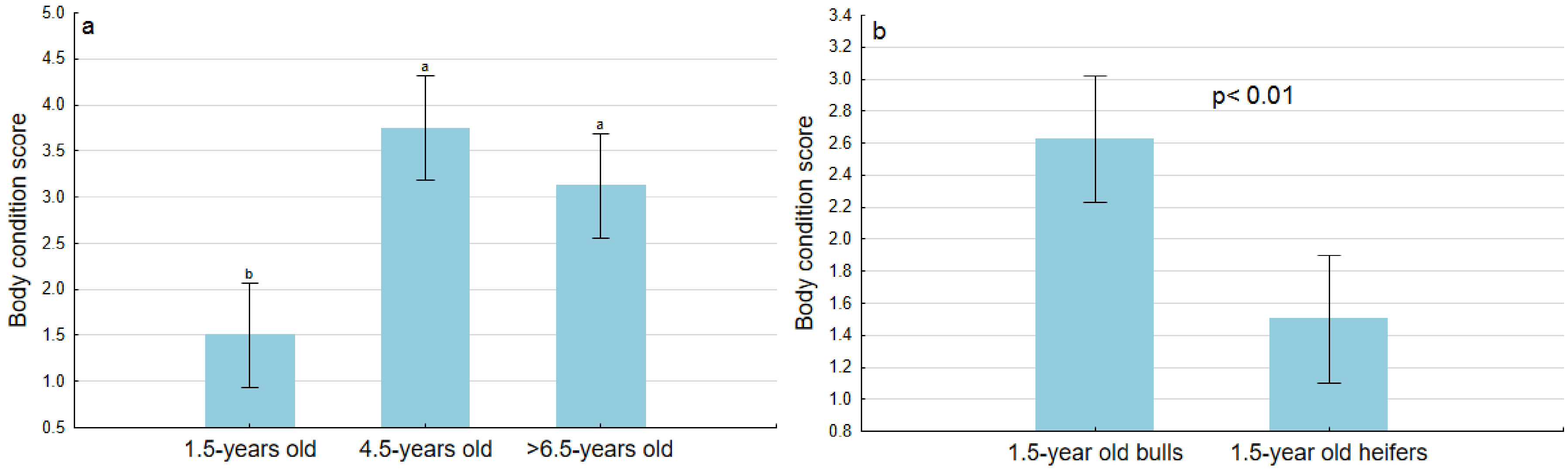

Figure 3.3 Least squares means of the body condition score (BCS) of the dressed carcasses of blue wildebeest (a) as influenced by age (1.5-, 4.5- and >6.5-years old) (b) and sex (1.5-year old bulls and heifers).

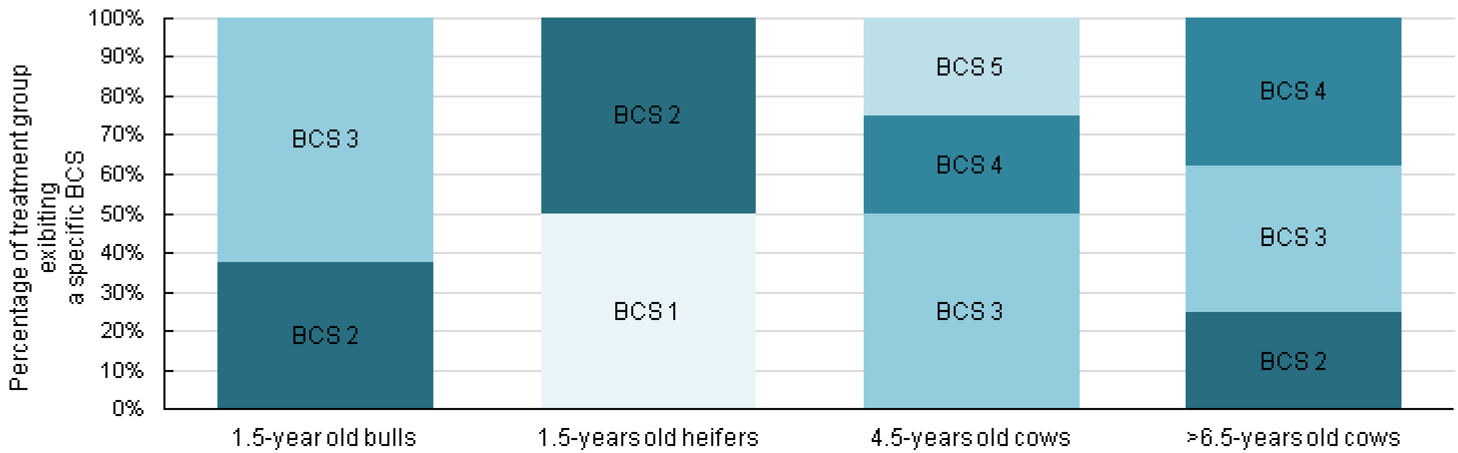

Figure 3.4 The percentage of treatment groups exhibiting a specific body condition score (BCS).

Table 3.4 Least squares means (± SD of the mean) weights (kg) of seven muscles (excised from the left side of the carcass) and percentage contribution (%) to the cold carcass weight of blue wildebeest as influenced by age and sex.

Muscle		**Age**				**P-values**	
				Sex			
				Female	**Male**		
		>6.5-years (n=8)	**4.5-years** (n=8)	**1.5-years** (n=8)	**1.5-years** (n=8)	**Age**	**Sex**
LTL	kg	3.14^{a} ± 0.36	3.07^{a} ± 0.26	1.73^{b} ± 0.23	2.93 ± 0.40	**<0.01**	**<0.01**
	%	3.13^{a} ± 0.10	2.91^{b} ± 0.20	3.07^{ab} ± 0.18	3.10 ± 0.13	**0.04**	0.68
BF	kg	2.79^{a} ± 0.29	3.00^{a} ± 0.22	1.54^{b} ± 0.18	2.57 ± 0.36	**<0.01**	**<0.01**
	%	2.79^{ab} ± 0.05	2.85^{a} ± 0.10	2.73^{b} ± 0.12	2.72 ± 0.11	**0.05**	0.94
SM	kg	2.58^{a} ± 0.33	2.75^{a} ± 0.32	1.66^{b} ± 0.16	2.49 ± 0.42	**<0.01**	**<0.01**
	%	2.57^{b} ± 0.15	2.61^{b} ± 0.17	2.96^{a} ± 0.18	2.64 ± 0.21	**<0.01**	**<0.01**
ST	kg	0.75^{a} ± 0.07	0.81^{a} ± 0.07	0.44^{b} ± 0.08	0.70 ± 0.10	**<0.01**	**<0.01**
	%	0.70 ± 0.12	0.77 ± 0.03	0.78 ± 0.07	0.75 ± 0.06	0.18	0.32
IS	kg	0.74^{a} ± 0.21	0.90^{a} ± 0.19	0.52^{b} ± 0.07	0.83 ± 0.09	**<0.01**	**<0.01**
	%	0.74 ± 0.18	0.86 ± 0.17	0.93 ± 0.04	0.88 ± 0.05	0.06	0.07
SS	kg	0.61^{a} ± 0.12	0.68^{a} ± 0.05	0.36^{b} ± 0.05	0.61 ± 0.07	**<0.01**	**<0.01**
	%	0.60 ± 0.08	0.65 ± 0.05	0.64 ± 0.02	0.65 ± 0.04	0.30	0.37
Fillet	kg	0.49^{a} ± 0.07	0.55^{a} ± 0.04	0.28^{b} ± 0.05	0.47 ± 0.07	**<0.01**	**<0.01**
	%	0.49 ± 0.04	0.52 ± 0.02	0.50 ± 0.04	0.49 ± 0.03	0.19	0.95
Total (seven muscles)	kg	11.34^{a} ±1.12	11.77^{a} ± 0.90	6.53^{b} ± 0.78	10.60 ± 1.43	**<0.01**	**<0.01**
	%	11.35± 0.80	11.16 ± 0.37	11.60 ± 0.42	11.24 ± 0.40	0.31	**0.01**

Abbreviations: LTL=*longissimus thoracis et lumborum*, BF=*biceps femoris*, SM=*semimembranosus*, ST=*semitendinosus*, IS=*infraspinatus*, SS=*supraspinatus*.
[a,b,c] Different superscripts within a row for a specific parameter indicate significant differences between age groups. Significant differences (p≤0.05) are highlighted in bold.

3.4 DISCUSSION

The growth of an animal can be measured as an increase in weight per unit time as well as in the changes in composition resulting from differential growth of the components of an animal's body (Fowler, 1986). The growth of tissue, muscle, fat and bone and their proportions in the carcass are considered the most important aspects which will largely determine the economic value of the carcass.

It is evident that an animal with access to additional feed (supplement) tend to have heavier dead weight than those without (Berg & Butterfield, 1976). The latter was observed in the current study, where the 4.5-year old cows had a heavier mean dead weight (±15 kg heavier), and also showed a trend towards higher BCS scores than the >6.5-year old cows. The 4.5-year old cows had access to supplementary feed throughout their growth phase, which explains the better growth and body conditioning as reflected by BCS scores. In addition, supplementary feeding also contributed to heavier GIT weight when compared to the >6.5-year old cows, due to higher gut fill. The combined effects of supplemental feeding contributed to the heavier dead weight associated with these animals. The older cows were all purchased as mature breeding stock from wild populations and brought onto the farm two years prior to the experimental trial. The latter had received no additional nutrition in their early stages of development. The results observed in the current study are similar to that noted by Attwell (1982), where the average body weight of adult blue wildebeest females was 187 kg and the maximum body weight was 215.9 kg. Atwell (1982) also noted that as the animal's age increases, the rate of increase in body weight (kg) declines. A 94.3 kg increase in body weight was observed before the blue wildebeest reached an age of one year; a further 49 kg increase to reach two years of age and another 17.5 kg when it reached the age of three years (Attwell, 1982). It has also been reported that female game species such as the greater kudu *(Tragelaphus strepsiceros)* reach maximum weight at 4-5-years of age, thereafter the weight will start to decrease (Furstenburg, 2009).

The dead weight of an animal can be misleading due to the variability of non-carcass parts (blood, skin, head and feet); therefore, carcass weight is more useful as an end point for growth (Berg & Butterfield, 1976). The 4.5-year old cows exhibited similar cold carcass- and muscle weights, as well as dressing percentage than that reported for the mature >6.5-year old cows, which means that the additional feeding advanced carcass maturation in this.

The dressing percentage of an animal is calculated by expressing the dressed carcass weight as a percentage of the dead weight. High dressing percentages indicate lower offal and high meat and fat yield, which is more desired (Van Zyl & Ferreira, 2004). The dressing percentages of the blue wildebeest cows in all three of the age groups (50.24-53.10 %) in the current trial are comparable to the dressing percentage of adult (52.6 %) and sub-adult (51.5 %) blue wildebeest bulls observed by Van Heerden & Hoffman (2018) and Van Schalkwyk, Hoffman & Muller (2004). The dressing percentage can be influenced by various factors, including dressing techniques used during slaughter as well as the GIT fill (Mostert & Hoffman, 2007). Van Heerden & Hoffman (2018) concluded that a higher GIT percentage contribution results in a lower dressing percentage. The same trend was observed in the current study, where the percentage contribution of the GIT was lower for the oldest age group, resulting in a higher dressing percentage. The lower than expected dressing percentage of the 4.5-year old age group, because of the relatively high carcass weight, was due to higher gut fill. The dressing percentage of the animals from all three age groups fell in the range of the dressing percentage of popular domestic and commercial breeds such as Nguni, Bonsmara and Angus which exhibit dressing percentages that range between 50.3-53.8 % (Muchenje, Dzama, Chimonyo, Raats, & Strydom, 2008). However, it is essential to consider the fat percentage of a dressed carcass as well as the blood loss when comparing different species.

Sex is another factor that affects the carcass composition and distribution of weight within the different tissues (Berg & Butterfield, 1976). Generally, males tend to gain weight faster, convert feed more efficiently and produce heavier carcasses without excess fat. This phenomenon was also shown in the current study where the 1.5-year old bulls exhibited ±62 kg heavier mean dead weight, ±38 kg heavier cold carcass weight and ±4 % higher dressing percentage than the heifers (Table 3.3). Associated with higher carcass weights were higher BCS for male animals.

Similar results were reported for male and female fallow deer (*Dama dama*), where the males exhibited heavier live weight (±6 kg heavier), warm- (±4 kg heavier) and cold carcass weights (±5 kg heavier) (Fitzhenry et al., 2019). However, contrasting results were reported for the aforementioned parameters measured in adult male and female black wildebeest (*Connochaetes gnou*) (Van Schalkwyk et al., 2004), mountain reedbuck (*Redunca fulvorufula*) (Hoffman, Van Schalkwyk, & Muller, 2008) and common eland (*Taurotragus oryx*) (Needham, Laubser, Kotrba, Bureš, & Hoffman, 2019) for which no differences occurred for the dressing percentage. In a study on kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*), adult kudu males were associated with heavier dead weight and carcass weight than females, while no differences occurred between the adult female and female impala. Furthermore, no differences occurred between sub-adult male and female impala for the parameters (Mostert & Hoffman, 2007).

When game animals are slaughtered, edible by-products are produced, including internal and external offal. It is essential to investigate the production potential of the by-products of animals in order to determine the economic value of the individual (Young, Wagener, & Bronkhorst, 1969) and as the offal plays a vital role as a food source in Africa (Hoffman, Laubscher, & Leisegang, 2013; Magwedere, Sithole, Hoffman, Hemberger, & Dziva, 2013). In the current study, the external, as well as internal offal yields (kg) were measured and expressed as a percentage of the dead weight. The heaviest mean total internal offal weight was observed for the 4.5-year old cows (55.8 kg), whilst the 1.5-year old heifers exhibited the lightest weights (31.7 kg) (Table 3.3). However, the higher offal weight was mainly due to the higher gut fill which resulted in heavier GIT weights. A different tendency was noted by Van Heerden & Hoffman (2018) where no significant differences were observed between the total internal offal weights of adult (52.8 kg) and sub-adult (45.1 kg) blue wildebeest bulls.

Animal tissue and organs undergo differential growth which will be visible by changes in the shape, size and structure and proportions of parts of an animal at different stages of the natural growth curve of an animal (Jones, 2004). The 4.5-year old cows received supplementary feed during their growth period, which could explain the similar external and internal offal weights than that of the oldest cows (excluding the GIT) observed in the current study. Furthermore, the fifth quarter parts grow proportionally faster than carcass parts up to a certain age; thereafter the carcass parts will catch up. The latter was also observed in the current study where the 1.5-year old heifers tended to have the highest total external (17.94 %), total internal (28.27 %) and total offal (46.21 %) percentages than the two older age groups.

Due to the similar weights recorded for the edible offal (except the GIT) of the 4.5- and >6.5-year old cows, it is possible to harvest older cows while achieving a highly profitable production potential in terms of offal weights. The internal offal weights of the 4.5-year old yields to a similar weight range noted for English cattle breeds and <50 % *B. indicus* heifers (Terry, Knapp, Edwards, Mies, Savell & Cross, 1990). The older blue wildebeest cows produce heavier offal yields when compared to various game species such as the kudu (Mostert & Hoffman, 2007), blesbok (*Damaliscus dorcas phillipsi*) (Smit, Hoffman, & Muller, 2004) and impala (Mostert & Hoffman, 2007).

