YIELDS AND MEAT-QUALITY ATTRIBUTES OF WILD FALLOW DEER (*DAMA DAMA*) IN SOUTH AFRICA

LEON BRETT FITZHENRY

Thesis presented for the degree of

MASTER OF SCIENCE IN ANIMAL SCIENCE

in the Faculty of AgriSciences at Stellenbosch University

Supervisor: Prof. L. C. Hoffman

Co-supervisor: Dr. D. M. Cawthorn

Co-supervisor: Prof. V. Muchenje

March 2016

DECLARATION

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Date: March 2016

GENERAL ABSTRACT

Fallow deer (*Dama dama*), although not native to South Africa, are abundant in the country and could contribute to domestic food security and economic stability. Nonetheless, this wild ungulate remains overlooked as a protein source and no information exists on their production potential and meat quality in South Africa. The aim of this study was thus to determine the carcass characteristics, meat- and offal-yields, and the physical- and chemical-meat quality attributes of wild fallow deer harvested in South Africa. Gender was considered as a main effect when determining carcass characteristics and yields, while both gender and muscle were considered as main effects in the determination of physical and chemical meat quality attributes. Live weights, warm carcass weights and cold carcass weights were higher ($p < 0.05$) in male fallow deer (47.4 kg, 29.6 kg, 29.2 kg, respectively) compared with females (41.9 kg, 25.2 kg, 24.7 kg, respectively), as well as in pregnant females (47.5 kg, 28.7 kg, 28.2 kg, respectively) compared with non-pregnant females (32.5 kg, 19.7 kg, 19.3 kg, respectively). Accordingly, dress-out percentages were higher ($p < 0.05$) in males (61.5%) than females (59.0%). Total consumable offal (excluding stomach and intestines) comprised *ca*. 9% of the fallow deer live weights, although gender and pregnancy influenced ($p < 0.05$) some individual organ weights and yields. The weights of seven muscles (*longissimus thoracis et lumborum* [LTL], *infraspinatus* [IS], *supraspinatus* [SS], *biceps femoris*, [BF], *semimembranosis* [SM], *semitendinosus* [ST] and *psoas major* [PM]) did not differ ($p > 0.05$) with gender, with the LTL and BF being the heaviest. Total meat and bone weights were higher ($p < 0.05$) for males (20.4 kg and 9.1 kg, respectively) than for females (16.0 kg and 6.9 kg, respectively), but no gender differences were found for the meat-to-bone ratios (2.2–2.3). Physical meat quality measurements and proximate analyses were conducted on six different muscles (LTL, BF, SM, ST, IS and SS) from male (n = 6) and female (n = 6) fallow deer. Ultimate pH (pH_u), drip loss, cooking loss and shear force values were influenced ($p < 0.05$) by muscle, but not by gender. Mean pH_u readings ranged from 5.4 to 5.6 in the six muscles, while drip loss, cooking loss and shear force values ranged from 1.3–1.6%, 29.4–36.1% and 31.3–61.9 N, respectively. In terms of colour, the fallow deer muscles were characterised by $L^* < 40$, high a* and low b* values, being in line with the values generally desired by venison meat consumers. Muscle, however, had an effect ($p < 0.05$) on all the measured colour parameters (L*, a*, b*, chroma, hue-angle), whereas gender only influenced ($p < 0.05$) the a* and chroma values in certain muscles. The proximate composition of the six fallow deer muscles ranged from 73.3–76.2% moisture, 20.4–23.1% protein, 2.2–3.2% lipid and 1.1–1.5% ash. The concentrations of all the proximate components were influenced ($p < 0.05$) by muscle, but not by gender. Fatty acid (FA) and mineral analyses were conducted on two fallow deer muscles, namely the LTL and BF.

Polyunsaturated fatty acids (PUFAs) were found to be the major class of FAs in the muscles (*ca*. 13.57 mg/g meat), followed by saturated FAs (SFAs; *ca*. 10.20 mg/g meat) and monounsaturated FAs (MUFAs; *ca*. 6.46 mg/g meat). Linoleic acid (C18:2n6) and arachidonic acid (C20:4n6) made up the largest proportions of the PUFAs, while stearic acid (C18:0) and palmitic acid (C16:0) were the main SFAs measured. Nonetheless, the PUFA content was influenced ($p < 0.05$) by muscle (BF > LTL), the MUFA content was influenced ($p < 0.05$) by gender (female > male), and a significant ($p < 0.05$) muscle × gender interaction was observed for the SFAs. Overall, the fallow deer muscles had favourable PUFA/SFA ratios (> 0.4) and omega-6/omega-3 (< 4) ratios and could thus be considered as healthy lipid sources. The main essential macro-minerals measured in the LTL and BF were potassium, phosphorus, sodium and magnesium, while iron, zinc and copper represented the primary micro-minerals. The mineral concentrations appeared to be influenced more by muscle than by gender. This study represents the first attempt to quantify the yields and meat quality attributes of wild fallow deer in South Africa, the results of which should lay a foundation for the enhanced utilisation, promotion and consumer acceptance of the derived products.

ALGEMENE UITTREKSEL

Die takbok (*Dama dama*) is nie inheems tot Suid-Afrika nie, maar wel volop teenwoordig en kan daarom 'n groot bydrae lewer tot voedselsekerheid en die land se ekonomiese stand. Nie te min word die waarde van hierdie wildspesie, as bron van proteïen, dikwels oor die hoof gesien. Tot op hede is daar ook geen inligting rakende die produksiepotensiaal en vleiskwaliteit van hierdie spesie in Suid-Afrika te vinde nie. Daarom was die doel van hierdie studie om die karkaseienskappe, vleis- en afval-opbrengs, asook die fisiese en chemiese vleiskwaliteitseienskappe, van takbokke in Suid-Afrika te bepaal. Geslag is beskou as die hoofeffek in terme van die karkaseienskappe en opbrengste terwyl beide geslag en spiertipe gesien is as die hoofeffekte in die bepaling van die fisiese en chemiese vleiskwaliteitseienskappe. Die lewendige massa, warm karkas massa en koue karkas massa was hoër ($p < 0.05$) in die manlike diere (47.4 kg, 29.6 kg, 29.2 kg, onderskeidelik) in vergelyking met die vroulike diere (47.5 kg, 28.7 kg, 28.2 kg, onderskeidelik), so ook in die dragtige takbokke (32.5 kg, 19.7 kg, 19.3 kg, onderskeidelik) teenoor die nie-dragtige takbokke (32.5 kg, 19.7 kg, 19.3 kg, onderskeidelik). Die uitslagpersentasies was ook hoër ($p < 0.05$) in die manlike (61.5%) as die vroulike (59.0%) takbokke. Die totale eetbare afval (uitsluitend maag en ingewande) beslaan ongeveer 9% van die lewende gewig. Geslag en dragtigheid het wel die individuele orgaan massas en opbrengste beïnvloed. Die massas van die sewe spiere (*longissimus thoracis et lumborum* [LTL], *infraspinatus* [IS], *supraspinatus* [SS], *biceps femoris*, [BF], *semimembranosis* [SM], *semitendinosus* [ST] and *psoas major* [PM]) het nie verskil ($p > 0.05$) as gevolg van geslag nie en die LTL en BF was die swaarste spiere. Die totale massa van die vleis en bene was hoër by die manlike takbokke (20.4 kg en 9.1 kg, onderskeidelik) as by die vroulike takbokke (16.0 kg en 6.9 kg, onderskeidelik), alhoewel daar geen verskil was in die vleis tot been verhoudings nie (2.2–2.3). Die fisiese vleiskwaliteit en proksimale samestelling is bepaal op ses verskillende spiere (LTL, BF, SM, ST, IS and SS) van manlike ($n = 6$) en vroulike ($n = 6$) takbokke. Die finale pH (pH_u), dripverlies, kookverlies en instrumentele sagtheid is beïnvloed ($p < 0.05$) deur spiertipe, maar nie deur geslag. Die gemiddelde pH_u varieer van 5.4 tot 5.6 in die ses spiere, terwyl die persentasies dripverlies, kookverlies en instrumentele sagtheid strek van 1.3–1.6%, 29.4–36.1% en 31.3–61.9%, onderskeidelik. Die kleur van die takbokvleis toon $L^* < 40$, hoë a^* en lae b^* waardes wat ooreenstem met die kenmerkende kleur van wildsvleis. Spiertipe het wel 'n invloed gehad op al die kleur parameters (L^*, a^*, b^*, chroma, hue), terwyl geslag net die a^* en chroma waardes van sekere spiere geaffekteer het. Die proksimale analise van die ses spiere het getoon dat takbokvleis bestaan uit 73.3–76.2% vog, 20.4–23.1% proteïen, 2.2–3.2% lipied, en 1.1–1.5% as. Die persentasie van al die proksimale komponente is beïnvloed ($p < 0.05$) deur spiertipe, maar