As expected, sex also had a significant effect on the internal and external offal yields. The 1.5-year old bulls of the current study had ±14 kg heavier total external offal, ±6 kg heavier internal offal weights and ±20 kg heavier total offal weights than the heifers. Both sexes of the blue wildebeest bear well-developed horns, however, the horns of females are thinner and associated with smaller bosses compared to bulls. Therefore, the head weights of females are significantly lower than those of males (Skinner & Chimba 2005). The heavier skin weights of males can also be attributed to a thicker skin that protects them during fighting. Attwell (1982) noted that males already have a larger heart girth than females at an early stage of development resulting in heavier heart weights.

The dead weight of an animal affects the proportions of offal which was also observed in the current study. When the external-, internal- and total offal weights were expressed as a percentage contribution of the dead weight the bulls showed higher percentages for the total external offal (±2 % higher), whilst the heifers had higher percentage contributions for the total internal (±7 %) and total offal (±5 %). The higher percentages observed for the internal offal of the heifers could be attributed to the larger GIT proportion (±7 % higher) in relation to the dead weight, possibly due to higher gut fill. Similar results were reported by Engels, Hoffman, & Needham (2019), where male impala also exhibited higher total external offal percentages and lower total internal and total offal percentages than females. Contradicting results were reported for adult male and female common eland for which no differences occurred between the percentage contributions of internal offal (Needham et al., 2019). Mostert & Hoffman (2007) also observed no sex effect on the head, feet and skin weights of sub-adult male and female kudu and impala. However, when they compared the external offal weights of adult female and male kudu and impala, adult males exhibited heavier external offal weights compared to females. It may be possible that sexual dimorphism influences the external offal weights at an earlier growth stage in species such as the blue wildebeest.

The BCS (body condition score) is an indication of the body reserves of an animal, stored as adipose tissue, and is widely used in the sheep, beef and dairy cattle industries (Lowman et al., 1976). Wildlife management practices include regular body condition scoring often used as surrogates for fitness-related traits or as a measure of habitat quality which are of key interest (Morfeld, Meehan, Hogan, & Brown, 2016). Wildlife breeding is an import aspect of the wildlife production systems, intending to produce offspring that exhibits the favourable genes selected by the breeder. Due to the extensive nature of the farming practices and sometimes inaccessible terrain, it is difficult to measure a wild animal's reproductive success. Therefore, producers need to investigate alternative methods of measuring these reproductive parameters. Furthermore, according to Jakob, Marshall, & Uetz (1996), the body condition is an estimate of the nutritional state of an animal, providing information on the physiological fitness (which can affect reproductive performance) of the individual. The BCS evaluation can also be used as a *post-mortem* visual indication of the amount of fat visible on a carcass, which influences the meat production potential (Pryce, Coffey, & Simm, 2001). In the current study, the BCS, which was based on the principles used in the beef cattle industry, was recorded after the dressing process was completed on the chilled carcasses. According to Jones (2004), adipose tissue in the animal's body is deposited after muscle tissue, thus explaining the lower BCS observed in the youngest age group. Studies on dairy cows have shown that the body weight and BCS of the animals changes with age (Renquist, Oltjen, Sainz, & Calvert, 2006). In mammals, large herbivore females only start producing offspring at two or three years of age (Flajšman, Jerina, & Pokorny, 2017). The low body condition of the youngest group could thus be attributed to the relative proportional increase in growth at different times, as described by Berg & Butterfield (1976).

As depicted in Figure 3.4, many of the bulls exhibited a BCS of 3 (62.50 %) whilst 50 % of the heifers noted a BCS of 2 and the other 50 % exhibited a BCS of 1. The latter indicates better muscle conformation as well as a larger amount of fat present in the carcasses of the 1.5-year old bulls. The latter was also observed in the muscle weights for which the bulls had significantly heavier weights than the heifers. The heavier muscles exhibited by the bulls could be attributed to the larger body size and heavier dead weight. The development of muscle in the neck and thoracic regions of males increase as the bull becomes sexually mature. If animals are slaughtered at a constant weight, heifers tend to deposit fat sooner than bulls. As little research has been conducted on the growth patterns of tissue of wildlife species, the results reported in this study will be compared to those noted for domestic livestock species. As mentioned, males perform better than females in terms of growth and feed conversion due to the high anabolic effect of male sex hormones (Craigie et al., 2012; Crouse, Busboom, Field, & Ferrell, 1981). Therefore, male animal will develop higher muscle mass than females.

Individual muscle weights are important to investigate when determining the meat yield of an animal. Beef carcasses are divided into wholesale cuts or primals, each consisting of several muscles. However, when these cuts are portioned for packaging to be sold as fresh cuts, the meat may be derived from a single muscle (Lawrie & Ledward, 2006). Selected individual muscles are regarded as economically valuable cuts due to their better eating quality characteristics, and high lean meat to bone ratio compared to others or cuts with combined muscles (Ledger, 1963; Keane & Allen, 1998). In the current study, the seven muscles chosen is a good representation commercially important meat cuts of the carcass.

The muscle size and weight of animals are linked to the development of the body (Van Heerden & Hoffman, 2018). Both the older age groups from the current study showed heavier muscles weights than the 1.5-year old heifers, which can be regarded as a function of carcass weight. Żochowska-Kujawska et al. (2019) also compared the weights of the BF, SM, ST, LTL and IS muscles derived from reindeer bucks and reported similar tendencies; the 54-month old bucks also exhibited higher muscles weights in comparison to the 18-month old bucks due to carcass weight differences. Furthermore, the muscles' percentage contribution to body weight is high at birth relative to fat, thereafter it rises slightly and starts to decrease in percentage as the fattening phase takes over (Berg & Butterfield, 1976). Similar percentages were reported for most of the muscles when the 4.5- and >6.5-year old blue wildebeest cows were compared. The 1.5-year old heifers are at the onset of puberty, at which an increase in the hindquarters can be observed. According to Berg & Butterfield (1976), the prevalence of higher proportion of hindquarter muscles in younger animals tends to decrease as the animal gets older due to the movement of weight from the hind- to the forequarters of an animal.

When the muscle weights were expressed as a percentage contribution to cold carcass weights, no differences were noted for all the muscles of the bulls and heifers (except for the SM muscle). Similar percentage contributions of the LTL, SM and IS muscles were confirmed by Needham et al. (2019) when male and female common eland were compared. Grand (1991) reported that the highest percentage of back musculature in blue wildebeest was associated with the thoracic and cervical (neck) region of the animal. The blue wildebeest can thus be classified as dorsostable runners. The development in this region could counteract the proportional development of the muscles located in the hindquarter, such as the SM. An increase in muscle development in these regions, provides supports as the centre of gravity is shifted to the forelimbs and it also assists the animal when competing for the breeding of cows (Fitzhenry, Hoffman, Cawthorn, & Muchenje, 2016; Jones, 2004; Lawrie & Ledward, 2006). Although neck muscles were no weighed to support this theory, it was expected that the two shoulder muscles would have been better developed in the male animal, but no differences were recorded.

Regardless of age and sex, the LTL, BF and SM muscles had the highest percentage contribution to the cold carcass weight and the ST, IS, SS and fillet muscles the lowest. Grand (1991) illustrated that the percentage of muscle is the highest in the hind limb, followed by the forelimb of adult brindled gnu and sable antelope. These muscles are known for exhibiting high growth rates as a result of high functional demands to provide maximum performance (Jones, 2004). The muscles located in the hindquarters of an animal are of economic importance due to their high yields. According to Jones, Arnaud, Gouws & Hoffman (2017), the LTL muscle is popular for biltong production due to its elongated shape that allows for longer cuts along the muscle fibres. The IS and SS muscles are located in the shoulder of an animal and are classified as lower value cuts which are typically processed further into minced products (Van Heerden & Hoffman, 2018).

3.5 CONCLUSION

The aim of this research chapter was to explain the effect of age and sex on carcass characteristics of blue wildebeest. The information gathered from this chapter will be of value to wildlife farmers who aim to produce meat from older, surplus breeding cows as well as young sub-adult bulls which are unsuitable for breeding (1.5-years old). The study was divided into two trials.

Trial one investigated and compared various carcass yields between cows of 1.5-, 4.5- and >6.5-years of age. The 1.5-year old heifers had the lowest carcass, offal and muscle yields as well as the lowest BCS. Therefore, it is suggested that these animals are harvested at an older age for heavier carcass yields. Furthermore, no significant differences were observed between the 4.5- and >6.5-year old cows for carcass characteristics, such as cold carcass weight and dressing percentage and muscle yields. The latter is a clear indication that the older cows remain suitable for meat production in terms of carcass yields. It should also be emphasised that supplementary feeding, if cost effective, could advance the development of animals towards maturity.

The second trial investigated the influence of sex on carcass yields. The 1.5-year old bulls were associated with heavier dead weights, cold carcass weights, external and internal offal weights as well as higher dressing percentages compared to the same aged heifers. It was also concluded that the blue wildebeest could possibly fall into an early maturing breed category in comparison to other large wildlife species. Furthermore, the young bulls showed high dressing percentage and high carcass yields in terms of heavy total offal and the seven muscles' total weights, which indicates that these young bulls are suitable for meat production in terms of carcass yields.

This study provided baseline data on the carcass yield of blue wildebeest cows of differing ages; further research should include bulls of different ages as well to establish the age effect on carcass yields of bulls. Even though this trial provided a baseline indication of the differences between the three age groups, it is advisable for future studies to include more age groups. We recommend that future trials be conducted on animals that received similar feeding regimes and are of comparable genetic potential. Future studies could compare the effect of age and sex on meat-to-bone ratios as well as the effect on commercial and primal cut yields. Before the meat from animals of different ages can enter the supply chain, the effect of age and sex on the essential meat quality parameters should be established to ensure high-quality meat products.

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CHAPTER 4

THE PHYSICAL QUALITY OF BLUE WILDEBEEST (Connochaetes taurinus) MUSCLES AS INFLUENCED BY AGE AND SEX

ABSTRACT

The physical meat quality of six muscles (*Longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS)) of blue wildebeest females of different ages (1.5-, 4.5- and <6.5-years old) was determined to quantify the effect of age thereon. The effect of sex was also determined by comparing the same six muscles of 1.5-year old heifers to same-aged bulls. The >6.5-year old cows exhibited the highest pH_U values for all six muscles. The LTL, ST and IS muscles of the oldest cows had pH_U values >5.9 and was classified as dark-firm-dry (DFD) meat. Most of the muscles of 4.5- and >6.5-year old cows showed a tendency of lower drip loss than the heifers. The heifers exhibited higher cooking loss for the LTL, BF and ST muscles than the oldest cows. The 4.5- and >6.5-year old cows produced tougher meat (SS and IS) than the youngest age group. Many of the muscles of the 4.5-year old cows were associated with more vivid colour as a result of high a* and b* values. The latter was also associated with higher oxymyoglobin percentages (OMb) for the SS and IS muscles than the young heifers. The muscles of the 1.5-year old heifers showed a lighter (higher L* values), less red colour (high hue-angle) with higher metmyoglobin (MMb) percentages (more brown colour) in the ST and SS muscles than the two older age groups. Furthermore, the muscles of the young blue wildebeest bulls had higher pH_U values than the heifers; some muscles (LTL and ST) had pH_U >5.9. There were also little differences between the tenderness of the majority of the muscles, however the heifers exhibited tougher SM muscles than the bulls. Many of the muscles located in the back and hindquarters of bulls appeared darker (lower L* value and higher total Mb content) with a redder colour (lower hue-angle) than the heifers. The latter was attributed to the lower MMb% and higher OMb% observed for the BF and ST muscles of the bulls than the heifers. Most of the muscles of the blue wildebeest can be classified as tender (<42 N), with good water-holding capacity and desired colour, except for the some of the muscles classified as DFD and the ST muscle of the heifers exhibiting a light colour.

Keywords: Colour, Cooking loss, Drip loss, Fresh meat, Shear force, Ultimate pH

4.1 INTRODUCTION

Food security has become a predicament in a world with a rapidly growing population. It has been predicted that in the year 2025 the population would reach 7.5-8 billion and in the years 2050 and 2100 an extreme total of 11- and 16 billion, respectively (United Nations, 2004). In South Africa, a large proportion of the population consume high-protein foods, including meat and dairy products (ARC, 2015). Worldwide, approximately 56 billion land animals are raised and slaughtered annually for human consumption. Additionally, double the number of animals will need to be produced in the year 2050 in order to meet these increased demands for animal protein (Steinfeld, 2006). Currently, red meat production is considered as one of the largest agricultural commodities in South African agriculture (DAFF, 2018) and meat is regarded as an integral part of the South African cuisine by local citizens (Erasmus & Hoffman, 2017). At present, a R22-R28 price gap, in favour of meat from domestic animals, exists when compared to game meat (± R140/kg of fresh game meat) (Slabbert & Saayman, 2018). The latter implies that the game meat producing sector has the potential to grow even further with the production of a unique product (Furstenburg, 2018). Therefore, the goal of game meat producers should not only be to create a comparable product to livestock, but to market a niche product that is indigenous to South Africa (Hoffman, Schalkwyk, & Muller, 2008). In conjunction with the increasing population growth, a global shift is occurring towards a healthier, more sustainable lifestyle (Swanepoel, Leslie, Rijst, & Hoffman, 2016). The latter have led to increased consumer awareness of nutritional content of meat, health benefits as well as animal welfare and origin of meat (Revilla & Vivar-Quintana, 2006). Game meat is a protein rich and low in fat and cholesterol food source (Hoffman & Wiklund, 2006). More opportunities exist to exploit the production possibilities of game meat in South Africa due to it being an 'organic' (limited use of chemical production enhancers), 'ethical' (ethical harvesting and raising of animals) and 'sustainable' industry (Carruthers, 2007; Hoffman & Wiklund, 2006; Needham, Laubser, Kotrba, Bureš, & Hoffman, 2019).

The game farming industry consists of four pillars, including game breeding, hunting, game viewing (eco-tourism) and game meat products (DEA, 2018). Approximately 9000 commercial and private wildlife ranches cover ±16.8 % landmass (20.5 million hectares) of South Africa. When considering only processed game meat products, a total of R1.2 billion is generated per annum (DEA, 2018). Additionally, the game farming industry has evolved into a scientific as well as a species-specific discipline. The latter could be attributed to improved management techniques as well as the increase in available research on specific game species. Hunters also show preference for specific species, which may be based on the price of a species.

In the year 2015, blue wildebeest bulls and cows were the most popular species sold at auctions. The latter is also listed under the top ten preferred species for both trophy- and biltong hunting (DEA, 2018). The blue wildebeest has various colour variants of which the golden- and king wildebeest are the most preferred for trophy hunting (Olivier & Butler, 2015; Taylor et al., 2016). In past years, game breeders bred blue wildebeest splits (F1 generation) which carry the recessive genes responsible for the colour variants due to the increased interest and demand of breeders and trophy hunters for these coloured animals. Currently, the majority of game breeders have adequate numbers of colour variants and excess breeding stock which do not meet their high breeding criteria. This, coupled with the fact that some game ranchers also have limited vegetation to maintain excess animals, requires that the excess animals be removed (sold as live animals or to hunters) or harvested for meat. Game breeders also inspect the breeding potential of young bulls, selecting only the bulls exhibiting favourable characteristics for further breeding purposes. The sub-standard young bulls and older cows will consequently enter the meat production system. However, these surplus animals enter the meat production sector at different ages.

It is well-known that animal age influences the tenderness (Purslow, 2005), IMF (Żochowska-Kujawska, Kotowicz, Sobczak, Lachowicz, & Wójcik, 2019), fatty acid composition (Van Schalkwyk, Hoffman & Muller, 2004) as well as the colour of meat from domesticated and wildlife species (Neethling et al., 2017). Typically, meat from older animals is less tender than younger animals, possibly as a result of cross-linkages forming soluble heat-resistant structures (Hoffman et al., 2009).

The sex of an animal also plays an integral role in determining the quality of meat. Generally, the meat from young males tend to be relatively darker, as a result of higher myoglobin content, and tougher than that of females (Sebsibe, 2008; Seideman et al.,, 1982).

However, limited research is available on the influence of age and sex on physical characteristics of game meat, particularly from blue wildebeest. The aim of this study is to provide baseline data for the specialized game meat production industry of South Africa by evaluating the influence of age and sex on the physical quality of various blue wildebeest muscles.

4.2 METHODS AND MATERIALS

4.2.1 Animals and study location

The study was conducted on Romaco Ranch in the Limpopo province. The ranch utilises a semi-intensive management system which allocates a total of 7000 ha of veld to breed an abundance of wildlife species. The experimental trial included 32 blue wildebeest to determine the effect of age and sex on physical parameters of meat quality. The study was divided into two trials. The first trial consisted of 24 blue wildebeest females, the animals being divided into three age groups (1.5-, 4.5- and >6.5-years old) with eight animals allocated to each age group. The animals were maintained in 100-150 ha breeding camps. The 1.5-year old heifers and 4.5-year old cows had access to supplementary feed throughout their growth period. In contrast, the >6.5-year old cows were introduced onto the farm two years prior to the trial and received no supplementary feed during their growth phase. The second trial consisted of eight additional 1.5-year old bulls which were bred on the farm and also received a supplementary feed, formulated by Wildswinkel (protein (120 g/kg), energy (8.2 MJ/kg), moisture (120 g/kg), fat (25 g/kg), fibre (190 g/kg), Ca (7 g/kg), P (2 g/kg), K (1 g/kg), Mg (1 g/kg) & Na (1 g/kg)). These bulls were compared to the heifers from the first trial to quantify the effect of sex on physical characteristics of blue wildebeest muscles.

Refer to the Methods and Materials described in Chapter 3.2.1 for a more detailed description.

4.2.2 Harvesting and dressing

Refer to the Methods and Materials described in Chapter 3.2.2 for a detailed description of the harvesting and dressing techniques in the study.

4.2.3 Muscle sampling and analysis

After the 24-hour cooling period, six muscles were excised from the left side of the carcass for further analysis. The *infraspinatus* (IS) and *supraspinatus* (SS) muscles were removed from the shoulder; the *biceps femoris* (BF), *semimembranosus* (SM) and *semitendinosus* (ST) muscles were removed from the hind limb, whilst the *longissimus thoracis et lumborum* (LTL) muscle was removed from between the last lumbar vertebra and the cervical vertebra. The individual muscle weights were recorded and kept for physical analysis. Thereafter, a ±200 g sample of each muscle from every animal was taken for chemical analysis (Chapter 5). These samples were frozen at -20°C to await further analysis at the laboratory at the Department of Animal Sciences, Stellenbosch University.

4.2.4 Physical analysis

The standardized methods described by Honikel (1998) were used as a reference for the assessment of the physical characteristics of the meat. Steaks of ±2 cm thickness were cut from the central region of each muscle, perpendicular to the longitudinal axis of the muscle. Thereafter, various physical tests were performed on the steaks immediately after removal to determine their physical quality.

4.2.4.1 Acidity (pH) and Temperature

The ultimate pH (pH_U) was recorded in the centre of the individual muscles after removal, 24 hours *post-mortem*. An incision was made into the muscles, after which a calibrated Crison pH25 portable pH meter (Crison Instruments, Barcelona, Spain) was used to measure the pH_U. The electrodes were rinsed with distilled water between each measurement. Additionally, the temperature was recorded with the pH meter, since the electrodes have a built-in temperature sensor.

4.2.4.2 Colour

The surface colour of the fresh meat samples was measured using a calibrated Colour-guide 45˚/0˚ colorimeter which uses D65 lightning, 11mm diameter that measures aperture and 10° viewing angle with a specular component included in the measuring head. (BYK-Gardner GmbH, Gerestried, Germany). Five measurements were recorded on different sites on the exposed surface of the muscle samples after blooming for proximately 30 minutes at room temperature. The colorimeter reports coordinates measuring CIE L* (lightness), CIE a* (green-red value) and CIE b* (blue yellow). Furthermore, the hue-angle and chroma value were calculated using the CIE a* and CIE b* values as follows (Commission International de l'Eclairage, 1976):

$$\text{Hue-angle } (^\circ) = \tan^{-1}\left(\frac{b^*}{a^*}\right) \qquad \text{Chroma value } (C^*) = \sqrt{(a^*)^2 + (b^*)^2}$$

4.2.4.3 Water-holding capacity (WHC)

Various methods exist for measuring the WHC of meat. Drip loss and cooking loss are both functions of the WHC of meat and were therefore determined using the two procedures described by Honikel (1998).

Drip loss percentage: steaks (approximately 80-100 g) were cut and immediately weighed. Thereafter the steaks were suspended in an inflated plastic bag, ensuring that that the sample did not touch the sides of the bag. After the sample was chilled (4˚C) for 24 hours, the samples were gently blotted dry with absorbent paper and weighed again. The moisture loss was expressed as a percentage of the initial weight of each sample.

Cooking loss percentage: steaks (±2 cm thick) were cut perpendicular to the longitudinal axis of the muscles and weighed immediately (initial weight). The steaks were placed in plastic bags and submerged into a water-bath (80˚C) for 60 minutes. Thereafter, the samples were chilled at 4˚C. The cooled samples were removed from the plastic bags, gently blotted dry and weighed. The cooking loss percentage was determined by the difference between the raw and cooked weight and expressed as a percentage of the initial weight.

4.2.4.4 Warner Bratzler shear force (WBSF)

A mobile Instron machine (Emerson Electrics, S44EXTJ-988, ST. Louis, United States of America) fitted with a Warner Bratzler shear attachment (1.2 mm thick blade with a triangular opening, 13 mm at the widest point and 15 mm high) was used to determine the tenderness of the meat samples. Cooked meat samples used for cooking loss measurement were utilised to determine the tenderness of the meat. Samples were cooled to 10˚C temperature. A minimum of six cylindrical cores (1.27 cm diameter) were removed with a hand corer from the steaks and sheared perpendicularly to the fibres' longitudinal orientation. Maximum shear force values (kg/1.27 cm ø) at a cross head speed of 33.3mm/s were measured and recorded for each of the 6 samples. To determine the tenderness of the muscles, the average of the readings was calculated and converted into Newton (N) as follows:

$$\text{Shear force (N)} = (\text{kg per } 1.27 \text{ cm } \Phi) * 9.81 / (\text{Area of the } 1.27 \text{ cm } \Phi \text{ core}).$$

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

Larger N values are generally associated with tougher meat

4.2.5 Chemical analysis

4.2.5.1 Sample preparation

Prior to homogenisation, the samples were thawed for 18 hrs in their packaging (± 4°C). Thereafter, excess fat and connective tissue were trimmed from each sample where after the samples were cut into smaller pieces. The latter were homogenised to produce a paste-like mixture, vacuumed-packed to ensure no moisture loss or oxidation and stored at -20°C until scheduled for analyses. Before chemical analysis was performed, these samples were thawed overnight (± 4°C).

4.2.5.2 Relative proportion of myoglobin forms

To determine the myoglobin content of the meat, a 5 g sample was homogenised with 50 ml of a phosphate buffer (pH 6.8) and chilled on an ice bed for 1 hour. Thereafter, it was centrifuged at 4000rpm for 30 minutes at 4°C. The extract was filtrated through filter paper (Whatman 4), where after 200 µl were pipetted into separate wells of a microplate. The wells were scanned and spectrophotometer readings were recorded of the supernatant between 400-700 nm (Warris, 1979) Specific wavelengths were used to calculate the redox myoglobin forms (deoxymyoglobin; DMb, oxymyoglobin; OMb and metmyoglobin; MMb) of myoglobin (Mb) in six muscles of male and female blue wildebeest (Tang, Faustman, Hoagland, 2004). The method described by Tang et al. (2004) was used to calculate the latter. Reflex attenuance refers to the logarithm of the reciprocal of reflectance. Tang et al. (2004) used wavelength maxima at 503 nm for MMb, 557 nm for DMb, and 582 nm for OMb. The method is based on reflex attenuance which requires that all reflectance values be converted to their corresponding reflex attenuance values prior to any calculation (Tang, Faustman & Hoagland, 2004). The following calculations (5a-c) were used to calculate the percentages of the various Mb redox forms of fresh meat:

Equation 5a: MMb % = $\left(-0.159\left(\frac{R582}{R525}\right) - 0.085\left(\frac{R557}{R525}\right) + 1.262\left(\frac{R503}{R525}\right) - 0.52\right) \times 100$

Equation 5b: DMb % = $\left(-0.543\left(\frac{R582}{R525}\right) + 1.594\left(\frac{R557}{R525}\right) + 0.552\left(\frac{R503}{R525}\right) - 1.329\right) \times 100$

Equation 5c: OMb % = $\left(-0.722\left(\frac{R582}{R525}\right) - 1.432\left(\frac{R557}{R525}\right) - 1.659\left(\frac{R503}{R525}\right) - 2.599\right) \times 100$

Where R1, R2 and R3 where the absorbance (A ratios of A582/A525, A557.A525 and A503/A525, respectively (Warris, 1979; Krzywicki, 1982).

4.2.6 Statistical analysis

The data obtained from the various methods described above were analysed using Statistica version 13.5 (StatSoft, 2013). Various measurements were conducted on different muscles of the same animal, therefore a mixed model Analysis of Variance (ANOVA) was performed per muscle (LTL, BF, SM, ST, IS & SS). The study was divided into two trials to investigate the effect of age (trial one) and sex (trial two) independently. In the first trial, age was treated as a fixed effect; wherein the second trial sex was the fixed effect. For both of the trials, animals were treated as a random effect. Normal probability plots were inspected to check normality assumptions, and were found to be acceptable. A 5% significant level was set as a guideline for determining significant age and sex effects. Where significant differences occurred, a post hoc test (Fisher's least significant differences; $p \leq 0.05$) was run and the values were reported as the Least Square Means and standard error.

4.3 RESULTS

4.3.1 Acidity (pH$_U$)

As depicted in Figure 4.1(a), age significantly affected the pH$_U$ of the six muscles obtained from the blue wildebeest females. The >6.5-year old cows had the highest pH$_U$ values in comparison to the two younger age groups. Furthermore, no differences were observed between the pH$_U$ in all six muscles obtained from the 4.5- and 1.5-year old females. The 1.5-year old bulls exhibited higher pH$_U$ values in the LTL, BF, SM, and ST muscles than the heifers (Figure 4.1(b)).

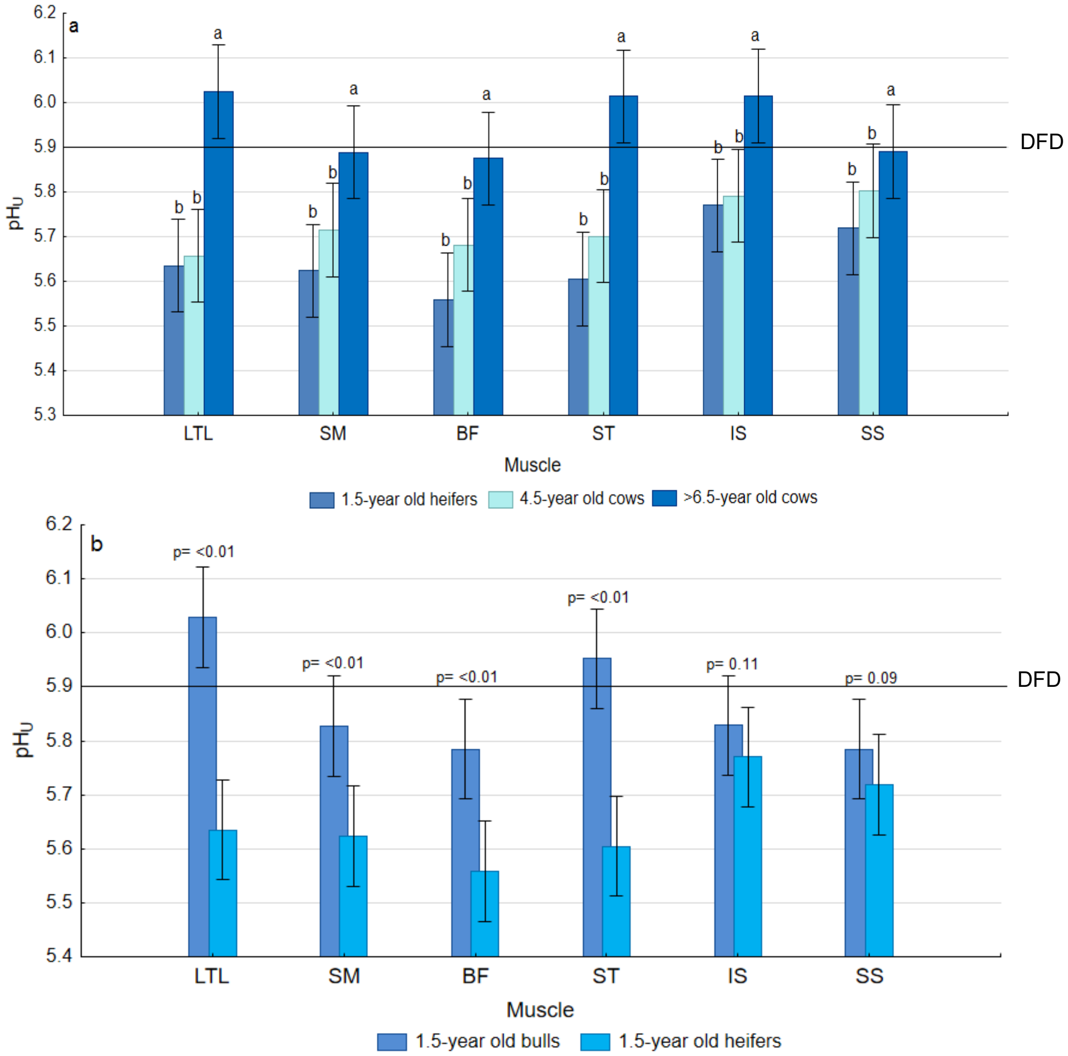

Figure 4.1 Least square means of the pH$_U$ values of six muscles of (a) blue wildebeest females of different ages and (b) 1.5-year old blue wildebeest bulls and heifers. The solid line indicates the muscles with pH$_U$ values >5.9 which is considered as DFD meat (Jerez-Timaure et al., 2019).

4.3.2 Water-holding capacity

Drip loss and cooking loss are both functions of WHC of meat and should thus be considered when measuring meat quality.

As pertaining to drip loss, the 1.5-year old heifers recorded significantly higher drip loss than the 4.5- and >6.5-year old cows for the BF, SM, ST and SS muscles (Table 4.1). However, for the LTL muscle, the 1.5- and 4.5-year old females showed higher drip loss than the >6.5-year old cows. With regards to the effect of sex on drip loss, the young bulls were associated with lower drip loss for the LTL, SM and SS muscles.

No significant differences occurred between the cooking loss of five of the muscles (LTL, BF, SM, ST and SS) of the 4.5- and >6.5-year old cows (Table 4.1). The >6.5-year old cows exhibited significantly lower cooking loss for the LTL, BF and ST muscle than the 1.5-year old heifers. The IS muscle of the 4.5-year old cows had a higher cooking loss than the 1.5- and >6.5-year old females. When the 1.5-year old blue wildebeest bulls and heifers were compared, the heifers exhibited higher cooking loss for the BF and ST muscles.