nie deur geslag nie. Vetsuur en mineraal analises is uitgevoer op slegs twee van die takbok spiere naamlik die LTL en BF. Die spiere het hoofsaaklik bestaan uit poli-onversadigde vetsure (PUFAs) (ongeveer 13.57 mg/g vleis) gevolg deur versadigde vetsure (SFAs; ongeveer 10.20 mg/g vleis) en mono-onversadigde vetsure (MUFAs; ongeveer 6.46 mg/g vleis). Linoleïensuur (C18:2n6) en aragidoonsuur (C20:4n6) is die individuele vetsure wat hoofsaaklik bygedra het tot die hoë PUFA vlakke terwyl steariensuur (C18:0) en palmitiensuur (C16:0) die hoof SFAs teenwoordig was. Die PUFA inhoud is beïnvloed ($p < 0.05$) deur spiertipe (BF > LTL), die MUFA inhoud deur geslag (vroulik > manlik) en ‘n betekenisvolle spiertipe x geslag interaksie is gevind rakende die SFA inhoud. In geheel het al die spiere gunstige PUFA/SFA verhoudings (> 0.4) asook omega-6 tot omega-3 verhoudings (< 4) en kan dus gesien word as gesonde bronne van vet. Die hoof essensiële makrominerale in die LTL en BF was kalium, fosfaat, natrium en magnesium terwyl yster, sink en koper die primêre mikrominerale teenwoordig was. Dit wil voorkom of die konsentrasie minerale meer deur spiertipe as deur geslag beïnvloed word. Hierdie studie verteenwoordig die eerste poging om die opbrengs en vleiskwaliteit van wilde takbokke in Suid-Afrika te kwantifiseer. Die resultate bied ‘n platform om sodoende die aanwending en verbruikers aanvaarding van takbokvleis te bevorder.

ACKNOWLEDGEMENTS

I would like to express my sincerest appreciation to the following people and institutions:

Prof. L.C. Hoffman (supervisor) and Dr. D.M. Cawthorn (co-supervisor) at the Department of Animal Sciences, Stellenbosch University, as well as Prof. V. Muchenje (co-supervisor) at the Department of Livestock and Pasture Science, University of Fort Hare. Their guidance, support and constructive criticism throughout this study enabled me to grow as a researcher. I am grateful that they believed in my abilities and always encouraged me to go far beyond what I thought I was capable of;

The National Research Foundation (NRF), for financial assistance (the opinions expressed and conclusions arrived at in this study are those of the author and are not necessarily to be attributed to the NRF);

Lood Van Deventer at Brakkekuil farm, for his patience, willingness to help and friendly assistance prior to and during the harvesting of the fallow deer for this study;

Gail Jordaan, Beverly Ellis, and Lisa Uys at the Department of Animal Sciences, Prof. M. Kidd at the Centre for Statistical Consultancy, and Riana Russouw at the Central Analytical Facility (CAF) for the help and patience with my analyses;

The staff members at the Department of Animal Sciences, for their friendly assistance during the laboratory analyses;

Fellow students whom I can now call my friends, for their helpfulness and encouragement during this study;

My family, for all their love, patience and continuous support whenever my thesis was the topic of conversation.

LIST OF ABBREVIATIONS

AA	Arachidonic acid (C20:4n6)
AI	Adequate intake
ALA	α-Linolenic acid (C18:3n3)
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BF	*Biceps femoris* muscle
DFD	Dark, firm and dry meat
DHA	Docosahexaenoic acid (C22:6n3)
EPA	Eicosapentaenoic acid (C20:5n3)
FA	Fatty acid
FAME	Fatty acid methyl esters
g	Gram
h	Hour
IS	*Infraspinatus* muscle
kg	Kilogram
L	Litre
LA	Linoleic acid (C18:2n6)
LSD	Least significant difference
LTL	*Longissimus thoracis et lumborum* muscle
mg	Milligram
Min	Minute
mL	Millilitre
MUFA	Monounsaturated fatty acid
N	Newton
n-6/n-3 ratio	Omega-6 to Omega-3 fatty acid ratio
pH_u	Ultimate pH
PM	*Psoas major* muscle
PUFA	Polyunsaturated fatty acid
PUFA/SFA	Polyunsaturated to saturated fatty acid ratio
RDA	Recommended dietary allowance
Sec	second
SFA	Saturated fatty acid
SM	*Semimembranosis* muscle
SS	*Supraspinatus* muscle
ST	*Semitendinosus* muscle
v/v	Volume to volume ratio
WHC	Water-holding capacity

NOTES

The language and style used in this thesis are in accordance with the requirements of the journal *Meat Science*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between the chapters, especially in the Materials and Methods sections, has therefore been unavoidable.

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CHAPTER 1

INTRODUCTION

For many thousands of years, our hunter-gatherer ancestors in the Pleistocene epoch capitalised on a wide array of wild ungulates to satisfy their protein requirements (Diamond, 1987; Mann, 2000). While often heralded as a momentous evolutionary step for mankind, animal domestication and the development of husbandry practices in the late Pleistocene / early Holocene period drastically narrowed the number of species upon which man would rely for food: only 14 of the world's *ca*. 148 large terrestrial mammals (> 45 kg) were domesticated (Diamond, 2002). This hunter-gatherer to food-producer transition indeed assured an ample and consistent supply of meat, however, it also spurred an increase in sedentism and human population growth – trends that have continued unabated ever since (Alvard & Kuznar, 2001).

In comparison with the estimated 10 million people on earth at the onset of agriculture development around 10 000 years ago (Chapman & Reiss, 1999), the global human population today far surpasses 7 billion. The worldwide demand for animal protein has consequently soared, with global meat consumption rates increasing by more than 80% over the last 50 years (Sans & Combris, 2015). This escalating demand has mainly been fuelled by the developing world, where rapidly expanding populations, higher incomes and urbanisation are promoting the greater inclusion of animal protein sources in the diet (Smith et al., 2013; Thornton, 2010). Global meat production has accordingly been forced to maintain pace, more than quadrupling over the past five decades to approach 309 million tonnes in 2014 (OECD, 2015). Although pig production has continued to rise, it has been the production of poultry that has contributed most spectacularly to the overall growth of the global meat industry, increasing over 10-fold since the 1960s to supply 105 million tonnes of meat in 2014 (FAOSTAT, 2015). Conversely, growth in the cattle and sheep sectors has largely stagnated, with decreasing demand being mainly ascribed to the health-, price- and welfare-concerns associated with red meat consumption (Hoffman, Muller, Schutte, Calitz, & Crafford, 2005; Kanerva, 2013; Taljaard, Jooste, & Asfaha, 2006).

With the global human population set to exceed 9 billion by 2050, it has been proposed that agricultural production will need to increase by more than 50% to sustain these intensifying needs (Ingram, Ericksen, & Liverman, 2010). Moreover, during the short time horizon to 2019, meat demand in developing countries is expected to increase by 23–38% (Boland et al., 2013). Nonetheless, the aforementioned projections do not take into account the limitations in resource availability, nor the impending effects of climate change (Boland et al., 2013; Nellemann et al., 2009). It is well known that most of the land available for livestock farming has already been exploited, and that urbanisation and biofuel production are rapidly reducing the remainder (Steinfeld et al., 2006). Much of the current grazing land is degraded, including 75% of Africa's drylands (IFAD, 2000), largely due to overgrazing by domestic livestock (Steinfeld et al., 2006). If not compensated for, the joint effects of land shortages, degradation, water scarcity, climate change, and increasing oil-, fertiliser- and feed- prices, could cause projected food yields to fall 25% short of anticipated demands in 2050 (Nellemann et al., 2009). Such a realisation would likely present a major impediment to achieving food security in many regions, particularly in sub-Saharan Africa, where one in four people are already considered undernourished (FAO, 2015).

Given the constraints on improving the productivity of domestic livestock, emphasis has progressively shifted to the role of alternative species in providing high-quality protein for human consumption (Cooper, 1995). More specifically, there has been a growing recognition of the importance of utilising marginal and sub-marginal lands more optimally by harvesting or stocking species that thrive under adverse conditions, especially those that are abundant in the wild or considered as agricultural pests (Cawthorn & Hoffman, 2014). Such an endeavour is epitomised by the game ranching industry in South Africa, whereby the stocking of wild ungulates that are adapted to local vegetation and conditions allows ranchers to operate with lower input and management costs compared with domestic livestock farming, while simultaneously reducing land degradation and maintaining biodiversity (Barnett, 2000; World Bank, 2005). This industry not only provides a valuable source of meat for consumption, but has also directly contributed to the 40-fold increase in game numbers in the country over the last 50 years (Van Hoven, 2015). In 2010, South African game meat exports were worth R 70 million, with springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus pygargus phillipsi*) and greater kudu (*Tragelaphus strepsiceros*) contributing most notably (Hoffman & Cawthorn, 2014; Uys, 2015).