4.3.3 Tenderness (Warner Bratzler shear force)

No significant differences occurred for the shear force values of the BF and SM muscles between all three age groups (Table 4.1). However, a tendency of a higher shear force of the LTL of the two older age groups than the youngest females was noted. The IS and SS muscles of the 4.5- and >6.5-year old cows were less tender than that of the 1.5-year old heifers. Furthermore, the 4.5-year old cows showed higher shear force values for the ST muscle than the oldest cows.

When the shear force values of the young bulls and heifers were compared, the heifers were associated with higher values for the SM and the SS muscles.

Table 4.1 Least square means for physical characteristics (±Standard deviation of the mean) and p-values indicating the effect of age and sex on the physical measurements of six muscles of male and female blue wildebeest.

Parameter	Muscle	Age				p-values	
				Sex			
				Female	Male		
		>6.5-years (n=8)	4.5-years (n=8)	1.5-years (n=8)	1.5-years (n=8)	Age	Sex
Drip loss %	LTL	$1.5^{b} \pm 0.27$	$2.0^{a} \pm 0.28$	$2.4^{a} \pm 0.61$	1.4 ± 0.20	**<0.01**	**<0.01**
	BF	$1.5^{b} \pm 0.39$	$1.6^{b} \pm 0.21$	$2.3^{a} \pm 0.61$	1.8 ± 0.55	**<0.01**	0.11
	SM	$1.8^{b} \pm 0.89$	$2.0^{b} \pm 0.64$	$3.6^{a} \pm 1.05$	2.1 ± 0.87	**<0.01**	**0.01**
	ST	$1.2^{b} \pm 0.30$	$1.3^{b} \pm 0.18$	$1.7^{a} \pm 0.37$	1.4 ± 0.53	**<0.01**	0.20
	IS	$0.9^{b} \pm 0.10$	$0.9^{b} \pm 0.07$	$1.3^{a} \pm 0.21$	1.1 ± 0.46	**<0.01**	0.20
	SS	$1.0^{b} \pm 0.06$	$1.1^{b} \pm 0.25$	$1.5^{a} \pm 0.25$	1.1 ± 0.08	**<0.01**	**<0.01**
Cooking loss %	LTL	$37.1^{b} \pm 1.57$	$38.2^{ab} \pm 1.31$	$39.1^{a} \pm 1.35$	39.1 ± 0.80	**0.03**	0.90
	BF	$38.3^{b} \pm 1.88$	$39.3^{b} \pm 0.81$	$42.0^{a} \pm 1.25$	40.1 ± 1.17	**<0.01**	**<0.01**
	SM	40.9 ± 1.77	41.1 ± 1.16	41.6 ± 0.74	41.1 ± 1.06	0.49	0.25
	ST	$40.5^{b} \pm 1.73$	$41.4^{ab} \pm 1.49$	$42.1^{a} \pm 0.91$	40.7 ± 1.15	0.10	**0.02**
	IS	$35.3^{b} \pm 1.24$	$37.4^{a} \pm 0.95$	$35.4^{b} \pm 1.19$	36.0 ± 1.13	**<0.01**	0.32
	SS	38.4 ± 0.86	39.5 ± 1.57	38.4 ± 0.62	39.2 ± 0.89	0.10	0.08
Shear force (N)	LTL	$32.9^{ab} \pm 8.84$	$34.5^{a} \pm 9.63$	$27.2^{b} \pm 6.55$	26.9 ± 7.75	0.11	0.90
	BF	27.9 ± 5.74	24.4 ± 6.22	29.8 ± 7.05	25.6 ± 6.46	0.14	0.08
	SM	30.8 ± 10.45	26.2 ± 7.70	31.3 ± 6.51	26.4 ± 8.36	0.29	**0.04**
	ST	$26.7^{b} \pm 4.18$	$31.4^{a} \pm 6.91$	$30.2^{ab} \pm 4.76$	26.2 ± 5.30	0.09	0.09
	IS	$26.3^{a} \pm 4.02$	$28.6^{a} \pm 4.82$	$23.4^{b} \pm 3.69$	21.1 ± 4.64	**<0.01**	0.32
	SS	$23.5^{a} \pm 4.60$	$23.7^{a} \pm 5.63$	$18.2^{b} \pm 3.29$	19.8 ± 4.58	**<0.01**	0.50

Abbreviations: LTL=*longissimus thoracis et lumborum*, BF=*biceps femoris*, SM=*semimembranosus*, ST=*semitendinosus*, IS=*infraspinatus*, SS=*supraspinatus*.

[a,b,c] Different superscripts within a row for a specific parameter indicate significant differences ($p \leq 0.05$) between age groups.

4.3.4 Surface colour

As depicted in Table 4.2, the 1.5-year old heifers were associated with significantly higher L* values in all six muscles when compared to the 4.5- and >6.5-year old cows. No differences occurred between the L* values of BF, SM, ST, IS and SS of the 4.5- and >6.5-year old cows, however the LTL muscle of >6.5-year cows were darker. The 1.5- and >6.5-year old females exhibited lower a* values than the 4.5-year old cows in the LTL, BF, SM and IS muscles. Furthermore, the 4.5- and >6.5-year old cows recorded significantly higher a* values (more redness) for the ST and SS muscles than the 1.5-year old heifers. Concerning the b* values, the 1.5- and 4.5-year old females reported significantly higher values for the LTL and ST muscles than the >6.5-year old cows. Furthermore, the 4.5- and 6.5-year old cows exhibited lower b* values for the BF and SM muscles than the 1.5-year old heifers. With regards to the chroma values, the >6.5-year old cows exhibited significantly lower chroma values in the LTL, BF, SM, ST, and IS muscles than the 4.5-year old cows. However, no differences occurred between the chroma values of the LTL, BF, ST and IS of the 1.5- and >6.5-year old females. The 1.5-year old heifers were associated with significantly lower chroma values of the ST, IS and SS muscles than the 4.5-year old cows. Furthermore, the 4.5- and >6.5-year old cows exhibited significantly lower hue-angle values of all the muscles than the 1.5-year old heifers.

When the effect of sex on L* values was investigated, the young bulls exhibited significantly lower values in the LTL, BF, SM and ST muscles than the heifers. No differences occurred between the a* values measured in five muscles of the bulls and heifers, however, the heifers exhibited lower values in the SS muscle. The 1.5-year old bulls were associated with significantly lower b* values in the LTL, SM and ST muscles than the heifers. Furthermore, the 1.5-year old bulls exhibited significantly lower chroma values for the LTL muscle than the heifers. The 1.5-year old bulls exhibited significantly lower hue-angle values in the SM, ST and SS muscles than the heifers.

Table 4.2 Least square means for colour characteristics (±Standard deviation of the mean) and p-values indicating the effect of age and sex on the colour parameters of six muscles of male and female blue wildebeest.

Parameter	**Muscle**	**Age**				**p-values**	
				Sex			
				Female	**Male**		
		>6.5-years (n=8)	**4.5-years** (n=8)	**1.5-years** (n=8)	**1.5-years** (n=8)	**Age**	**Sex**
CIE L*	LTL	30.6^{c} ± 2.37	32.5^{b} ± 1.47	37.7^{a} ± 1.73	33.3 ± 2.04	**<0.01**	**<0.01**
	BF	32.1^{b} ± 3.24	34.8^{b} ± 2.33	39.1^{a} ± 3.45	35.9 ± 2.78	**<0.01**	**0.05**
	SM	30.3^{b} ± 2.04	31.3^{b} ± 2.60	38.9^{a} ± 2.75	34.0 ± 2.74	**<0.01**	**<0.01**
	ST	34.0^{b} ± 3.58	35.8^{b} ± 2.21	43.0^{a} ± 2.12	37.3 ± 3.38	**<0.01**	**<0.01**
	IS	31.3^{b} ± 2.32	31.5^{b} ± 2.35	35.8^{a} ± 1.30	36.2 ± 1.57	**<0.01**	0.33
	SS	32.5^{b} ± 2.25	32.6^{b} ± 1.94	36.2^{a} ± 1.04	35.3 ± 1.58	**<0.01**	0.09
CIE a*	LTL	10.5^{b} ± 1.73	12.9^{a} ± 1.89	10.8^{b} ± 1.06	10.1 ± 1.10	**<0.01**	0.13
	BF	12.8^{b} ± 1.39	14.3^{a} ± 1.48	12.6^{b} ± 1.35	12.3 ± 1.35	**<0.01**	0.59
	SM	13.2^{b} ± 1.90	15.2^{a} ± 1.46	13.5^{b} ± 1.25	12.7 ± 1.94	**0.02**	0.20
	ST	12.6^{b} ± 1.41	14.3^{a} ± 1.61	10.9^{c} ± 1.75	11.2 ± 1.73	**<0.01**	0.68
	IS	14.4^{b} ± 1.44	15.5^{a} ± 1.51	13.8^{b} ± 1.24	13.7 ± 1.06	**<0.01**	0.85
	SS	15.2^{a} ± 1.30	15.0^{a} ± 1.07	13.5^{b} ± 1.26	14.3 ± 1.19	**<0.01**	**0.03**
CIE b*	LTL	7.9^{b} ± 1.45	9.3^{a} ± 1.13	9.8^{a} ± 1.83	8.3 ± 1.07	**<0.01**	**<0.01**
	BF	9.8^{b} ± 1.56	11.3^{ab} ± 1.61	11.9^{a} ± 2.02	10.9 ± 1.70	**0.02**	0.22
	SM	9.6^{b} ± 1.92	11.2^{b} ± 1.80	12.9^{a} ± 1.74	11.0 ± 1.96	**<0.01**	**0.03**
	ST	10.9^{b} ± 1.47	12.2^{a} ± 1.60	13.1^{a} ± 0.78	11.2 ± 1.46	**<0.01**	**<0.01**
	IS	10.2 ± 1.22	10.9 ± 1.38	11.1 ± 1.10	11.0 ± 0.81	0.12	0.80
	SS	10.8 ± 1.52	10.5 ± 1.31	10.9 ± 0.76	11.0 ± 0.91	0.71	0.60
Chroma	LTL	13.2^{b} ± 2.15	15.9^{a} ± 2.04	14.6^{ab} ± 1.45	13.1 ± 1.40	**<0.01**	**0.01**
	BF	16.2^{b} ± 2.00	18.3^{a} ± 2.06	17.4^{ab} ± 2.22	16.5 ± 1.97	0.08	0.30
	SM	16.4^{b} ± 2.61	18.9^{a} ± 2.19	18.7^{a} ± 1.99	16.9 ± 2.39	**0.03**	0.06
	ST	16.7^{b} ± 1.70	18.8^{a} ± 1.92	17.1^{b} ± 1.22	15.9 ± 1.83	**<0.01**	0.06
	IS	17.7^{b} ± 1.78	19.0^{a} ± 1.90	17.7^{b} ± 1.56	17.5 ± 1.25	**0.04**	0.81
	SS	18.7^{a} ± 1.85	18.4^{a} ± 1.40	17.4^{b} ± 1.33	18.1 ± 1.42	**0.03**	0.07
Hue-angle	LTL	36.7^{b} ± 2.99	36.0^{b} ± 2.69	41.9^{a} ± 6.76	39.6 ± 2.79	**<0.01**	0.17
	BF	37.2^{b} ± 2.30	38.1^{b} ± 2.36	43.3^{a} ± 3.21	41.3 ± 3.11	**<0.01**	0.09
	SM	35.9^{b} ± 2.37	36.3^{b} ± 2.23	43.7^{a} ± 2.39	40.9 ± 5.35	**<0.01**	**0.05**
	ST	40.9^{b} ± 3.81	40.5^{b} ± 3.71	50.3^{a} ± 5.04	45.1 ± 4.90	**<0.01**	**0.02**
	IS	35.2^{b} ± 2.01	35.1^{b} ± 2.21	38.8^{a} ± 1.85	38.8 ± 1.59	**<0.01**	0.99
	SS	35.1^{b} ± 2.39	35.0^{b} ± 2.96	39.0^{a} ± 1.98	37.6 ± 1.51	**<0.01**	**0.02**

^{a,b,c} Different superscripts within a row for a specific parameter indicate significant differences (p≤0.05) between age groups.

4.3.5 Myoglobin redox forms and total myoglobin content

As pertaining to Table 4.3, a significant age effect was observed for MMb % and OMb % measured in the ST and SS muscles of blue wildebeest females. The two older age groups showed lower MMb % for the ST and SS muscles and exhibited higher OMb % for the SS muscle than the 1.5-year old heifers. The 4.5-year old cows also exhibited higher OMb % for the IS muscle than the young heifers. Furthermore, the >6.5-year old cows had higher OMb % for -the ST and SS muscles than the 1.5-year old heifers.

Interesting results were observed when DMb % of the six muscles of different ages was compared. The 1.5- and >6.5-year old females were associated with higher DMb % in the LTL, SM and ST muscles than the 4.5-year old cows. Furthermore, total Mb (mg/g) content of all six muscles increased significantly from the youngest age group to the oldest age group.

Regarding the effect of sex, the 1.5-year old bulls were associated with lower MMb% and higher OMb% for the BF and ST muscles than the 1.5-year old heifers. Furthermore, the bulls showed higher total Mb content for five of the muscles (LTL, SM, ST, IS & SS) than the heifers. Regardless of age and sex, the muscles had the highest MMb%, followed by OMb% and DMb%.

Table 4.3 Least square means (±Standard deviation) for the myoglobin content of six muscles of male and female blue wildebeest, demonstrating the influence of age and sex on the different muscle types.