One ungulate species in South Africa that has received far less attention as a meat producer is the fallow deer (*Dama dama*), which although not native, is abundant, adaptable and often regarded as a pest by local farmers (Bothma, 2014; Jensz & Finley, 2013; Moore, Hart, Kelly, & Langton, 2000). In contrast, fallow deer are widely famed in continental Europe and Oceania, where the derived meat is a highly marketed commodity due to its high protein and low fat contents (Hudson, Drew, & Baskin, 1989; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003). While fallow deer meat could contribute meaningfully to food security in South Africa and potentially represent a "pest to profit" scenario, its contribution to the local game meat industry remains minimal and it has been noted that the consumer uptake of game meat is frequently hindered by poor quality perceptions and inadequate information on nutritional value (Hoffman et al., 2005; Issanchou, 1996). The overarching aim of this study was thus to provide new insight on the carcass characteristics, as well as on the physical quality, composition and nutritional value of the meat from wild fallow deer harvested in South Africa.

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CHAPTER 2

LITERATURE REVIEW

2.1. EVOLUTION OF THE GAME INDUSTRY IN SOUTH AFRICA

Around the middle of the 20th century, game animals in South Africa had very little economic value. Rather, it was believed that game competed with domestic livestock for grazing and carried transmissible diseases, with the general consensus being that these animals should be exterminated to make way for cattle, sheep and goats (Carruthers, 2008). Earlier epidemics of bovine pleuropneumonia (1850s), rinderpest (1896–1897) and Nagana (1929–1931) had, however, already dramatically reduced wildlife populations in South Africa, while the eradication of copious numbers of large mammals to control the spread of tsetse fly further exacerbated these losses (Bond et al., 2004). In addition, since wildlife up until this time was considered '*res nullius*' (without ownership) and hunting was unregulated, the overexploitation of game species by sport- and subsistence-hunters was rife. As a result of these factors, wildlife numbers in South Africa plummeted to their lowest figures ever by 1960. At this point, only 500 000 wild animals were estimated to remain in the country (including in public protected areas), with a mere 19 bontebok (*Damaliscus pygargus pygargus*), 2 000 blesbok (*D. pygargus phillipsi*), 1 700 black wildebeest (*Connochaetes gnou*) and 90 mountain zebra (*Equus zebra*) (Brand, 1965; Dry, 2011).

With concern mounting on the precarious state of South African wildlife, a process began in the 1960s that would progressively raise the national value of game species and vest ownership rights over these resources to private landowners (Bond et al., 2004). In what came to be regarded as a "conservation revolution", the work of Raymond Dasmann and Archie Mossman on a remote farm in Rhodesia (now Zimbabwe) in 1959–1961 concluded not only that game and cattle could co-exist and that 'mixed farming' could improve profitability, but also that game ranching on its own held substantial potential for boosting Africa's protein supply (Dasmann, 1964; Dasmann & Mossman, 1960; 1961). On one level, domestic livestock farming in sub-Saharan Africa continued to be hampered by disease, reliance on grain-based feeds, water scarcity, unpredictable climates and limited support services, while also contributing directly to land degradation (World Bank, 2005). On another level, since game animals are exceptionally well adapted to harsh environmental conditions, survive well on low-quality vegetation and can be kept at high stocking densities, the input and management costs of game ranching operations can be considerably lower than those incurred by livestock farmers (Barnett, 2000). Moreover, the proposed advantages of wildlife ranching over cattle ranching lay not only in meat production, but also in the multiple values accruing from trophy hunting, biltong hunting, ecotourism and hides (Lindsey et al., 2013). Subsequent investigations provided support to these findings, suggesting that game ranching could indeed represent a more suitable and profitable alternative to cattle ranching in the fragile drylands of Southern Africa (Child, 1988; Jansen, Bond, & Child, 1992; Riney, 1963; Talbot, 1966). While this research marked the birth of the local game industry, the formal acceptance of wildlife ranching as a fully-fledged agricultural activity by the Department of Agricultural Development in 1987 catalysed the transition of wildlife rights from '*res nullius*' to private land ownership status (Van Hoven, 2015). The evolution of the industry that followed was spectacular, with wildlife ranching becoming the fastest growing agricultural activity in the country over the past three decades (NAMC, 2006).

Today, up to 11 600 game ranches exist in South Africa, resulting in the conversion of *ca*. 25 million hectares of marginal agricultural land into thriving operations. These expansions have allowed local game populations to flourish, with numbers increasing by 40-fold since the 1960s to reach 21 million in 2013 (Dry, 2011; Van Hoven, 2015). Of these numbers, 16 million head are kept on private conservation land, exceeding the number of cattle (14 million) in the country (Van Hoven, 2015). The main species harvested in South Africa for the commercial meat supply are springbok (*Antidorcas marsupialis*, >80%), blesbok and greater kudu (*Tragelaphus strepsiceros*), while wildebeest (*Connochaetes* spp.), impala (*Aepyceros melampus*) and gemsbok (*Oryx gazella*) contribute to a lesser but notable extent (Hoffman & Cawthorn, 2014a). All of these animals come from free-range, extensive production systems (Hoffman & Wiklund, 2006).

Accurate data on the consumption and trade of South African game meat is scarce, however, it is estimated that this contributes <20% of the total fresh red meat consumed locally (SAMIC, 2009; Van der Merwe, Jooste & Hoffman, 2011). In addition, 30 000 tonnes of game meat is said to be consumed annually in the country in the form of processed meat products (Cloete, 2015). Although a foot-and-mouth disease related ban on South African game meat exports was implemented between 2011 and 2014, official statistics indicate that almost 6 000 tonnes (R 70 million) was exported from the country in 2010 (FAO-STAT, 2015). About 2 000 tonnes of this meat was destined to countries in the European Union (EU), whereas the actual annual demand for game in these countries is thought to exceed 100 000 tonnes (Cloete, 2015). Nonetheless, considering its potential, not only does the local market for game meat remain underdeveloped, but South African game meat exports continue to be overshadowed by those from deer production in, amongst others, New Zealand and Germany (Cloete, 2015; Uys, 2015).

2.2. DEER FARMING GLOBALLY

In comparison to the 70 antelope species known to occur in sub-Saharan Africa alone (East, 1999), 53 species of deer (family Cervidae) are recognised globally. The Cervidae are further divided into two families, namely Cervinae that includes the fallow deer (*Dama* spp.), axis deer/chital (*Axis axis*), various *Cervus* species and other Old World deer, as well as Capreolinae that includes the reindeer (*Rangifer tarandus*), moose (*Alces alces*), roe deer (*Capreolus* spp.), white-tailed deer (*Odocoileus virginianus*) and many other New World deer (Mattioli, 2011). Like African antelope (Bovidae), deer are ruminants, and thus differ remarkably in their feeding habits and digestive strategies in comparison with monogastric (single-stomached) animals (Kay, Engelhardt, & White, 1980). The main morphological characteristic differentiating cervids from bovid species is that male deer grow antlers rather than horns (Chapman & Chapman, 1997).

Deer farming has both very old and very new origins (Drew, 1989). While this activity is thought to have had its roots in the Far East some 3 000 years ago (Chardonnet et al., 2002), today more than 5 million deer are farmed extensively or intensively in many parts of the world (Table 2.1). Modern deer farming was pioneered in New Zealand in the early 1970s (Loudon & Fletcher, 1983), where the industry effectively began to apply scientifically-advanced techniques to convert animals that were regarded as pests into a major commodity (Chardonnet et al., 2002; Hoffman & Wiklund, 2006). From its humble beginnings, New Zealand now has the world's largest farmed deer population (*ca*. 1.1 million, 85% being red deer, *Cervus elaphus*, Table 2.1). Accordingly, New Zealand is also the leading global supplier of farmed venison, exporting *ca*. 23 000 tonnes of meat in 2014 with a value of NZ$ 181 million (R 1 billion) (Cloete, 2015).

Following New Zealand's success, commercial deer farming became increasingly popular in North America in the 1970s. This practice subsequently developed to the point where it is now considered the fastest growing industry in rural America (Anderson, Frosch, & Outlaw, 2007). The fallow deer (*Dama dama*), wapiti (*Cervus canadensis*), chital (*A. axis*), sika deer (*C. nippon*) and white-tailed deer (*Odocoileus virginianus*) are most commonly farmed in Canada and the United States, while reindeer (*R. tarandus*) are herded in the Arctic regions (Hoffman & Cawthorn, 2014a,b; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003) (Table 2.1).

Deer farming in Europe is primarily focused on venison production from fallow deer (*D. dama*) and red deer (*C. elaphus*), with Germany being the largest producer (Table 2.1). While Asia has a considerable deer farming industry (>1.1 million head; Chardonnet et al., 2002), this is almost entirely based on the production of velvet antler for use in medicinal products (Drew, Bai, & Fadeev, 1989) (Table 2.1).

Table 2.1 Cervid species farmed around the world.

Continent	Region	Main taxa	Estimated numbers	Production system	Main products	Source
Oceania	Australia	Red (48%), fallow (44%) deer	43 856	Intensive / extensive	Venison, velvet antler	Shapiro, 2010.
	New Caledonia	Rusa deer	20 000			Hudson, 2002.
	New Zealand	Red (85%), fallow deer and wapiti	1 100 000			DINZ, 2015.
Asia	China	Sika (70%) and red (29%) deer	500 000	Mostly intensive, some extensive	Mostly velvet antler	Chardonnet et al., 2002.
	Russia[1]	Sika deer, wapiti	400 000			Chardonnet et al., 2002.
		Reindeer (herded)	2 500 000			Chardonnet et al., 2002.
	Korea	Sika, wapiti, red	200 000			Chardonnet et al., 2002.
	Malaysia	Rusa, fallow deer	15 000			Chardonnet et al., 2002.
	Taipei, China	Sika, sambar, red deer	36 000			Chardonnet et al., 2002.
	Thailand	Rusa, sambar deer	5 000			Chardonnet et al., 2002.
	Vietnam	Sika, sambar deer	15 000			Chardonnet et al., 2002.
Americas	Argentina	Red, fallow, axis deer	2 000	Intensive / extensive	Venison, velvet antler	Chardonnet et al., 2002.
	Brazil	Rusa deer	1 000			Chardonnet et al., 2002.
	Canada	Wapiti, fallow, white-tailed deer	99 000			Chardonnet et al., 2002.
		Reindeer (herded)	9 825			Chardonnet et al., 2002.
	USA	Fallow, red, wapiti, axis, sika	250 000			Chardonnet et al., 2002.
		Reindeer (herded, Alaska)	25 000			Chardonnet et al., 2002.
Europe	Austria	Fallow deer	39 600	Intensive / extensive	Venison	Chardonnet et al., 2002.
	Belarus	Sika deer	1 300			Chardonnet et al., 2002.
	Benelux	Red deer	3 300			Chardonnet et al., 2002.
	Czech Republic	Red deer	9 800			Chardonnet et al., 2002.
	Denmark	Fallow, red deer	31 200			Chardonnet et al., 2002.
	France	Fallow deer	30 000			Hudson, 2002.
	Germany	Fallow deer	150 000			Hudson, 2002.
	Great Britain	Red, fallow deer	36 000			Chardonnet et al., 2002.
	Hungary	Red, fallow deer	1 100			Chardonnet et al., 2002.
	Ireland	Red, fallow deer	61 000			Chardonnet et al., 2002.
	Italy	Fallow, red deer	24 000			Chardonnet et al., 2002.
	Lithuania	Sika deer	850			Chardonnet et al., 2002.
	Norway	Red deer	1 000			Hudson, 2002.
	Poland	Red deer	1 000			Chardonnet et al., 2002.
	Portugal	Red deer	1 300			Chardonnet et al., 2002.
	Spain	Red deer	4 000			Chardonnet et al., 2002.
	Slovakia	Red deer	2 000			Chardonnet et al., 2002.
	Sweden	Red, fallow deer	35 000			Hudson, 2002.
	Switzerland	Red, fallow deer	7 600			Chardonnet et al., 2002.
Island nations	Reunion	Rusa deer	2 000	Intensive / extensive	Mostly venison	Chardonnet et al., 2002.
	Mauritius	Rusa deer	60 000			Chardonnet et al., 2002.

[1] Russia spans parts of Asia and Europe

2.3. FALLOW DEER (*DAMA* SPP.)

2.3.1. General description

The genus *Dama* comprises the European fallow deer (*D. dama*) and Persian fallow deer (*D. mesopotamica*) (Pitra, Fickel, Meijaard, & Groves, 2004), although the latter has previously been regarded as a sub-species of the former (Chapman & Chapman, 1980; Feldhamer, Farris-Renner, & Barker, 1988; Geist, 1998). Only small variations exist between the two, including differences in size (*D. mesopotamica* being slightly larger), antler morphology and tail markings. Fallow deer exhibit the largest colour variation of all the cervids, with the coats being darker and duller during winter than during summer (Chapman & Chapman, 1997).

The European fallow deer (*D. dama*) is geographically widespread, being native only to western Eurasia, but being introduced to many countries throughout Europe, Africa, Oceania, Asia and the Americas (Chapman & Chapman, 1997). Due to their remarkable adaptability and ability to survive in diverse habitats, these deer have thrived in the regions where they have been introduced and increased greatly in number. As a result, *D. dama* is currently listed as "least concern" by the International Union for Conservation of Nature (IUCN) (Masseti & Mertzanidou, 2008). Conversely, Persian fallow deer (*D. mesopotamica*) have largely been extirpated from their former range in the Near and Middle East, mainly as a result of ongoing hunting and land conversion. The wild population is now confined to about 250 adults in Iran and Israel, and the species is listed as "endangered" by the IUCN (Werner, Rabiei, Saltz, Daujat, & Baker, 2015).

The diet of European fallow deer (hereafter referred to as fallow deer) consists largely of graze, although some browsing does occur on the leaves of woody plants, berries, nuts and the bark of trees. Male fallow deer (buck) generally weigh between 46 and 94 kg (Bothma, 2014), but can exceed 100 kg (Chapman & Chapman, 1997). Female fallow deer (does) usually have a weight range of 35–56 kg and have a lower shoulder height than the buck. These animals are agile and fast sprinters, being able to jump 1.75 metres high and as far as 5 metres. Fallow deer are also gregarious, forming herds of up to 150 animals (Bothma, 2014). The breeding season (rut) lasts approximately 4 weeks. Fallow does reach sexual maturity between 16- and 24-months-of-age, with those in the weight class of *ca*. 55 kg being most likely to fall pregnant (Anon., 1994).

2.3.2. Fallow deer in South Africa

Although the precise date of fallow deer introduction to South Africa remains uncertain, the earliest records indicate that these animals were kept in a park at Newlands House in Cape Town in 1869 (Chapman & Chapman, 1980). Following the sale of Newlands House, the entire population (*ca*. 100 animals) is believed to have been sold to a farmer from Somerset West (Western Cape). Owing to their outstanding adaptability, fallow deer soon grew in number and expanded in range (Fig. 2.1). Today, these animals are found in semi-desert Karoo shrublands and large areas across the Western Cape, Eastern Cape, Free State, KwaZulu-Natal and Gauteng (Chapman & Chapman, 1980). Due to their expanding populations, fallow deer are now frequently perceived as agricultural pests that compete for livestock grazing and damage vegetation (Bothma, 2014; Jensz & Finley, 2013; Masseti & Mertzanidou, 2008). Unlike many other countries in the world where the species is farmed (Table 2.1), the fallow deer in South Africa are all currently part of free-roaming, wild populations. In further contrast to other countries, fallow deer in South Africa are largely overlooked as meat producers and contribute little to the local game meat industry.

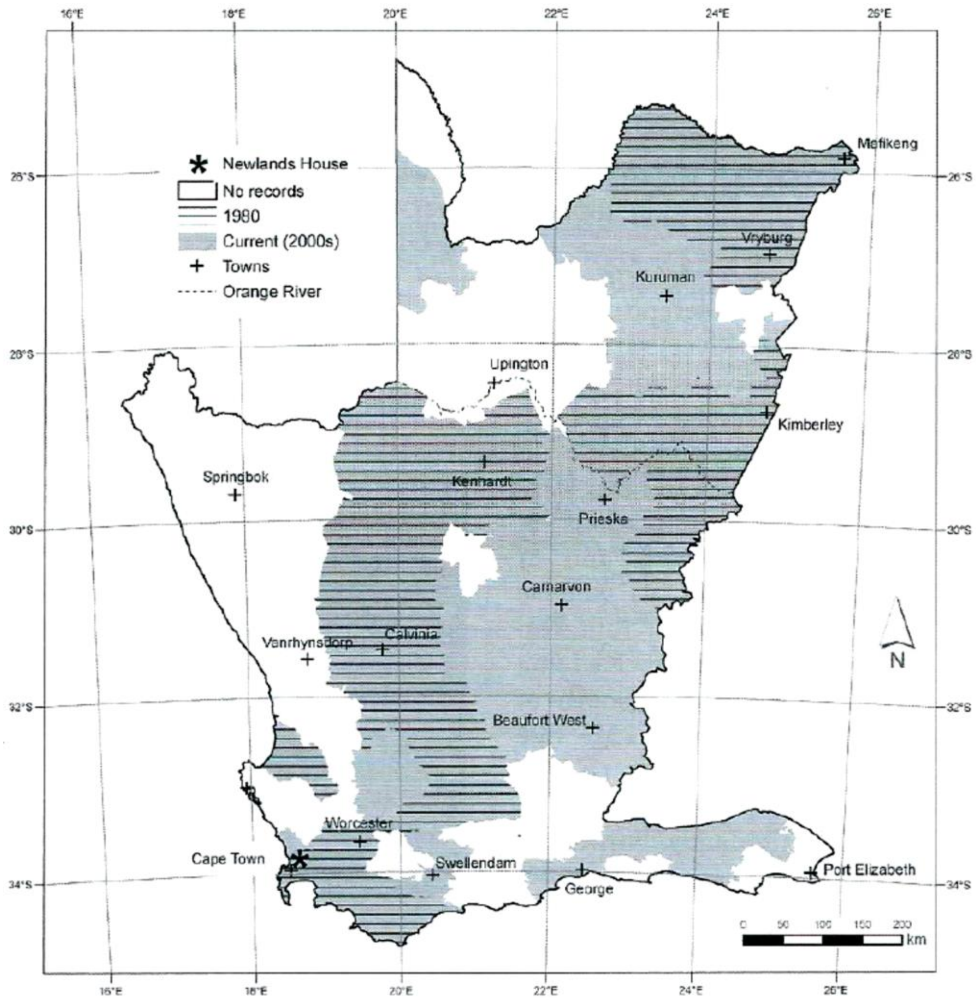

Figure 2.1 The district-level distribution of fallow deer in the broader Western and Northern Cape of South Africa, indicating their original introduction, their spread prior to 1980 (horizontal bars – Chapman & Chapman, 1980) and the expansion in their distribution based on the most current records (shaded area – Skead, 2011) [Figure adapted from Skead, 2011].