Parameter	Muscle	Age				p-values	
				Sex			
				Female	Male		
		>6.5-years (n=8)	**4.5-years** (n=8)	**1.5-years** (n=8)	**1.5-years** (n=8)	**Age**	**Sex**
MMb%	LTL	49.6 ± 5.43	50.7 ± 10.04	51.4 ± 4.58	49.2 ± 2.17	0.59	0.08
	BF	47.1 ± 3.39	50.6 ± 9.04	50.4 ± 5.22	46.2 ± 3.80	0.13	**<0.01**
	SM	46.4 ± 3.90	49.9 ± 9.43	49.9 ± 4.63	48.8 ± 5.34	0.08	0.92
	ST	49.5^{b} ± 3.04	48.0^{b} ± 5.79	52.9^{a} ± 3.28	49.8 ± 2.49	**<0.01**	**<0.01**
	IS	43.0 ± 3.77	42.2 ± 8.83	45.6 ± 2.82	44.1 ± 2.68	0.23	0.17
	SS	42.6^{b} ± 1.99	39.1^{b} ± 9.11	50.3^{a} ± 8.51	45.8 ± 3.33	**<0.01**	0.12
OMb%	LTL	31.3 ± 6.11	34.5 ± 10.12	30.6 ± 5.19	33.0 ± 3.69	0.34	0.14
	BF	35.4 ± 3.67	30.0 ± 14.90	31.8 ± 5.25	37.1 ± 6.15	0.06	**0.03**
	SM	36.1 ± 4.18	32.1 ± 15.32	33.0 ± 4.91	33.7 ± 6.28	0.15	0.95
	ST	31.6^{a} ± 3.19	32.4^{ab} ± 9.49	27.8^{b} ± 2.76	32.0 ± 4.01	**<0.01**	**<0.01**
	IS	40.0^{ab} ± 1.74	40.1^{a} ± 1.74	35.0^{b} ± 1.74	37.6 ± 4.46	**0.03**	0.11
	SS	40.6^{a} ± 2.87	42.2^{a} ± 14.23	31.4^{b} ± 7.41	34.7 ± 5.62	**<0.01**	0.27
DMb%	LTL	19.1^{a} ± 2.12	14.7^{b} ± 3.29	17.7^{a} ± 2.33	17.6 ± 2.24	**<0.01**	0.75
	BF	17.5 ± 1.08	19.7 ± 9.26	17.6 ± 2.02	16.4 ± 3.09	0.67	0.32
	SM	17.6^{a} ± 0.92	15.1^{b} ± 2.67	16.9^{a} ± 1.91	17.3 ± 2.80	**<0.01**	0.78
	ST	19.1^{a} ± 1.12	16.9^{b} ± 1.57	19.3^{a} ± 1.97	18.2 ± 2.40	**<0.01**	0.25
	IS	17.1 ± 1.14	17.5 ± 5.78	19.2 ± 3.91	18.1 ± 4.11	0.13	0.22
	SS	16.8 ± 1.11	18.8 ± 8.71	18.2 ± 4.66	19.3 ± 4.19	0.35	0.30
Total Mb (mg/g)	LTL	13.4^{a} ± 2.19	8.7^{b} ± 1.74	6.8^{c} ± 1.39	10.0 ± 1.70	**<0.01**	**<0.01**
	BF	12.6^{a} ± 2.33	8.8^{b} ± 1.39	7.9^{b} ± 2.50	9.0 ± 1.90	**<0.01**	0.08
	SM	11.6^{a} ± 2.75	8.8^{b} ± 1.72	6.9^{c} ± 1.35	10.2 ± 3.80	**<0.01**	**<0.01**
	ST	11.7^{a} ± 2.07	8.9^{b} ± 0.82	7.5^{c} ± 1.07	9.7 ± 1.90	**<0.01**	**<0.01**
	IS	13.9^{a} ± 1.01	11.1^{b} ± 1.90	9.3^{c} ± 0.80	11.4 ± 1.81	**<0.01**	**<0.01**
	SS	15.2^{a} ± 1.80	11.4^{b} ± 2.02	9.7^{c} ± 1.40	12.9 ± 1.55	**<0.01**	**<0.01**

MMb=Metmyoglobin, OMb= Oxymyoglobin, DMb=Deoxymyoglobin, Mb=Myoglobin
^{a,b,c} Different superscripts within a row for a specific parameter indicate significant differences ($p \leq 0.05$) between age groups.

4.4 DISCUSSION

The rate and extent of *post-mortem* pH decline affects the water-holding capacity, tenderness, colour as well as the shelf-life of fresh meat products (Hughes, Oiseth, Purslow, & Warner, 2014). The ultimate pH (pH_U) of the muscle normally decreases from the normal pH of 7.2 to 5.3-5.8 *post-mortem* (Honikel, 2004). The pH_U is also a very important determinant of microbial growth, where most bacteria grow at pH 7 (Lawrie & Ledward, 2006). Meat with high pH_U (>5.9) is classified as dark-firm-dry (DFD) meat which is often associated with reduced shelf life as a result of bacterial spoilage due to a more alkaline environment (Shange, Gouws, & Hoffman, 2019). Under anaerobic conditions (vacuum packed) an organism such as *Altermonas putrefaciens* will grow on DFD meat. This organism produces hydrogen sulfide (H_2S), which converts the muscle pigment to green sulfmyoglobin, a colour that consumers strongly discriminate against (Gill & Newton, 1979).

At a high pH_U, less water is released from the muscle, whilst the water binding is the lowest at pH between 5.0-5.5 which corresponds to the isoelectric point of the muscle proteins (Huff-Lonergan & Lonergan, 2005). Previous studies have concluded that DFD meat, often associated with older game animals, have superior WHC due to the low acidification (Newton & Gill, 1981; Viljoen, De Kock, & Webb, 2002). The water-holding capacity (WHC) of meat influence the consumer’s acceptance of meat as well as the amount of product available for the market (Campo, Sanudo, Panea, Alberti, & Santolaria, 1999; Trout, 1988). Therefore, producers strive to reduce water loss as far as possible to avoid discrimination as a result of large amount of bloody liquid present in the packaging.

Ante-mortem conditions experienced by the animal leading up to harvest, play a major role in the pH_U of the meat product. These factors include acuteness and duration of stress, fitness level as well as various other factors, but for the purpose of this chapter the effect of helicopter harvesting will be focused on (Van Schalkwyk, Hoffman & Laubscher, 2011). The trial animals were culled from a helicopter which induces running (sprinting). Increased activity, such as high-speed running (associated with short-term stress) results in lower glycogen levels to support in the muscles *ante-mortem*. Consequently, the amount of lactic acid produced via anaerobic glycolysis *post-mortem* will decline which results in higher pH_U in the muscle (Hoffman & Wiklund, 2006).

In the current study, the oldest blue wildebeest cows exhibited the highest pH_U values for all six muscles (Figure 4.1a). Three of the muscles (LTL, ST and IS) from the oldest cows had pH_U >5.9 and could therefore be classified as DFD meat. A total of six >6.5-year old cows were associated with pH_U>5.9 for the three muscles (LTL, ST and IS). Furthermore, a tendency of higher drip- and cooking loss was observed for many of the muscles of the young heifers (1.5-years old) compared to that from the oldest cows (>6.5-years old). Notwithstanding the low drip- and cooking loss recorded for the muscles of the oldest cows, the LTL, ST and IS muscles of the >6.5-year old blue wildebeest cows would be more suitable for further processing into meat products as a result of the high pH_U values (Pospiech & Montowska, 2011). Furthermore, the higher amounts of moisture loss exhibited for the muscles of the heifers may be attributed to the lower pH_U (5.6-5.8) values corresponding with higher moisture loss (Troy & Kerry, 2010).

The heating of meat (80˚C) causes changes in the properties of the proteins thereby causing actin and titin proteins to denature (Hamm & Deatherage, 1960; Hughes et al., 2014). The degradation of proteins, increased amount of extracellular spaces as well as the increased rigidity of the myofibrillar structure is often associated with increased water loss during cooking (Hughes et al., 2014; Watanabe, Motoyama, Nakajima, & Sasaki, 2018). *Post-mortem* shrinkage of myofibrils leads to the shrinkage of the whole muscle cell which results in the movement of water from the intra- to extracellular water compartment (Hughes et al., 2014). It has been reported that the muscle structures of meat from older animals are less susceptible to *post-mortem* changes (Brewer, 2004). DFD meat, noted for the LTL, ST and IS muscles of the >6.5-year old cows were associated with low cooking loss (Table 4.1), possibly as a result of small extracellular space which could lead to a more juicy final product (Hamm & Deatherage, 1960).

Hopkins, Stanley, Martin, Toohey & Gilmour (2007) also noted higher pH_U (6.0) and lower cooking loss values for the ST muscle of older sheep. They attributed the higher pH_U values to the decreased ability of older animals to withstand stress. It may thus be possible that the oldest cows had lower muscle glycogen concentrations after an adrenaline challenge due to excessive activity prior to killing, as they are less resilient in this regard than younger animals. In addition, these older cows had longer flight distances than the younger animals, whom had received additional feed during their lifetime and are more habituated to the human activities. This would have resulted in lower muscle glycogen levels in the muscle at time of death, resulting in a higher pH_U post *rigor*. In contrast, Hoffman et al. (2007) reported higher pH_U values in the *Longissimus thoracis et lumborum* (LTL) muscle of sub-adult (1-2-years old: pH_U=5.9) springbok *(Antidorcas marsupialis)* in comparison to adults (2-5-years old: pH_U=5.5). The latter study also reported higher cooking- and drip loss for the adults, which contradicts the findings of the current study. However, it is difficult to compare their results to the current study's results due to different *ante-mortem* factors such as culling methods used, which have an influence on the physical quality attributes of meat. In addition, comparison amongst species is challenging due to different extrinsic factors that influence the meat quality differently. According to Żochowska-Kujawska et al. (2019), younger fallow deer *(Dama dama)* bucks were also associated with higher pH_U values and lower thermal drip loss for the BF, SM and LTL muscles. The latter was attributed to the difference to which the muscles are influenced by physical activity (which influence muscle glycogen content) and consequently the muscle fibre type composition (Wegner et al., 2000). Studies on sub-adult and adult wildebeest bulls (Van Heerden & Hoffman, 2018), kudu *(Tragelaphus strepsiceros),* impala *(Aepyceros melampus) (*Mostert & Hoffman, 2007*)*, blesbok *(Damaliscus pygargus phillipsi) (*Smit, Hoffman, & Muller, 2004*)* and yearling and adult free-ranging white-tailed deer *(Odocoileus virginianus)* (Hewitt, Hellickson, Wester, & Bryant, 2014), reported no significant age effect on the pH_U values of various muscles.

Regardless of the significantly higher drip loss (1-4 %) reported for the muscles of the 1.5-year old heifers, the values were similar to that recorded for various game species such as impala (±2-3 %) (Engels et al., 2019), mountain reedbuck (±4-5 %) (Hoffman et al., 2008), springbok (±2-3 %) (Hoffman, Kroucamp, & Manley, 2007) and blesbok (±2-8 %) (Smit et al., 2004). However, the cooking loss reported for the BF (±42 %), SM (±42 %) and ST (±42 %) muscles of the heifers were higher than that recorded for other game species. The latter could result in less juicy cooked meat.

In the current study four of the muscles (LTL, BF, SM and ST) of the blue wildebeest bulls showed higher pH_U values than the heifers' (Table 4.1b). The LTL (6.0 ± 0.23) and ST (6.0 ± 0.20) muscles of the bulls had a pH_U >5.9, which falls into the category of DFD meat which will be more suitable for further processing. A total of six and five bulls exhibited DFD characteristics (pH_U >5.9) for the ST and LTL muscles, respectively. The bulls showed a tendency towards a lower drip loss in the LTL, SM and SS muscles and lower cooking loss in the BF and ST muscles than the heifers. The young bulls exhibited higher pH_U values for these muscles, which are associated with increased WHC of meat and consequently lower drip loss. Van Schalkwyk, Hoffman & Muller (2004) reported contrasting results than that reported in the current study, where adult female black wildebeest *(Connochaetes gnou)* had lower drip loss in the LTL muscle than the males. Previous studies conducted on the LTL muscle of various male and female game species reported no sex effect on the drip loss percentage of the muscle (Fitzhenry, Hoffman, Cawthorn, & Muchenje, 2016; Hoffman et al., 2008; Swanepoel et al., 2016).

The BF and ST muscles, for which differences in cooking loss were recorded, are located in the hindquarters of the animal. According to North & Hoffman (2014), the BF muscle of male springbok exhibited a significantly lower percentage of Type IIX muscle fibres (fast-twitch glycolytic fibres) and higher Type I muscle fibres. Their study also observed larger fibres in females when compared to males. Muscle fibre diameter is inversely correlated to pH of meat, which indicates that larger muscle fibres (larger fibre diameter) could possibly lead to lower pH and ultimately lower WHC associated with female muscles (Brewer, 2004; North & Hoffman, 2014).

Regardless of age and sex, many of the muscles had high cooking loss ranging between 35.3-42.1 % which is higher than that recorded for beef (13-35 %; Muchenje et al., 2009). However, the species differences need to be considered which makes it a challenge to compare the physical parameters such as cooking loss which is a variable and complex parameter. The pH_U values of all the muscles (except those exhibiting DFD characteristics) fell into the same pH_U range (5.6-5.8) reported for the muscles of blue wildebeest bulls by Van Heerden & Hoffman (2018).

Meat tenderness is another important eating quality trait which affects the consumer's purchasing decisions (Joo & Kim, 2011). According to Lawrie & Ledward (2006), the degree of tenderness is related to connective tissue, myofibril and sarcoplasm characteristics which are classified as the structural elements of protein in muscles. Interesting results were reported regarding the shear force values of the six muscles of the blue wildebeest; the >6.5-year old cows had similar shear force values as the 1.5- and 4.5-year old females for most of the muscles (Table 4.1). These findings are contradictory to results reported in previous literature stating that, meat from older animals were less tender, particularly cuts containing a high connective tissue content (Hoffman & Fisher, 2001; Moholisa, Hugo, Strydom, & Van Heerden, 2017; Van Heerden & Hoffman, 2018; Żochowska-Kujawska et al., 2019). According to Purchas, Yan & Hartley (1999), the relationship between pH_U and shear force showed a bell-shaped pattern with a peak shear force at pH_U of 5.9; thereafter the shear force values start to decrease as the pH_U ranges from 6.1-6.8. Devine, Graafhuis, Muir & Crystall (1993) showed that meat from older lambs (14-months old) had higher shear force values when the pH_U ranged between 5.6-6.0 where after the tenderness increased as pH_U >6.2. In their study, the young lambs (7-months old) had the lowest shear force values when pH_U ranged from 5.4-5.6. Figure 4.2a and 4.2b were included to illustrate the correlation between the pH_U and shear force values of the six muscles combined. Although different equations were fitted to try to describe this relationship. Low goodness of fit was found and as illustrated, the linear equations are depicted.

Regardless of the difference between pH_U values recorded for the muscles of the oldest blue wildebeest cows (pH_U: 5.9-6.0) and the 4.5-year old cows (pH_U: 5.7-5.8), similar shear force value were observed for most of the muscles (Table 4.1). The lack of difference between the shear force values of two older age groups may be due to collagen reaching maturity after 4.5-years of age in which the differences in cross linkage would not change (Devine et al., 1993). It was expected that higher proportion of heat stable connective tissue would have a negative influence on the tenderness in older animals. The latter was possibly partly overcome by the higher pH_U values that had a greater contribution to more tender meat (Figure 4.2).

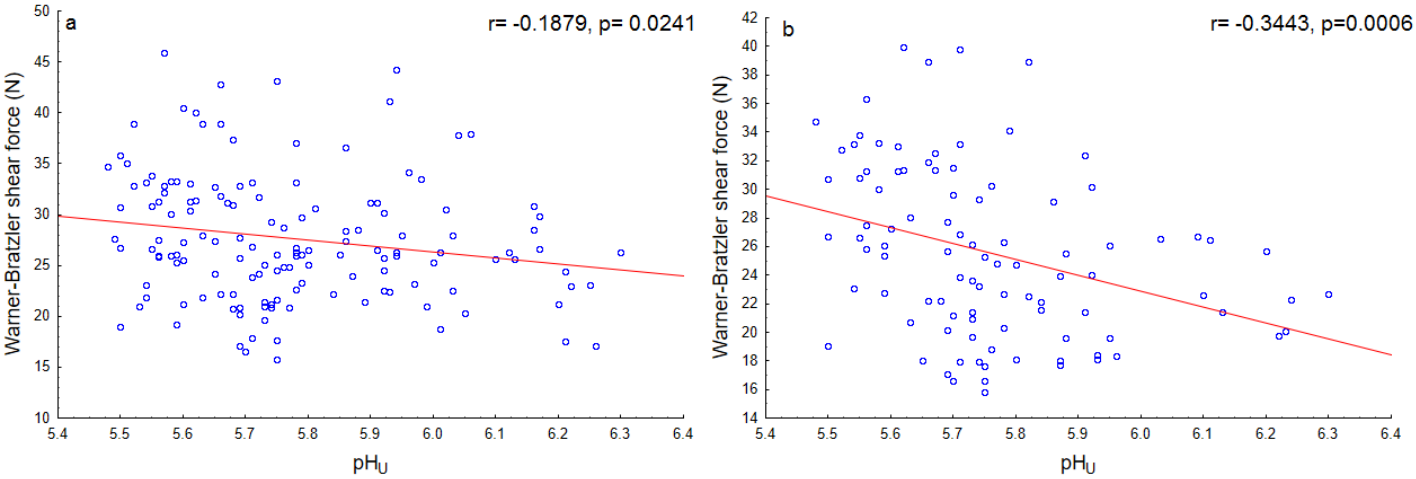

Figure 4.2 Correlation between the pH_U and Warner-Bratzler shear force values of the six muscles combined of a) blue wildebeest females of different ages and b) 1.5-year old blue wildebeest bulls and heifers.