2.4. TRAITS OF SUCCESSFUL MEAT-PRODUCING SPECIES

For an animal species to be successful in terms of commercial meat production, it must compete with domestic livestock species on a number of levels (Hoffman & Cawthorn, 2013). For many generations, domestic livestock have been genetically selected for enhanced reproductive fitness, faster growth rates and optimum feed conversion ratios, while more recently also being selected for reduced greenhouse-gas emission rates (Hayes, Lewin, & Goddard, 2013). In an ideal situation, successful meat producers would thus have favourable on-farm production potential, including high reproductive or fecundity rates (polygamous rather than monogamous, short gestation periods, polytocous), good feed conversion rates and adaptability in their diet, a herding instinct or amenability to intensive management, resistance to disease, as well as low-carbon and water footprints (Hoffman & Cawthorn, 2013). Moreover, the candidate species should have favourable carcass and meat yields, delivering a final product that has desirable physical and nutritional attributes and that, above all, is acceptable to the consumer (quality, price, convenience, ethically and culturally suitable) (Font-i-Furnols & Guerrero, 2014).

2.4.1. Production potential

Unlike the majority of the game species (including fallow deer) that are ranched extensively in South Africa, deer farming in many parts of the world is increasingly being carried out under intensive or semi-intensive management systems (Hoffman & Cawthorn, 2013; 2014a). Inherent to the last mentioned systems is the growing use of interventions that often parallel those used in conventional livestock farming, including genetic selection, artificial insemination, progeny testing, castration, supplementary feeding, veterinary procedures and organised slaughter at suitable abattoirs (Chardonnet et al., 2002; Hoffman & Cawthorn, 2013). Although deer farming as such may not appear to capitalise on the unique ecological adaptations of wild ungulates, deer are particularly amendable to intensive systems (Drew, 1989). The practical benefits of intensive farming include the capacity to assure high standards of disease control and hygiene, which promotes the market acceptance of the meat. Furthermore, such systems facilitate the use of small land bases and diversification of existing agricultural operations (Drew, 1989). Nonetheless, the production potential of animals is known to be influenced by various extrinsic (environmental) and intrinsic (mostly genetic) factors, including species, diet, reproductive rate and gender (Hoffman & Cawthorn, Lawrie & Ledward, 2006a).

Diet

Ruminants, in general, are better equipped at using low-quality nutrition in comparison with monogastric animals (Van Soest, 1994). Regardless of the production system, game and deer species tend to adapt particularly well to different vegetation types, convert feed into protein efficiently and can be reared on marginal land where appropriate management is implemented (Anon., 1994; Von La Chevallerie, 1970). Nevertheless, both the production region and season can influence the quantity, quality and suitability of the vegetation available to these species and thus also impact on their growth and development (Hoffman, Kritzinger, & Ferreira, 2005a). Different deer species may have different dietary requirements (broadly categorised by Hofmann, 1985), with these requirements generally varying according to season and reproductive status (Haigh, 2012). In many countries, particularly in continental Europe and North America, free-ranging deer are commonly provided with supplementary feeding (e.g. hay, silage, root crops, maize, commercial pelleted rations) during the winter or dry months (Putman & Staines, 2004; Volpelli et al., 2003). Such strategies are principally aimed at increasing stocking densities, balancing rations (especially trace minerals), increasing body weight and condition, as well as improving reproductive performance (Putman & Staines, 2004). Supplementation becomes particularly important for males following the rut, since they can lose up to 20% of their body weight during this period (Clutton-Brock, Guinness, & Albon, 1982). In China, where stocking rates are particularly high for velvet antler production, deer are predominantly confined to feedlot systems and raised on hay, concentrates and grain-based feeds (Haigh, 2012).

Reproductive potential

The large majority of deer species are polygamous, with one fallow deer buck being capable of breeding up to 35 does (Anon., 1994). Most Old World deer (including fallow deer) have gestation periods of *ca*. 7.5 months, whereas this may be shorter in New World deer (Geist, 1998). While deer most often give birth to single offspring, twins and triplets are not uncommon for many species (Bothma, 2014; Stefoff, 2007), which can result in increased production outputs. On the other hand, single fawns typically gain weight more rapidly than twins or triplets, likely due to their ability to consume more milk per feeding (Ozoga, 1996). Moreover, the young of farmed species are typically removed soon after weaning for rearing and subsequent slaughter, whereas the harvesting of mature, often breeding stock, in wild systems alters both the structure of the breeding herd and its production rate (Hoffman & Cawthorn, 2013).

Gender

In terms of gender, sexual size dimorphism (SSD), defined as the difference in mean body size between males and females, can have a marked influence on production potential and resultant meat yields. Among polygynous mammals, the ungulates provide one of the most striking examples of male-biased SSD, which is thought to evolve due to natural selection, sexual selection or both (Darwin, 1871; McElligott et al., 2001). In particular, fallow deer are considered to be the most sexually dimorphic of all the cervids, with male to female live weight ratios of 1.7 (Loison, Gaillard, Pélabon, & Yoccoz, 1999), 2.2 (Carranza, 1996) and 2.4 (McElligott et al., 2001) having been recorded. One prominent reason for this marked male-biased SSD in fallow deer is thought to be due to larger (skeletal size) males gaining more mating success than their smaller counterparts, which in turn results in selection for larger male size. Heavier (body mass) males may also have an indirect advantage in terms of mating success, mediated through the dominance ranks attained before and during the rut (McElligott et al., 2001). Although sexual selection on male size is theoretically expected to exert a corresponding effect on females (Lande, 1980; 1987), it has been suggested that larger size lowers the reproductive rate in female mammals. Since it would not be in the female's best interest to grow larger, fecundity selection is thought to act as a counteracting factor selecting for smaller size in female mammals (Lindenfors, 2002; 2007).

Apart from differences in overall size, gender further affects the growth and development of individual muscles and muscle groups, e.g. forequarter and/or hindquarter muscles (Lawrie & Ledward, 2006a,b). In general, carcasses with greater proportions of hindquarter are more valuable owing to both their higher ratios of lean to bone and to the higher-priced joints derived from this region (Ledger, 1963). Female game species mature earlier than males and typically have higher hindquarter percentages (relative to whole carcass weight) than mature males (Ledger, 1963). Males, on the other hand, generally develop larger neck and thorax muscles (Jones, 2014), with the latter being used in fights for dominance (Lawrie & Ledward, 2006a).

2.4.2. Carcass yields

Game meat and venison is sold per animal or per kilogram (Hoffman & Wiklund, 2006), thus it is important to have an understanding of the species that deliver the highest marketable yields (Issanchou, 1996). Whereas live weight alone does not necessarily predict an animals' meat production potential, knowledge of the carcass weight and dress-out percentage can give a good indication of this potential when data on the carcass composition are available (Van Zyl, Von La Chevallerie & Skinner, 1969; Von La Chevallerie, 1970).

Previous research has suggested that wild game species are able to produce comparable or higher dress-out percentages in relation to domestic livestock species (Table 2.2), reportedly as a result of the higher proportion of muscle in the former carcasses (Ledger, 1963; Skinner, 1984; Von la Chevallerie, 1970). The high ratio of lean meat produced as a proportion of live weight has also been cited as an advantage in terms of deer production (Anon., 1994). Moreover, wild ungulates are believed to compare favourably with livestock due to their ability to achieve mature weights at a younger age under harsh conditions (Skinner, 1984). The variations in dress-outs between game, deer and domestic livestock as cited in the literature (Table 2.2) may thus not only reflect the differences in maturity at normal slaughter weight, but also the differences in management procedures and sexual status (castrated, intact, females) (Van Zyl & Ferreira, 2004). Furthermore, dress-out percentages across species can contrast considerably due to the differing proportions of external offal (head, feet and skin) and internal offal (organs and entrails) (Van Zyl & Ferreira, 2004). For instance, the proportion of external offal in game species (13.1–17.3%, relative to live weight) is considerably lower than that found for sheep (*ca*. 19.1%) and goats (*ca*. 20.6%) that have heavier skins (wool/mohair) (Atti, Nozière, Doreau, M., Kayouli, & Bocquier, 2000; Ferreira, Van der Merwe, & Löest, 1999; Owen & Norman, 1977; Riley, Savell, Shelten, & Smith, 1989), potentially contributing to the higher dress-out percentages in most game species (Table 2.2). It should, however, be noted that dress-out percentages may additionally be influenced by a number of other factors, including the presence/absence of horns or antlers, gut fill and the quantity of fat depots (more visceral and kidney fat results in lower dress-out percentages) (Swatland, 1994; Van Zyl & Ferreira, 2002).