In the current study, a lower shear force values for the LTL, IS and SS muscles of the heifers than the 4.5-year old cows were observed (Table 4.1). The difference in tenderness is predominantly due to higher salt-soluble collagen in muscle of younger animals (Gross, 1938) and the fact that the degree of intra- and inter-molecular cross-linking between polypeptide chains in collagen increases with age (Bailey, 1968). A study on young and spent water buffalo bulls confirmed significantly higher collagen solubility (%) and lower shear force (N) in the LTL muscle of the young bulls than the spent bulls.

Blue wildebeest bulls and heifers showed similar shear force values for five of the muscles. These results are comparable to results noted for species such as the impala*,* kudu (Mostert & Hoffman, 2007), springbok (Hoffman, Kroucamp, & Manley, 2007), mountain reedbuck *(Redunca fulvorufula)(*Hoffman et al., 2008*)* and common eland *(Taurotragus oryx) (*Needham et al., 2019*),* for which no differences in tenderness of the LTL muscle occurred between males and females. Fitzhenry, Hoffman, Cawthorn & Muchenje (2016) also reported no differences between the shear force values (N) of six muscles (LTL, BF, SM, ST, IS and SS) of male and female fallow deer. Regardless of age and sex, all of the muscles were associated with shear force values <42.8 N (Table 4.1) which is considered as tender meat (Destefanis, Brugiapaglia, Barge, & Dal Molin, 2008).

The colour of uncooked meat is dependent on the content, chemical state of myoglobin (Mb) as well as the pH_U, water-holding capacity and light scattering properties thereof (Geay, Bauchart, Hocquette, & Culioli, 2001; Neethling, Suman, Sigge, Hoffman, & Hunt, 2017).

When no ligand is bound to the sixth binding site on the iron of Mb, the iron is in its reduced state (Fe^{2+}) also known as deoxymyoglobim (DMb) (Mancini & Hunt, 2005). In fresh meat, oxymyoglobin (OMb) is considered the most important chemical form which is associated with a bright red colour (Lawrie & Lenard, 2006). Consumers consider the bright red colour as an indication of fresher meat (Mancini & Hunt, 2005; Neethling et al., 2017; Stevenson-barry, Duncan, & Littlejohn, 1999). In the current study, the frozen muscle samples were thawed prior to the measurement of Mb-state. Repeated freezing-thawing cycles leads to lower metmyoglobin-reducing ability (MRA) which ultimately results in lower MRA and consequently cause premature browning defects. Nonetheless, the results obtained regarding the redox forms of Mb under the present environmental circumstances provide additional data to support the results obtained from the instrumental colour measurements. The results depicted in Table 4.3 demonstrates a 'snap shot' of the myoglobin forms taken under the same conditions as described earlier in the Methods and Materials sections and gives an indication of what can be expected.

Meat derived from venison is typically a darker, red and brown colour in comparison to the meat of domestic livestock species (Hoffman, 2000; Neethling et al., 2017). The latter could be attributed to the higher myoglobin content in muscles of free-roaming wild ungulates as a result of greater activity load (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012). Therefore, game meat is more susceptible to oxidative changes due to the higher Mb content in the muscles (Lawrie & Ledward, 2006).

In the current study, the older blue wildebeest cows (4.5- and >6.5-years old) exhibited darker meat than the young heifers. Van Heerden & Hoffman (2018) also reported darker meat colour for muscles of adults (40-months to >4-years old) compared to sub-adult (16-28-months old) blue wildebeest bulls. They attributed the difference in L* values to the influence of the structure of the muscles and the extent of protein denaturation which changes with animal age. High pH_U values leads to increased survival of the cytochrome enzymes, causing muscle proteins to be above their isoelectric point. The fibres of the muscles will be tightly packed causing a barrier to diffusion, as a result of much of the water being associated with the muscle proteins resulting in more of the light rays being absorbed causing the meat to be darker (Lawrie & Ledward, 2006). This effect would have been more evident in muscles of old cows. As mentioned previously, muscles with high pH_U is often classified as DFD meat. Despite high pHu values in all muscle of the oldest age group, only the LTL muscle of the >6.5-year old cows exhibited the colour coordinates associated with DFD meat (L*=30, a*=10.54, b*=7.9, chroma=13.2, hue-angle=36.7) (Shange et al., 2019).

Furthermore, a positive relationship exists between the age of an animal and Mb content in meat. However, a negative relationship exists between animal age and affinity of oxygen for Mb (Humada, Sañudo, & Serrano, 2014; Kim, Stuart, Black, & Rosenvold, 2012; Onyango, Izumimoto, & Kutima, 1998). Therefore, the demand for Mb synthesis increases to store oxygen. This phenomenon leads to a darker (lower L* values) and redder (higher a* values) meat colour in older animals as a result of higher concentration of Mb in the muscles (Insausti et al., 1999). The latter was also observed in the current study, where the >6.5-year old cows had the highest Mb content (mg/g) in all six muscles, followed by the 4.5- and 1.5-year old heifers (Table 4.3). Similar results were reported for kid and goat meat, where the older animals exhibited increased Mb concentration (Dhanda, Taylor, McCosker, & Murray, 1999). In a study on beef, mature animals were associated with higher concentration of Mb (16-20 mg) than young animals (4-10 mg) (Seideman, Cross, Smith, & Durland, 1984). Furthermore, consumers consider game meat with L* values lower than 40, more attractive (Shange et al., 2019; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003). The ST (L*=42.7) and BF (L*=39.1) muscles of the youngest age group may be discriminated against due to their L* values being slightly higher or slightly lower respectively, than 40.

Many of the muscles of the 4.5-year old cows in the current study were associated with a more vivid colour (higher chroma values). Colours become more vivid around the periphery of the colour space. Therefore, the high a* and b* values exhibited for the muscles of the 4.5-years old cows are further from the origin which results in colour appearing more vivid (Table 4.2). In contrast, most of the muscles of the 1.5- and >6.5-year old females had lower a* and b* values, therefore exhibiting a less vivid colour than the 4.5-year old cows.

According to Shange, Gouws & Hoffman (2019), a* values are lower in muscles exhibiting pH_U values >6.06, which was observed in the muscles of the >6.5-year old cows. According to Van Heerden & Hoffman (2018), a positive correlation exists between a* values and the Mb concentration in blue wildebeest which could also explain the higher a* values observed in the 4.5-year old cows of the current study. The lower concentration of Mb expected in the muscles of the 1.5-year age group could explain the lower a* values (Insausti et al., 1999). In contrast to our results, Mostert & Hoffman (2007) noted no difference between the a* values of the SM muscle of sub-adult and adult kudu and impala. Smit, Hoffman & Muller (2004) also confirmed that age had no effect on the L*, a* b* and chroma values of blesbok muscles. Volpelli et al. (2003) also reported no age effect on the colour of muscles of 18- and 30-month old fallow deer.

The muscles of the 1.5-year old blue wildebeest heifers had a less red colour (higher hue-angle), often associated with more metmyoglobin present in the muscle (brown colour) (American Meat Science Association, 2012). According to Mancini & Hunt (2005), higher a* and OMb% results in meat appearing redder, whilst a higher hue-angle and MMb% gives an indication of meat discolouration (browner colour). The 1.5-year old heifers from the current study were associated with lower a* values and the highest hue-angle values for the majority of the muscles and higher MMb% in the ST and SS muscles than the other two age groups (Table 4.2). The latter is another indication of browner muscles associated with the heifers.

When the effect of sex was investigated on the colour of six muscles of blue wildebeest bulls and heifers, few differences occurred (Table 4.2). Many of the muscles located in the back and hindquarters of 1.5-year old bulls had lower L*, b* and hue-angle values than the heifers. These muscles appear darker with a redder colour (lower hue-angle values) when compared to the heifers. The latter could be attributed to the bulls exhibiting lower MMb% and higher OMb% for the BF and ST muscles than the heifers (Table 4.3). The muscle fibre types of these muscles influence the amount of myoglobin present and oxidative capacity of the muscle, as well as the pH decline *post-mortem* which will ultimately influence colour (Hunt & Hedrick, 1977; Neethling et al., 2017). A study on blesbok muscles observed a significant sex effect for only the IS muscle for which females were associated with lower OMb % (Neethling et al., 2017). In the current study, differences occurred in the hindquarter muscles of the bulls and heifers. North & Hoffman (2014) reported higher percentage of Type I muscle fiber in the BF muscle of male springbok which is associated with higher Mb concentration in the muscle (Lawrie & Ledward, 2006). Males tend to have high amounts of Mb present in their muscles as a result of greater levels of physical activity (Seideman, Cross, Oltjen, & Schanbacher, 1982). The latter were also observed in the current study where the muscles of the young bulls exhibited high Mb content than the heifers which could contribute to decreased colour stability in the muscles of the bulls (Table 4.3).

In summary, the colour of the majority of the muscles of the blue wildebeest were comparable to the results observed by Van Heerden & Hoffman (2018) for various muscles of blue wildebeest (a* =11.3-15.1; b*= 7.3-9.7; Chroma= 13.8-17.4; Hue-angle= 29.4-41.9). However, the L* values of many of the muscles of the young bulls and heifers (L*= 33.3-43.0) exceeded the values (L*= 30.6-33.8) reported by Van Heerden & Hoffman (2018). Brooks (1938) reported that the brown pigment in meat is only noticeable and classified as unattractive when the MMb % form of Mb exceeds 60 %. Regardless of age and sex, none of the investigated muscles had MMb % higher than 60% (Table 4.3) and will thus not be discriminated against (Brooks, 1938).

4.5 CONCLUSION

It can be concluded that the LTL, ST and IS muscles of the >6.5-year old cows and the LTL and ST muscles of the young bulls should be designated to further processing, primarily due to the high pH_U (>5.9) values for these muscles which could be classified as dark-firm-dry

(DFD) meat. The ST muscle of the 1.5-year old heifers is also more suitable for further processing due its undesired colour (L*=42.69). The 1.5-year old heifers produced more tender meat for three muscles (LTL, IS and SS) than the 4.5-year old cows. Sex had a negligible effect on the tenderness of most of the muscles obtained from young male and female blue wildebeest. It can also be concluded that the meat from all the animal of the current study can be classified as tender (<42 N). Furthermore, the remaining muscle of all the ages and sexes are suitable for fresh meat products.

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CHAPTER 5

COMPARING THE CHEMICAL COMPOSITION OF SIX MUSCLES OF BLUE WILDEBEEST (*Connochaetes taurinus*) AS INFLUENCED BY AGE AND SEX

ABSTRACT

The chemical composition of six muscles (*longissimus thoracis et lumborum* (LTL)*, biceps femoris* (BF)*, semimembranosus* (SM)*, semitendinosus* (ST)*, infraspinatus* (IS) and *supraspinatus* (SS)) of male and female blue wildebeest was determined to quantify the effect of age (Trial 1) and sex (Trial 2) thereon. The 1.5-year old heifers had higher moisture content in the ST (<1.5 % difference), IS and SS muscles (<1% difference) than the two older age groups (4.5- and >6.5-year old). The oldest blue wildebeest cows had the highest protein content in the ST muscle (21.92 ± 0.38 %), followed by the 4.5- (21.26 ± 0.64 %) and 1.5-year old females (20.54 ± 0.74 %). The oldest cows exhibited higher fat content in the LTL, BF and SS muscles than the 1.5- and 4.5-year old females (<0.5 % difference). No significant age effect was observed for the ash content in all six muscles. With regards to the effect of sex, the heifers exhibited higher moisture- and lower protein content in the SM and ST muscles than the bulls (<1 % difference). The heifers were also associated with lower protein content in the IS muscles (<0.5% difference) than the bulls. The LTL muscle of the heifers had a lower fat content than the males (<0.5 % difference). Furthermore, sex did not significantly affect the ash content of all six muscles of blue wildebeest. Regardless of age and sex, the proximate composition of all six muscles of the blue wildebeest had a high nutritional value.

Keywords: Chemical composition, Game meat, Meat quality, Nutritional value

5.1 INTRODUCTION

The Indigo Wellbeing Index has rated South Africa as the country with the lowest health index in comparison to the other G20 countries (The Indigo Wellness Index, 2019). The latter is based on the occurrence of obesity, blood glucose levels, diabetes risk and life expectancy of the population of the specific country. Current research shows that the diabetes pattern has improved in high-income countries, whilst worsening in low-income countries (Imamura et al., 2015). In South Africa, the mortality rate between the age of 30 and 70 was 26.2 % in the year 2016 and was primarily due to cardio vascular disease and diabetes (World Health Organization, 2018b). According to the World Health Organization (WHO) (2018), non-communicable diseases (NCD), including cardiovascular diseases (19 %) and diabetes (7 %), accounted for 51 % of all deaths is South Africa. In South Africa, it has been predicted that one in three men and one in four women will have a heart condition by the time they reach the age of 60 (Mahungo, 2013). The WHO also predicted a steep increase in obesity in the next ten years which is also one of the risk factors (11% in the year 2016) of NCD in South Africa (World Health Organization, 2018a). The middle-income developing countries with high obesity ratings such as South Africa are also prone to under-nutrition.

Although various health reports have resulted in a negative connotation with red meat due to its association with saturated fat, not all saturated fats lead to health problems and the negative association with health can probably only be justified by high consumption (portions) of meat with high fat content combined with other poor lifestyle factors (Zeraatkar et al., 2019; Wassenaar, Kempern & van Eeden, 2018). In developing countries, red meat is often regarded as a solution for the malnutrition as well as to increase food security (McNeill & Van Elswyk, 2012). It has been predicted that the beef production in developing countries will continue to increase by 17 % in the year 2028 (OECD/FAO, 2019). Therefore, the popularity of red meat is not expected to decrease which emphasise the importance to investigate healthier, alternative red meat sources such as game species with lower fat content (<3 %) (Radder & Le Roux, 2005; Sebranek, 2014). Due to the consumer's increasing awareness on nutritive value of food, there is a great need for information on the composition of meat derived from different game species.

The basic nutritional value of meat can be defined as the chemical composition of the moisture, protein, intramuscular fat (IMF) and the ash (Ang, Young, & Wilson, 1984). Nutritional value is further complemented by individual vitamin and mineral content. Variations in the chemical composition of meat can be attributed to species, diet, maturity, sex and the anatomical location of muscles within the animal (Hocquette et al., 2010). Game meat is generally low in intramuscular fat (<3%) (Sebranek, 2014) and cholesterol, but high in protein

(Pauw, 1993), which makes it a suitable alternative for beef (Hoffman, 2013; Radder & Le Roux, 2005).

The blue wildebeest (*Connochaetes taurinus*) have become a popular species to farm within South Africa due to its high population growth (29-35 % increase annually), and ability to adapt in harsh environments with limited resources (Furstenburg, 2002). The golden wildebeest and king wildebeest are two colour variants of the blue wildebeest which can be bred from blue wildebeest splits (F1 generation) that carry the recessive genes responsible for these colour variants (Olivier & Butler, 2015; Taylor et al., 2016). In the past years, blue wildebeest splits were farmed with to produce offspring exhibiting the desired colours. However, many game breeders have adequate numbers of colour variants and excess female breeding stock that does not conform to the strict breeding criteria. Consequently, farmers have shown interest in the potential of these animals for the meat supply chain to maintain the profitability of these surplus animals while producing quality products. As mentioned previously, sub-standard young males are also culled to enter the meat production chain.