In general, conflicting results have been reported on the effects of gender and castration on the dress-out percentages of game and deer. For instance, gender was reported to have no significant ($p > 0.05$) effect on the dress-out of blesbok, springbok and impala (Van Zyl & Ferriera, 2004), greater kudu (Mostert & Hoffman, 2007; Hoffman, Mostert, Kidd, & Laubscher, 2009), nor on that of fallow deer (Stanisz et al., 2015). Conversely, Kroucamp (2004) recorded significantly higher ($p < 0.05$) dress-out percentages in male springbok compared with females. Although most available literature indicates that castrated male deer have decreased growth rates, lower live weights and higher carcass fat levels than entire males of comparative age (Drew & Hogg, 1990; Tuckwell, 2003), this does not necessarily lead to significant differences in the dress-out percentages of the two groups (Asher, Archer, Ward, Mackintosh, & Littlejohn, 2011; Kay et al., 1981; Kim, Kim, Park, Kim, & Yim, 2015).

Table 2.2 Dress-out percentages (relative to live weight) of selected deer, game and domestic livestock species

Species	Dress-out (%)	Reference
Deer		
Fallow deer	57.2–67.2	Mulley et al., 1996; Stanisz et al., 2015; Tuckwell, 2003; Volpelli et al., 2002; Wiklund et al., 2005.
Red deer	53.5–58.8	Drew & Hogg, 1990; Tuckwell, 2003; Wiklund et al., 2003.
Reindeer	46.0–51.8	Wiklund et al., 2000.
Rusa deer	60.0–62.0	Woodford & Dunning, 1992.
Wapiti	52.5–56.4	Drew & Hogg, 1990; Tuckwell, 2003.
Game		
Blesbok	49.5–53.7	Hoffman et al., 2008; Huntley, 1971; Van Zyl & Ferriera, 2004.
Impala	54.7–60.9	Hoffman et al., 2009; Van Zyl & Ferriera, 2004; Van Zyl et al., 1969.
Kudu	55.9–58.3	Hoffman et al., 2009; Huntley, 1971.
Red hartebeest	47.5–55.0	Hoffman et al., 2010.
Springbok	56.2–57.9	Van Zyl & Ferriera, 2004; Van Zyl et al., 1969.
Domestic ruminant livestock		
Cattle (Nguni, Bonsmara, Angus)	50.3–53.8	Muchenje et al., 2008.
Sheep (South African mutton merino and dormer sheep)	41.5–44.2	Cloete et al., 2004.

2.4.3. Offal yields

Game or deer harvesting generally leaves behind a number of by-products, including a considerable proportion of edible offal (e.g. heart, kidneys, liver, stomach, intestine, head and feet) that should be considered part of the total yield of usable products (McCrindle, Siegmund-Schultze, Heeb, Zárate, & Ramrajh, 2013). In impala, internal offal alone comprises 18% of the live weight (Van Zyl & Ferreira, 2004) and it is estimated that a single impala provides about 3 kg of edible offal (McCrindle et al., 2013). Moreover, the proportional percentage of protein in the internal offal of impala, springbok and blesbok (17.0–21.9%) is reported to be similar to that found for sheep (16.5–23.5%) (Van Zyl & Ferreira, 2004). Game offal is part of the traditional diet of many Africans and is generally considered marketable by informal vendors in South Africa. Nonetheless, game offal remains underutilised in South Africa relative to that from domestic livestock, mainly due to a lack of adequate distribution channels. If the latter situation could be improved and satisfactory food safety controls implemented, game offal could provide a nutritious and affordable source of protein, especially suitable for lower-income groups (McCrindle et al., 2013).

2.5. PHYSICAL MEAT QUALITY

The physical quality attributes of meat can be partitioned into two broad categories. The first of these categories encompasses those qualities that are perceived by the senses, including the visual properties (colour, textural appearance, amount of fat and visible water) and the palatability properties (tenderness and flavour) (Brewer, Lan, & McKeith, 1998; Brewer, Zhu, Bidner, Meisinger, & McKeith, 2001; Nollet, 2012). The second category encompasses those technological parameters that define the utility and ability to produce high-quality products, but also influence the visual and palatability properties, such as pH, drip loss and cooking loss (Czarniecka-Skubina, Przybylski, Jaworska, Kajak-Siemaszko, & Wachowicz, 2010; Strydom, Jaworska, & Kołożyn-Krajewska, 2015). Although their interactions are often complex, all of the aforementioned quality attributes are known to be influenced to some degree by intrinsic (species, gender, age) and extrinsic (season, diet) factors, the pre-slaughter experiences of the animal and the early post-mortem treatment of the carcases (Arana, 2012; Hoffman, Kroucamp, & Manley, 2007a; O'Halloran, Troy, & Buckley, 1997).

2.5.1. Ultimate pH

Above all, pH likely has the greatest effect on the physical quality of meat. In particular, the rate and extent of post-mortem pH decline, which is directly related to the amount of lactic acid produced from muscle glycogen reserves during anaerobic glycolysis, is known to influence the water-holding capacity, tenderness, colour, flavour and shelf-life of meat products (Hughes, Oiseth, Purslow, & Warner, 2014; Honikel, 2014; Wiklund, Manley, & Littlejohn, 2004). Under normal circumstances, pH will gradually decline from a value of 7.0–7.2 in living muscle to an ultimate pH (pH_u) of 5.3–5.8 within 24–48 hours post mortem (Huff-Lonergan, 2009). However, a lack of normal acidification in the muscle during the development of rigor mortis can give rise to abnormally high pH values (pH_u>6) and result in dark, firm and dry (DFD) meat (Tarrant & Sherington, 1980; Warriss, 2000a). The latter is a common phenomenon in game and deer meat, since these species often have low muscle glycogen reserves prior to slaughter and since the available reserves may be depleted if the animals are harvested under stressful conditions (Daszkiewicz et al., 2015; Hoffman, 2000; Wiklund et al., 2004). The effects of high pH_u values on the physical quality attributes of meat are summarised in Table 2.3.

Table 2.3 Consequences of high ultimate pH values (pH_u>6) on physical meat quality attributes.

Quality attribute	Effects	Reference
Water-holding capacity	• Protein denaturation rates in muscle are reduced, intra-cellular water is tightly bound, little or no exudate formed. • Higher water-holding capacity.	Warriss, 2000a.
	• Lower drip loss percentages.	Warner, 2014.
	• Lower cooking loss percentages.	Aaslyng et al., 2003.
	• Good properties for use in processed meats.	Greaser & Guo, 2012.
Tenderness	• Large variations in tenderness.	Silva et al., 1999.
	• Maximum toughness at intermediate pH_u (5.8–6.2).	Bouton et al., 1973; Stevenson-Barry et al., 1999.
	• Tenderness possibly increased at pH_u>6.3 due to enhanced proteolytic enzyme activity.	Devine et al., 1993; Yu & Lee, 1986.
Colour	• Limited protein denaturation, thus little or no shrinkage of myofilament lattice.	Warriss, 2000a.
	• More translucent “closed” muscle structure that absorbs rather than reflects lights.	Warriss, 2000a.
	• Meat appears darker.	Swatland, 2008.
	• “Closed” structure reduces oxygen penetration; only a thin bright red surface layer of oxymyoglobin formed, underlying purple reduced myoglobin shows through. • Meat appears less red.	Warriss, 2000a.
	• Lower L*, chroma and hue-angle (°) values.	Warriss & Brown, 1993.
Shelf-life	• High spoilage potential and reduced shelf life. • Elevated pH favours growth of spoilage bacteria.	Feiner, 2006.
	• Low muscle glycogen levels retard growth of lactic acid bacteria that “compete” with spoilage bacteria.	Newton & Gill, 1981; Warriss, 2000a.
Flavour	• In the absence of glycogen, spoilage bacteria metabolise proteins and amino acids.	Warriss, 2000a.
	• Leads to production of ammonia, “off” flavours/odours.	Dave & Ghaly, 2011.