Little research is available on the influence of age and sex on the chemical composition of blue wildebeest meat. Van Heerden & Hoffman (2018) compared only sub-adult (16- to 28-months old) and adult (40-months to >4-years old) blue wildebeest bulls whilst an earlier study by Van Schalkwyk Hoffman, & Muller (2004), delivered inconclusive answers due to various experimental constraints such as too few animals per treatment group and not all trial animals being harvested in the same season (seasonal effect). Taking these baseline studies into account, this research project was designed to provide more comprehensive answers regarding the effect of age and sex on meat quality of this species.

5.2 METHODS AND MATERIALS

5.2.1 Animals and study location

A total of 32 blue wildebeest were obtained from Romaco Ranch, located on the outskirts of the Modimolle regions in the Limpopo province, South Africa. The trial animals were harvested during April 2018; the end of the region's rainfall season. The study was sub-divided into two trials. The first trial included a total of 24 blue wildebeest females, which were culled according to their age. Each of the three age groups (1.5-, 4.5- and >6.5-years old) included eight females to quantify the effect of age on the chemical composition of their meat. The second trial included an additional eight blue wildebeest bulls of 1.5-years of age. These bulls were harvested to determine the effect of sex on the chemical composition of meat of young blue wildebeest bulls and heifers (1.5-years old). The farm utilizes a semi-intensive management system to optimize the growth and development of the animals to ensure high-quality breeding stock. All the animals were maintained in large breeding camps and had access to supplementary feed, formulated by Wildswinkel (protein (120 g/kg), energy (8.2 MJ/kg), moisture (120 g/kg), fat (25 g/kg), fibre (190 g/kg), Ca (7 g/kg), P (2 g/kg), K (1 g/kg), Mg (1 g/kg) & Na (1 g/kg)), during winter. The >6.5-year old blue wildebeest cows were not bred and reared on the farm; they were brought in from another farm approximately two years prior to the trial and received no supplementary feed throughout their growth period.

Refer to Chapter 3.2.1 for a more detailed description of the study location and experimental design of the current study.

5.2.2 Harvesting and dressing

The animals were culled during the day from a helicopter from which an experienced marksman used an appropriate calibre shotgun. The trial animals were harvested in different slots over a 7-day period to minimize the possible variation in each of these groups as a result of stress. The culling and slaughtering were done according to Van Schalkwyk & Hoffman (2010). After the dressing procedure, the carcasses were stored overnight at ±4°C.

Chapter 3.2.2 describes the harvesting and dressing procedures in more detail.

5.2.3 Removal of muscles and sample preparation

Six muscles were excised from the carcasses after it was cooled overnight (24 hours, ± 4°C), viz *longissimus thoracis et lumborum* (LTL), *biceps femoris,* (BF), *semimembranosus* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS). Thereafter, a ±200 g sample of each muscle from every animal was taken for proximate analysis. These samples were frozen at -20°C to await further analysis at the laboratory at the Department of Animal Sciences, Stellenbosch University.

5.2.4 Chemical analysis

5.2.4.1 Sample preparation

Prior to homogenisation for chemical analyses, the samples were thawed for 18 hours in their packaging (± 4°C). Thereafter, excess subcutaneous fat and connective tissue were trimmed from each sample where after the samples were cut into smaller pieces. The latter were homogenised to produce a paste-like mixture, vacuumed-packed to ensure no moisture loss or oxidation and stored at -20°C until scheduled for analyses. Before chemical analysis was performed, these samples were thawed overnight (± 4°C).

5.2.4.2 Proximate analysis

The moisture, protein, intramuscular fat (IMF) and ash content were analysed in duplicate of which the average was taken as the final measurement. Whenever the reading of the duplicated differed by more than 5 % from the first reading, additional analyses were performed.

The Association of Official Analytical Chemists (AOAC) official method 934.0 was used to determine the moisture content (AOAC International, 2002c). A 2.5 g homogenised sample was dried at 100°C for 48 hours. Thereafter the moisture-free sample was placed in a furnace of 500°C for a period of 6 hours. The ash percentage was then determined following the method 942.05of the AOAC (AOAC International, 2002a).

The total crude protein content was determined according to the AOAC 992.15 Dumas combustion method (also known as the LECO combustion method) (AOAC International, 2002b). The samples were defatted, dried at 60°C and ground prior to the analysis. Thereafter a 1 g sample was encapsulated in LecoTM foil and analysed in a LECO Nitrogen/Protein Analyser (LECO Fp-528, eco Corporation). The LECO analyser was calibrated regularly with ethylene-diamine-tetra-acetic acid (EDTA), to ensure the accuracy of the analysis. The results obtained were in the form of nitrogen content (N %) which was then multiplied by 6.25 to determine the crude protein (%) of each sample.

The total lipid content percentage, referred to as IMF (inter musculature fat), was determined using the method described by Lee, Trevino & Chaiyawat (1996). A 5 g homogenized muscle sample was analysed in duplicate using a simple extraction with a solvent (1:2 (v/v) mixture of chloroform/methanol) as it was expected that the samples contained less than 5 % lipid (Lee, Trevino, & Chaiyawat, 1996).

5.2.5 Statistical analysis

The data obtained from the various methods described above were analysed using Statistica version 13.5 (StatSoft, 2013). Various measurements were conducted on different muscles of the same animal, therefore a mixed model Analysis of Variance (ANOVA) was performed per muscle (LTL, BF, SM, ST, IS & SS). The study was divided into two trials to investigate the effect of age (trial one) and sex (trial two) independently. In the first trial, age was treated as a fixed effect; wherein the second trial sex was the fixed effect. For both of the trials, the animals were treated as a random effect. Normal probability plots were inspected to check normality assumptions, and were found to be acceptable. A 5 % significant level was set as a guideline for determining significant age and sex effects. Where significant differences occurred, a post hoc test (Fisher's least significant differences) was run and the values were reported as the Least Square Means and standard error.

5.3 RESULTS

5.3.1 Proximate composition

As depicted in Table 5.1, age had a significant effect on the moisture content of the SM, ST, IS and SS muscles of the blue wildebeest females. The ST and SS muscles of the two older age groups had lower moisture content than that observed for the youngest age group. The 1.5- and 4.5-year old cows exhibited higher moisture content in the SM and IS muscles than the oldest cows. A significant sex effect was reported for both the SM and ST muscles, where the heifers were associated with higher moisture content in these muscles than the bulls.

With regards to the protein content, the ST muscle of the oldest cows had the highest content, followed by the 4.5-year cows and the 1.5-year old heifers. Furthermore, the young blue wildebeest heifers had lower protein content in the SM, ST and IS muscles than the bulls.

The fat content of the LTL, BF and SS muscles of the 1.5- and 4.5-year old cows were significantly lower than that of the >6.5-year old cows. Sex had little effect on the fat content on the muscles of blue wildebeest. The 1.5-year old bulls showed higher fat content in only the LTL muscle than the heifers.

Furthermore, neither age nor sex had a significant effect on the ash content of all six muscles obtained from male and female blue wildebeest.

Table 5.1 Least squares means (± Standard deviation) of the proximate composition of six muscles of male and female blue wildebeest, demonstrating the influence of age and sex on the different muscle types.

Parameter	Muscle	Age		Sex		p-values	
				Female	Male		
		>6.5-years (n=8)	**4.5-years** (n=8)	**1.5-years** (n=8)	**1.5-years** (n=8)	**Age**	**Sex**
Moisture	LTL	75.9 ± 1.47	76.03 ± 1.05	76.4 ± 1.48	76.4 ± 1.15	0.70	0.99
	BF	76.3 ± 0.88	76.15 ± 1.91	77.1 ± 0.96	76.3 ± 0.72	0.31	0.09
	SM	76.0 ± 0.92^{b}	76.72 ± 0.94^{ab}	77.1 ± 0.67^{a}	76.3 ± 0.28	0.06	**0.01**
	ST	76.4 ± 0.39^{b}	76.89 ± 0.57^{b}	77.9 ± 0.56^{a}	77.0 ± 0.48	**<0.01**	**<0.01**
	IS	76.9 ± 0.29^{b}	77.50 ± 0.35^{a}	77.9 ± 0.58^{a}	77.4 ± 0.35	**<0.01**	0.06
	SS	77.0 ± 0.60^{b}	77.36 ± 0.58^{b}	77.9 ± 0.48^{a}	77.6 ± 0.57	**<0.01**	0.18
Protein	LTL	22.2 ±1.47	22.16 ±0.93	22.0 ±1.34	22.1 ± 0.95	0.92	0.94
	BF	21.7 ± 0.85	22.05 ± 1.95	21.1 ± 0.87	21.8 ± 0.40	0.35	0.06
	SM	22.2 ± 1.03	21.40 ± 1.04	21.2 ± 0.60	21.9 ± 0.31	0.11	**0.02**
	ST	21.9 ± 0.38^{a}	21.26 ± 0.64^{b}	20.5 ± 0.74^{c}	21.3 ± 0.36	**<0.01**	**0.03**
	IS	20.4 ± 0.41	20.11 ± 0.59	20.0 ± 0.45	20.4 ± 0.37	0.26	**0.04**
	SS	20.4 ± 0.68	20.39 ± 0.44	19.9 ± 0.65	20.2 ± 0.41	0.18	0.37
Fat	LTL	1.7 ± 0.14^{a}	1.21 ± 0.14^{b}	1.2 ± 0.13^{b}	1.4 ± 0.12	**<0.01**	**0.04**
	BF	1.7 ± 0.09^{a}	1.43 ± 0.20^{b}	1.5 ± 0.18^{b}	1.5 ± 0.28	**0.02**	0.57
	SM	1.5 ± 0.11	1.42 ± 0.20	1.4 ± 0.17	1.14 ± 0.16	0.78	0.98
	ST	1.4 ± 0.15	1.42 ± 0.31	1.4 ± 0.17	1.4 ± 0.20	0.82	0.88
	IS	2.0 ± 0.20	1.70 ± 0.34	1.8 ± 0.39	1.7 ± 0.17	0.13	0.69
	SS	2.1 ± 0.15^{a}	1.66 ± 0.21^{b}	1.7 ± 0.33^{b}	1.8 ± 0.21	**<0.01**	0.38
Ash	LTL	1.2 ± 0.05	1.2 ± 0.06	1.2 ± 0.11	1.1 ± 0.06	0.70	0.07
	BF	1.1 ± 0.09	1.1 ± 0.10	1.1 ± 0.07	1.2 ± 0.23	0.98	0.56
	SM	1.1 ± 0.10	1.1 ± 0.12	1.2 ± 0.09	1.1 ± 0.07	0.45	0.12
	ST	1.2 ± 0.18	1.2 ± 0.11	1.4 ± 0.08	1.1 ± 0.05	0.62	0.56
	IS	1.1 ± 0.12	1.2 ± 0.08	1.1 ± 0.06	1.1 ± 0.07	0.06	0.51
	SS	1.1 ± 0.10	1.1 ± 0.08	1.1 ± 0.11	1.3 ± 0.57	0.83	0.34

Abbreviations: LTL=*longissimus thoracis et lumborum*, BF=*biceps femoris*, SM=*semimembranosus*, ST=*semitendinosus*, IS=*infraspinatus*, SS=*supraspinatus*.
^{a,b,c} Different superscripts within a row for a specific parameter indicate significant ($p \leq 0.05$) differences between age groups.

5.4 DISCUSION

In order to successfully market game meat products, the nutritive composition is essential for the correct labelling thereof (Van Schalkwyk et al., 2004). Meat comprises of five primary chemical constituents viz. moisture (75-80 %), protein (20-24 %), intramuscular fat (IMF) (1-

10 %), inorganic matter/ash (±1 %), and negligible amounts of carbohydrates (Huff-Lonergan & Lonergan, 2005). Determining the proportions of these components could indicate the nutritive content of the meat (Keeton & Eddy, 2004). The proximate composition of meat will vary between species, maturity at harvest, sex, plane of nutrition as well as between different muscles (Hocquette et al., 2010; Sebranek, 2014; Hoffman et al., 2009).

The composition of an animal carcass is mostly dependent on the stage of the animal's growth as well as the plane of nutrition it was exposed to. The moisture, protein and ash content of meat tend to decline as the fat content increases from birth to maturity (Berg & Butterfield, 1976; Kandeepan, Anjaneyulu, Kondaiah, Mendiratta, & Lakshmanan, 2009; Lawrie & Ledward, 2006; Pflanzer & de Felício, 2011). A negative linear relationship exists between the fat and protein content of meat however, a stronger negative relationship occurs between the fat and moisture content (Kandeepan, Anjaneyulu, Kondaiah, Mendiratta, & Lakshmanan, 2009; Lawrie & Ledward, 2006; Pflanzer & de Felício, 2011). However, in game species such as blesbok (*Damaliscus pygargus phillipsi*), a strong negative correlation (r= -0.82) between the moisture and protein content has been reported (Neethling, Hoffman & Britz, 2013). As depicted in Figure 5.1a and 5.1b, a negative correlation was also observed for the fat and protein content of the muscles of blue wildebeest, however the correlations between fat and moisture content were less evident. The latter could be attributed to the low IMF content of the muscles of blue wildebeest.

The water content of *post-mortem* muscle tissue makes up the majority of the cell mass (Keeton & Eddy, 2004). Game meat tends to have higher moisture content than domestic species as a result of a higher ratio of meat to fatty tissue (Aidoo & Haworth, 1995). The water content influences the shelf life of meat, which is determined by the resistance to microbial growth and biochemical and chemical reactions during the storage of these meat products (Velisek, 2014). The moisture content of meat also affects the organoleptic character of meat, which is described as the sensory experience when eating meat, as well as the final yield of the product (Kadim et al., 2006; Pearce, Rosenvold, Andersen, & Hopkins, 2011).

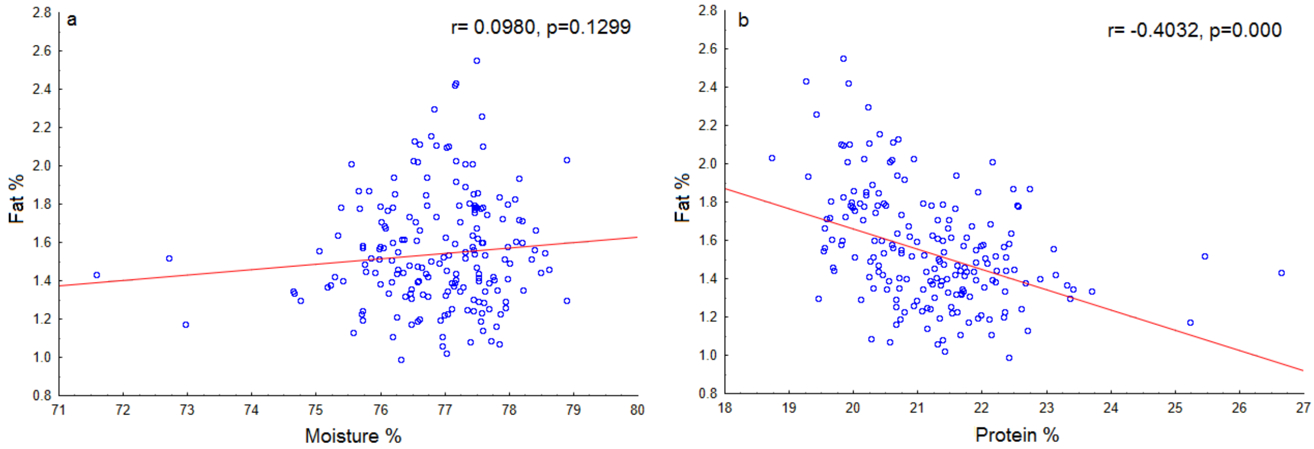

Figure 5.1 Correlation between a) the fat- and moisture content (%) of the six muscles of male and female blue wildebeest from the current study b) the fat- and protein content (%) of the six muscles of male and female blue wildebeest.

Fat, which is central to the nutritional value of meat, also acts as one of the precursors of flavour by combining with amino acids from proteins when heated (Dinh, 2006). The fat of muscle tissue has a considerable content of phospholipids, structural lipids and storage lipids (triglycerides). The latter is mainly stored in muscle adipocytes which occur between muscle fibres and fibre bundles (80 %), whilst the remaining portion is stored as intracellular lipids (Essén-Gustavsson & Fjelkner-Modig, 1985). Fat is the last tissue to reach maturity; however the first to be utilized in certain conditions (Lawrie & Ledward, 2006). The meat of game animals is generally associated with <3 % IMF (Sebranek, 2014). This could result from a lower plane of nutrition and higher level of activity of these species (Hoffman, Schalkwyk, & Muller, 2011; Keeton & Eddy, 2004). From a nutritional point of view, protein is considered the most valuable component in meat. The latter could be attributed to it being the building block of the muscular tissue as well as its utilization for the production of hormones, enzymes and haemoglobin (Hoffman and Falvo, 2004).

As the animal ages, the IMF of bovine muscles increases, whilst the moisture content decreases up until approximately 40-months (3.5-years) of age (Lawrie & Ledward, 2006). The latter could explain the lower moisture content observed in the ST and SS muscles of the two oldest age groups compared to the young heifers. Similar results were also observed in fallow deer, where the ST muscle of 30-month old males exhibited lower moisture content than the 18-month old males. The study attributed the aforementioned finding to increased fatness in older animals which leads to lower moisture content in meat (Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003). The latter was also observed in the current study where the older animals tended (<0.05 %) to have higher IMF content in the LTL, BF and SS muscles than the 1.5-year old heifers, however, the differences were very small (Table 5.1).

Muscle fibres are classified according to their metabolism and could explain the differences in muscle fat content across muscles. Type I muscle fibres (red muscle fibres) are mainly located in muscles used in continuous motion that require slow-twitch contractions (OpenStax, 2013). The latter contain large amounts of mitochondria, low glycogen and high fat content which serve as the main source of energy during these prolonged activities (Lawrie & Ledward, 2006). Furthermore, Type IIB muscle fibres (white muscle fibres) are located in muscles which require fast rates of contraction particularly during rapid movement (Cassens & Cooper, 1971). These muscle fibres are characterised by higher glycogen and protein contents and lower lipid content (Lawrie & Ledward, 2006). Kirchofer, Calkins & Gwartney (2002) concluded that the LTL, BF, SM and ST muscles of beef contained high proportions of Type IIB fibers and that the IS and SS muscles comprised of a high amount of Type I fibres (Kirchofer, Calkins, & Gwartney, 2002). It has also been reported that the proportion of red muscle fibres increases with animal age which could also lead to higher fat content (Wegner, Albrecht, Fiedler, Teuscher, Papstein & Ender. 2000). A study on fallow deer confirms the above by noting an increase in Type I fibers in the LTL, BF and SM muscles; 18-month old bucks had the lowest proportion of Type I fibres, followed by the 30-, 42- and 54-month old animals (Żochowska-Kujawska, Kotowicz, Sobczak, Lachowicz, & Wójcik, 2019). Similar results to the latter findings were reported for Arabian camels (*Camelus dromedaries*), where the fat content in the *longissimus thoracis et lumborum* (LTL) muscle of the two older age groups (3-5-years and 6-8-years) was higher than that of the younger age group (1-3-years) (Kadim et al., 2006). However, for species such as kudu (*Tragelaphus strepsiceros*), impala (*Aepyceros melampus*) (Mostert & Hoffman, 2007), black wildebeest (*Connochaetes gnou*) (Van Schalkwyk et al., 2004) and springbok (*Antidorcas marsupialis*) (Hoffman et al., 2007), no differences or relationship were observed between the fat and moisture content of the LTL muscles of sub-adults and adults; most probably because these ungulate species all had very low IMF contents compared to the afore mentioned deer and camels.

A marginal sex effect was observed for the moisture and fat content of the muscles of male and female blue wildebeest (Table 5.1). The young heifers tended to have higher moisture content in some muscles (SM and ST) than the males, however the defences were negligible (<1 % difference). No differences were observed in the fat content of these muscles. Similarly, no sex effect was reported for the moisture content of the LTL, BF, SM, ST, IS and SS muscles of male and female common eland (*Taurotragus oryx*) (Needham, Laubser, Kotrba, Bureš & Hoffman, 2019) and fallow deer (*Dama dama*) (Fitzhenry, Hoffman, Cawthorn, & Muchenje, 2016). Similar results to the current study were reported for the moisture content of the LTL muscle of male and female kudu and impala (Mostert & Hoffman, 2007), blesbok (Smit, Hoffman, & Muller, 2004), black wildebeest (Van Schalkwyk et al., 2004), water buffalo (Kandeepan et al., 2009), springbok (Hoffman, Kroucamp, & Manley, 2007) and the LTL muscle of mountain reedbuck (*Redunca fulvorufula*) (Hoffman, van Schalkwyk, & Muller, 2008). The blue wildebeest bulls of the current study reported higher percentages of fat for the LTL muscle compared to heifers. The latter contradicts previous literature conducted on game species such as kudu, impala (Mostert & Hoffman, 2007), blesbok (Smit et al., 2004), roe deer (*Capreolus capreolus*) (Daszkiewicz et al., 2012) and water buffalo (Kandeepan et al., 2009) that showed lower IMF content in the LTL muscles of males than females. Male and female blue wildebeest reach sexual maturity at ±16-months; however males will only start mating once they have become territorial at the age of 5-years (Estes, 1991). It can be concluded that young bulls in the study did not partake in reproductive activities and therefore did not utilise their IMF reserves during fighting typically associated with the rut (Bothma et al., 2010).

Generally, meat derived from game species is often associated with higher protein content (as depicted in Table 5.1) in comparison to domestic livestock (19 %) (Lawrie & Ledward, 2006). In the current study, age had little effect on the protein content of the six muscles investigated. The protein content of the ST muscle of the oldest blue wildebeest females was the highest and decreased as the age decreased, however, the difference was less than 1.5 % which is also negligible. There was also no apparent linear relationship between moisture and protein content of the muscles of the different age groups. Previous studies conducted on game species such as water buffalo (Kandeepan et al., 2009), kudu, impala (Mostert & Hoffman, 2007), blesbok (Smit et al., 2004) and black wildebeest (Van Schalkwyk et al., 2004) also reported no difference in the protein content of the LTL muscles of sub-adults and adults. A study on the protein content of blue wildebeest bulls' muscles (LTL, BF, SM, ST, IS & SS) also confirmed no significant age effect (Van Heerden & Hoffman, 2018). Contrasting results were reported when the protein content of the striploin of Hanwoo cows of different maturities were compared. In their study, the 7-year old cows exhibited lower protein content in comparison to the 3.5- to 4.5-year old cows, however as explained, these differences were magnified due to the high IMF contents (Cho et al., 2017). Hoffman, Kroucamp & Manley (2007) also reported lower protein content in the LTL muscle of adult springbok than in sub-adults'. Similar to the springbok, young camels (1-3-years old) were associated with higher protein content in the LTL muscle than the older camels (3-8-years old) (Kadim et al., 2006). The latter could be attributed to the inverse relationship of fat and protein content of meat (Needham et al., 2019) which was also observed in the study of Kadim et al. (2006) where the older animals exhibited higher fat content (8.3 ± 1.15 %) in their muscles than the younger camels (4.4 ± 1.10 %). It can therefore be concluded that a stronger negative correlation exists between fat and protein content in species containing higher IMF percentages.

Furthermore, the 1.5-year old bulls tended to have higher protein content in the BF (close to significance), SM, ST and IS muscles than the heifers (Table 5.1). This was expected due to the females exhibiting higher moisture content in the SM, ST and IS (p= 0.06), muscles. The latter could be attributed to the effect of masculine hormones such as testosterone (Morgan, Wheeler, Koohmaraie, Crouse, & Savell, 1993). Testosterone increases muscle growth and suppresses muscle protein degradation (Lobley, Connell, Buchan, Skene, & Fletcher, 1987). Contrasting results were reported for male and female mountain reedbuck (Hoffman et al., 2008) and roe deer (*Capreolus capreolus L.*) (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012). In these studies, the females were associated with higher protein content in the LTL muscle. Furthermore, no differences were reported between the protein content of the LTL muscle of male and female kudu, impala (Mostert & Hoffman, 2007), blesbok (Smit et al., 2004), water buffalo (Kandeepan et al., 2009) and springbok (Hoffman et al., 2007). However, it is difficult to compare the latter with the results noted in the current study due to age differences. In the current study sub-adult male and female blue wildebeest were compared whereas in the other studies adults were compared.

The ash content of meat refers to the inorganic matter and is used to estimate the total mineral content. The latter comprise of cellular constituents (myoglobin, haemoglobin) and bone (bone fragments) (Keeton & Eddy, 2004; Van Heerden & Hoffman, 2018). Low calcium content and an abundance of potassium, phosphorus, sodium, zinc, iron, copper and magnesium have been reported in muscle tissue (Keeton & Eddy, 2004). Studies have also reported an increase in iron and sodium and decrease in potassium as the animals get older (Doornebal & Murray, 1981; Lin et al., 1988). As depicted in Table 5.1, age and sex had no significant effect on the ash content of all six muscles investigated. Similar results were reported for adult and sub-adult game species such as fallow deer (Daszkiewicz et al., 2012), springbok (Hoffman et al., 2007), kudu, impala (Mostert & Hoffman, 2007), common eland (Needham et al., 2019), blue wildebeest (Van Heerden & Hoffman, 2018) and black wildebeest (Van Schalkwyk et al., 2004).

The differences observed between the chemical composition of different ages and sexes were, in most cases, <1% which likely would not have an actual effect on the nutritional value (g/100g meat) or taste of meat. Regardless of age and sex, the moisture (75.9-78.0 %), fat (1.2-2.1 %), protein (19.9-22.3 %) and ash (1.1-1.4 %) content of all of the muscles from all of the trial animals fell into a similar range reported for other game species such as fallow deer (Fitzhenry et al., 2016), kudu, impala (Mostert & Hoffman, 2007), common eland

(Needham et al., 2019), blesbok (Smit et al., 2004) and blue wildebeest (Van Heerden & Hoffman, 2018).

5.5 CONCLUSION

The study concluded high nutritional value of six muscles of all the trial animals. Furthermore, the chemical composition of the muscles of the older cows (>6.5-years old) were not inferior to the muscles of the younger animals and would therefore be as good a source of low fat and high protein meat than younger animals. The results reported in this chapter will aid in the marketing of game meat by educating the consumer about the health benefits associated with game meat.

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CHAPTER 6
GENERAL CONCLUSIONS AND RECOMMENDATIONS

The game ranching industry of South Africa has experienced tremendous growth over the past two decades which could be attributed to improved farm management systems implemented to increase the efficiency and profitability of the industry. Specially formulated diets enable farmers to supplement the veld in dry periods to sustain optimum animal production in terms of reproduction or hunting purposes. Also, intensive and semi-extensive management systems have implemented breeding programmes to enhance the genetic potential of the breeding stock and future offspring to ensure continues growth of high standard breeding populations. Selective culling has enabled farmers to cull surplus, sub-standard stock which will also remove pressure from the veld and provide more resources for the selected animals. Typically, surplus sub-adult females and males will be harvested for meat, as well as older breeding stock with decreased production. Consequently, animals will enter the meat production chain at different ages which influences the carcass yields and meat quality. Thus, the aim of this research was to investigate and quantify the effect of age (Trial 1) and sex (Trial 2) on the carcass yields and meat quality of six muscles (*Longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosus* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS)) obtained from blue wildebeest (*Connochaetes taurinus)*.

Trial 1 showed that young blue wildebeest heifers (1.5-years old) had lower carcass-, muscle- and offal yields than the two older age groups, between which little differences occurred. The latter indicates that older, surplus females remain suitable for meat production in terms of yield; it also demonstrates the benefits of supplementary feeding which advances the development of animals (Chapter 3). Regardless of the high carcass yields reported for the >6.5-year old cows, the LTL, ST and IS muscles of these older animals had high ultimate pH values (pH_U >5.9) and could result in dark-firm-dry (DFD) meat. The ST muscle of the young heifers had an undesirable light colour (L* >40); therefore, the four muscles mentioned above would be more suitable for further processing .An age effect was observed for the tenderness of the muscles, the 1.5-year old heifers produced more tender muscles (LTL, IS and SS) than the 4.5-year old cows. It was also concluded that all of the muscles of the blue wildebeest females were tender (<42 N) (Chapter 4). With regards to chemical composition, the muscles of the oldest cows were not inferior to that of the younger animals. In addition, all six muscles of all the females showed high nutritional value and would be a good source of low fat (<3%) and high protein (>19.9 %) meat (Chapter 5).

Trial 2 reported sexual dimorphism for the majority of the carcass-, muscle- and offal yields measured in the study. The 1.5-year old bulls exhibited high carcass and offal yields, which make them suitable for meat production. The research also reported that blue wildebeest may fall into an early maturing breed category in comparison to other large wildlife species (Chapter 3). With regards to the physical meat quality, the bulls showed high pH_U values for the LTL and ST muscles which could potentially result in DFD meat. Sex had little effect on the tenderness of the muscles, which was also classified as tender (<42 N) (Chapter 4). Furthermore, the effect of sex on the chemical composition of the muscles of the bulls and heifers was negligible. Surplus bulls and heifers have the potential to be culled at a young age to produce meat with good physical quality, as well as high nutritional value (Chapter 5).

There were several factors in the study that warrants future research. The study included old blue wildebeest females brought onto the farm two years before the onset of the trial, which had had no access to supplementary feed prior to their arrival. The game industry has evolved into a more scientific discipline of which supplementary feeding plays an essential role in the development and production of an animal. It would be recommended that future research should include older cows that had similar feeding regimes and are of comparable genetic potential to quantify the actual effect of age on carcass yields and meat quality. Furthermore, the inclusion of more age groups would demonstrate a more accurate growth curve and yield and meat quality changes of female blue wildebeest as they age. It would also be beneficial to investigate the effect of age and sex on the meat-to-bone ratios, as well as the effect on primal yields as this information will be of value to the producers who typically sell carcasses or primal cuts. The animals from this research were harvested from a helicopter, which induces running (high speed) *ante-mortem*. It may be interesting to investigate the manner and magnitude to which different age groups react, physiologically to different culling methods. Since the sensory attributes of meat products are essential to the consumer, it should also receive further attention due to previous studies reporting an age effect on these organoleptic attributes. The investigation of the physiological characteristics of muscles, such as the proportions of muscle fibres, their classification and diameter, will also provide more in-depth conclusions of the effect of age and sex on the meat quality. It would also be advisable to investigate the effect of age and sex on the fatty acid profile of different muscles.

Some game farmers are hesitant to cull surplus, older cows and young bulls for meat production due to the uncertainties regarding the meat quality of these animals. According to the findings of this research, the older surplus blue wildebeest cows (>6.5-years old) and young bulls (1.5-years) are suitable for meat production in terms of carcass yields and characteristics, physical (excluding those muscles exhibiting DFD characteristics), as well as chemical meat quality. This research project provides baseline data that will aid in the marketing and decision making of surplus animals for meat production.