2.5.2. Colour

The colour of meat is determined by the quality and quantity of the myoglobin pigment, the relative proportions of its derivatives (oxymyoglobin and metmyoglobin), as well as the ultimate pH (Mancini & Hunt, 2005; Ruiz de Huidobro, Miguel, Onega, & Blázquez, 2003). This colour is of utmost importance since it is the first and main sensory cue that consumers use to judge the quality, freshness and acceptability of meat products (Adams & Huffman, 1972; Mancini, 2009; Troy & Kerry, 2010). Meat products are generally expected to have a bright red and uniform colour, while any deviation from this (too dark, too pale, non-uniform) is normally rejected (Issanchou, 1996; Pérez-Alvarez & Fernández-López, 2010, Viljoen, De Kock, &

Webb, 2002). In comparison to red meats from domestic livestock, venison usually has a darker red-and-brown colour due to its higher myoglobin content (Ramanzin et al., 2010; Young & West, 2001). This higher myoglobin content is, in turn, related to the muscles of free-roaming ungulates having more continuous activity levels and thus higher proportions of red (type I, oxidative) muscle fibres (Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012; Ruiz de Huidobro et al., 2003). As previously mentioned, the darker colour of venison may also be an indirect result of a high pH_u due to pre-slaughter stress (DFD meat) (Table 2.3).

2.5.3. Tenderness

While tenderness is generally considered the most important palatability attribute of meat (Brewer & Novakofski, 2008; Huffman et al., 1996), it is also the most variable of the physical quality characteristics (Strydom et al., 2015). Variations in meat tenderness can largely be attributed to the properties of the skeletal muscles themselves, including the integrity of the contractile proteins, sarcomere length, connective tissue and intramuscular fat contents, and proteolytic enzyme activity (Juárez et al., 2012). Accordingly, the latter properties can be influenced by the intrinsic features of the animal (species, age, gender), the extrinsic factors prior to slaughter (diet, season), the levels of ante-mortem stress and the early post-mortem treatment of the carcass (temperature, pH decline) (Hoffman et al., 2007a; O'Halloran, Troy, & Buckley, 1997).

Venison is reported to be more tender than beef, due in part to its high post-mortem proteolytic enzyme activity and small muscle fibre diameter (Wiklund, Farouk, & Finstad, 2014). Nonetheless, the individual muscles within a given animal are known to differ in their function, activity levels and metabolic properties, which reflects in differences in their basic constitution (collagen content, muscle fibre type) and potentially also their tenderness (Juárez et al., 2012). For instance, the postural muscles of mammals generally have a low connective tissue (collagen) content and predominance of red muscle fibre (type I, “slow twitch”), whereas the muscles used during locomotion have comparatively higher proportions of connective tissue and white muscle fibre (type II, “fast twitch”) (Bailey & Light, 1989; Liem, 2001). The quantity and quality of connective tissue also changes with the animal’s age, generally increasing in total content and decreasing in solubility as age increases (Reagan, Carpenter, & Smith, 1976). The meat of older animals is thus expected to be less tender, which has been found to be the case for fallow deer (Volpelli et al., 2003), but not necessarily for wild African ungulates (Hoffman & McMillin, 2009). In terms of gender, higher tenderness scores have been noted for the meat from fallow deer does compared with fallow bucks (Piaskowska, Daszkiewicz, Kubiak, & Janiszewski, 2015), whereas no gender differences were found in this respect for roe deer

(*Capreolus capreolus*; Daszkiewicz et al., 2012), greater kudu (*T. strepsiceros*; Mostert & Hoffman, 2007) and mountain reedbuck (*Redunca fulvorufula*; Hoffman, Van Schalkwyk, & Muller, 2008). Intact cattle and sheep have also been reported to have higher intramuscular collagen contents in comparison with their castrated counterparts (Gerrard et al., 1987; Miller, Judge, & Schanbacher, 1990).

When considering pH, it is known that optimum meat tenderness is generally achieved at low pH_u values, but that great variations become apparent at pH_u>5.8 (Devine et al., 2006) (Table 2.3). Maximum toughness generally occurs at intermediate pH_u values of 5.8–6.2 (Bouton, Carroll, Fisher, Harris, & Shorthose, 1973; Stevenson-Barry, Carseldine, Duncan, & Littlejohn, 1999), largely as a result of decreased sarcomere length in this pH range (Purchas, 1990; Watanabe, Daly, & Devine, 1996). Conversely, tenderness may increase at pH_u>6.3 due to the enhanced action of proteolytic enzymes, however, the shelf life of such meat (pH>6) would likely be reduced (Devine, Graafhuis, Muir, & Chrystall, 1993; Stevenson-Barry et al., 1999).

2.5.4. Water-holding capacity

Water-holding capacity (WHC) refers to the ability of meat to retain its own or added water when force (pressure, heat) is applied (Brewer, 2014). Low WHC in meat manifests as a high “drip loss” or purge, which is considered undesirable from an economic and consumer acceptability viewpoint (Huff-Lonergan, 2009; Troy & Kerry, 2010). Moreover, low WHC results in greater moisture losses during cooking and the meat may consequently be perceived as dry.

Lean muscle comprises about 75% water, the large majority of which is entrapped within the myofibrils (*ca*. 85%) and in the extra-myofibrillar spaces (Huff-Lonergan, 2009). Changes in the intra-cellular architecture of the muscle cells during the early post-mortem stages (rate and magnitude of pH decline, proteolysis, protein oxidation) thus greatly influence the capacity of the muscle to hold its water (Huff-Lonergan & Lonergan, 2005). As rigor develops and pH declines, the diameter of the muscle cells decreases and sarcomeres shorten, limiting the space available for water in the myofibrils (Honikel, Kim, Hamm, & Roncales, 1986; Swatland & Belfry, 1985). As a result, fluid can be expelled into the extra-myofibrillar spaces, from where it is readily lost as “drip” (Huff-Lonergan & Lonergan, 2005). Muscle generally has a minimum WHC at a pH of 5.4–5.5, which corresponds with the isoelectric point of its major proteins (Brewer, 2014). Conversely, muscle tissue with an abnormally high pH_u (DFD meat) is expected to have optimal WHC, since protein denaturation rates are reduced and water remains bound within the myofibrils (Warriss, 2000a) (Table 2.3).

2.6. CHEMICAL COMPOSITION AND NUTRITIONAL VALUE OF MEAT

Modern consumers are increasingly aware of their health and are requesting more comprehensive information on the composition of the foods they purchase (Resurreccion, 2004; Font-i-Furnols & Guerrero, 2014). With specific reference to meat, there is a growing recognition that the individual components (i.e. protein, lipid and micronutrients), including the chemical makeup and proportions thereof, not only influence the quality and sensory properties of the product, but importantly also its nutritional value and healthiness (Sikorski, 2007; Dobranic, Njari; Miokovic, Fleck; & Kadivc, 2009). Meat is widely acknowledged as a good source of high-biological-value protein, essential amino- and fatty-acids, bioavailable minerals and vitamins (McAfee et al., 2010; Pereira & Vicente, 2013; Schönfeldt & Gibson, 2008). Nonetheless, its composition is known to be strongly influenced by a host of intrinsic and extrinsic factors (Guerrero, Velandia Valero, Campo, & Sañudo, 2013). Among the basic components of meat, the lipid fraction is generally considered the most variable (Hocquette et al., 2010; Purchas, 2012; Sebranek, 2014) and thus the focus will largely fall on this component in the subsequent discussions.

2.6.1. Intrinsic factors influencing meat composition

Species

Broadly speaking, it is well established that large differences occur in the composition of meat from ruminants and monogastric animals owing to their different digestive strategies, especially as pertaining to the lipid content (Kouba & Mourot, 2011). Whereas monogastric species reduce dietary fats into their parent fatty acids and incorporate these into their muscle tissues in a relatively unaltered form, ruminant species deposit substantially greater quantities of saturated fat into their muscles as a consequence of fatty acid biohydrogenation occurring in the rumen prior to assimilation (Wood et al., 2008).

Among the ruminants, the meat from deer and African antelope has been found to have a comparable or higher protein content (>20%) compared with domestic livestock species, while the former two almost always have a lower fat content (<3%) (Aidoo & Haworth, 1995; Bureš, Bartoň, Kotrba, & Hakl, 2014; Hoffman & Cawthorn, 2012; Ramanzin et al., 2010) (Table 2.4). Wild ungulates are often on a lower plane of nutrition in relation to domestic livestock (Neethling, 2012) and are thus expected to have lower levels of intramuscular fat, with corresponding increases in moisture and protein proportions (Keeton, Ellerbeck, & Núñez de González, 2014).

Table 2.4 Proximate composition (g/100g) of raw meat from cervids and African antelope, compared with that from domestic livestock species.

Animal species		Muscle	Moisture (g/100g)	Protein (g/100g)	Lipid (g/100g)	Ash (g/100g)	
Ungulates, Cervidae							
Fallow deer (wild)	*Dama dama*	LTL	74.9	22.0	2.5	1.08	Zomborszky et al., 1996.
Fallow deer (male, farm-raised)	*Dama dama*	LTL	74.33	22.46	0.24	1.09	Daszkiewicz et al., 2015.
Fallow deer (male, wild)	*Dama dama*	LTL	74.29	22.79	0.50	1.10	Daszkiewicz et al., 2015.
Fallow deer (male, pasture-fed)	*Dama dama*	LTL	76.27	21.56	0.56	1.12	Volpelli et al., 2003.
Fallow deer (male, concentrate fed)	*Dama dama*	LTL	75.76	21.78	0.72	1.15	Volpelli et al., 2003.
Red deer (wild)	*Cervus elaphus*	LTL	76.9	21.7	0.6	1.11	Zomborszky et al., 1996.
Red deer (wild, male)	*Cervus elaphus*	LTL	75.22	22.0	0.56	1.10	Daszkiewicz et al., 2009.
Red deer (wild, female)	*Cervus elaphus*	LTL	74.43	22.41	0.96	1.09	Daszkiewicz et al., 2009.
Roe deer (wild)	*Capreolus capreolus*	LTL	74.8	23	1.7	1.15	Zomborszky et al., 1996.
Reindeer	*Rangifer tarandus*	LTL	71.8	23.6	2.8	1.1	Wiklund et al., 2008.
Ungulates, Bovidae							
Common duiker (wild, male)	*Sylvicapra grimmia*	LTL	71.4	25.7	2.12	1.29	Hoffman & Ferreira, 2004.
Impala (wild, male)	*Aepyceros melampus*	LTL	74.96	22.63	2.06	1.22	Hoffman et al., 2009.
Impala (wild, female)	*Aepyceros melampus*	LTL	74.01	23.07	2.4	1.16	Hoffman et al., 2009.
Greater kudu (wild, males)	*Tragelaphus strepsiceros*	LTL	75.66	22.77	1.48	1.22	Hoffman et al., 2009.
Greater kudu (wild, female)	*Tragelaphus strepsiceros*	LTL	75.77	22.25	1.49	1.19	Hoffman et al., 2009.
Red hartebeest (wild, male)	*Alcelaphus caama*	LTL	75.0	23.3	0.6	1.2	Hoffman et al., 2010.
Springbok (wild, males)	*Antidorcas marsupialis*	LTL	74.24	18–21	1.35	1.24	Hoffman et al., 2007b.
Domestic livestock							
Cow (beef), lean	*Bos* spp.	NS	73.1	23.2	2.8	NS	Williams, 2007.
Cow (beef)	*Bos* spp.	LTL, with fat	67.01	19.22	9.78	0.92	Moreira et al., 2003.
Sheep (lamb)	*Ovis aries*	Shoulder, leg and loin	71.53	18.27	9.03	2.88	Schönfeldt et al., 2011.
Sheep (mutton)	*Ovis aries*	Shoulder, leg and loin	73.83	20.43	8.98	1.19	Schönfeldt et al., 2011.
Goat	*Capra hircus*	NS	75.99	18.0	2.51	1.38	Arain et al., 2010.
Chicken (white meat)	*Gallus gallus*	White meat portions	74.01	23.29	2.91	1.11	Van Heerden et al., 2002.
Chicken (dark meat)	*Gallus gallus*	Dark meat portions	72.47	19.16	8.91	1.00	Van Heerden et al., 2002.
Domestic pig	*Sus scrofa domesticus*	LTL	75.51	21.79	2.02	0.99	Kim et al., 2008.

Abbreviations: NS = not specified; LTL = *longissimus thoracis et lumborum*

Furthermore, wild ungulates tend to deposit their fat in discrete depots around the kidneys and gonads and show little meat "marbling", while domestic livestock species have considerable fat depots within the abdomen, inter- and intra-muscularly, and subcutaneously (Mann, 2000). Apart from the quantity of intramuscular fat, the quality of the fat component is also a significant aspect. Polyunsaturated fatty acids (PUFAs) have been found to predominate in the muscle tissue of numerous game and deer species (Hoffman & Ferreira, 2004; Hoffman, Kritzinger, & Ferreira, 2005b; Razmaitė, Šiukščius, Pileckas, & Švirmickas, 2015; Volpelli et al., 2003), in contrast to domestic ruminants that deposit higher proportions of saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs) in their muscle tissue (Enser, Hallett, Hewitt, Fursey, & Wood, 1996; Rule, Broughton, Shellito, & Maiorano, 2002).

Muscle or cut (anatomical position)

Cross-carcass variation in intramuscular lipid concentrations can largely be ascribed to the diverse functions and activity levels of the various muscles, which is accordingly reflected in differences in muscle fibre type composition (Astruc, 2014; Hocquette et al., 2010). Muscle fibre types are usually classified as Type I, Type IIA and Type IIB in accordance with their metabolisms (Taylor, 2004). Type I (red, "slow twitch") muscle fibres are small in diameter, function aerobically (oxidative metabolism) and are mainly utilised for continuous or endurance activities (e.g. maintaining posture). These fibres have a rich supply of blood capillaries and mitochondria, as well as high concentrations of myoglobin and lipid, the last mentioned being the primary fuel source during prolonged activity (Cassens & Cooper, 1971; Pearson, 2012). While type IIA fibres are also red in colour, these are categorised as "fast-twitch" fibres that have an intermediate metabolism (oxidative and glycolytic metabolisms) and are moderately resistant to fatigue. Type IIA fibres also have a rich supply of mitochondria and myoglobin, as well as high myosin ATPase activity (Taylor, 2004). Lastly, type IIB (white, "fast twitch") fibres are large (broad), function anaerobically (glycolytic metabolism) and are mainly used for rapid movements (e.g. sprinting), although they fatigue rapidly (Kohn, Kritzinger, Hoffman, & Myburgh, 2005; Taylor, 2004). The latter are characterised by a low lipid content, but high glycogen and protein contents (Pearson, 2012). While muscles typically comprise heterogeneous mixtures of the aforementioned muscle fibre types, those that have a predominance of red fibres are expected to have higher intramuscular lipid and lower protein contents, while the opposite is expected for muscles comprising mostly type IIB fibres.

The concentrations of minerals can also vary in different muscles due to the diverse demands placed on the different muscles. Zinc concentrations are reported to be higher in muscles that are responsible for movement (Doornenbal & Murray, 1982). Lin et al. (1988) further postulated that red muscle fibres have higher levels of iron (Fe), sodium (Na), copper (Cu) and zinc (Zn), but lower levels of potassium (K), than white muscle fibres.

Gender

In ruminant animals, the females generally reach maturity earlier than the males (Ledger, 1963) and deposit more intramuscular fat (Cunningham, Carpenter, King, Butler, & Shelton, 1967; Hedrick, Thompson, & Krause, 1969), particularly during the gestation period. Castrated males also tend to deposit more carcass fat than intact males (Jones, 2014). Adipose deposition can largely be linked to hormonal differences between genders. It is postulated that oestrogen plays a role in adipocyte growth and fat deposition, whereas testosterone has been linked to decreasing fat deposition and leaner carcasses in males (Mersmann & Smith, 2004). In addition, males can lose considerable amounts of body fat during the rut, due to reductions in feed intake and the energy expended in fighting for dominance and maintaining the harem (Hoffman, 2000). Significantly ($p < 0.05$) higher intramuscular fat levels have been reported in female red deer (*C. elaphus*; Daszkiewicz, Janiszewski, & Wajda, 2009) and springbok (*A. marsupialis*; Hoffman, Kroucamp, & Manley, 2007b) in relation to their male counterparts, whereas gender did not influence the chemical composition of blesbok (*D. pygargus phillipsi*) meat (Hoffman, Smit, & Muller, 2008). Gender does not appear to have a major influence on the concentrations of macro-minerals in meat (Ortega-Barrales & Fernández-de Córdova, 2015).

Age and maturity

The growth and development of animals leads to an increase in most of the muscle constituents. During early growth, the majority of ingested energy is expended on protein synthesis, with only the surplus being deposited as fat (Lawrie & Ledward, 2006a). Fat is therefore the last tissue to develop in the animal, with deposition typically coinciding with the onset of puberty and then increasing with age (Warriss, 2000b). Fat deposition also differs across the different body compartments, usually being deposited first around the organs, followed by intermuscularly, subcutaneously and lastly intramuscularly (Lawrie & Ledward, 2006a). As a result, the meat of older animals usually has greater quantities of intramuscular fat (Hocquette et al., 2010). This pattern has been observed in the meat from fallow deer, where older bucks had significantly ($p < 0.05$) higher fat contents (Volpelli et al., 2003).

Several researchers have reported that animal age can influence the mineral concentrations in meat. Most notably, the concentrations of Fe and Na appear to increase with increasing age, whereas K seems to decrease (Doornenbal & Murray, 1982; Kotula & Lusby, 1982; Lin et al., 1989). Nonetheless, comparisons of mineral concentrations with age can be complicated by a number of factors, such as the differences in the nutritional status, stress levels, origin and management of the animals (Doornenbal & Murray, 1982; Lin et al., 1989).

2.6.2. Extrinsic factors influencing meat composition

Diet

From the available literature relating to domestic livestock, it is evident that dietary manipulation exerts a greater influence on the composition of meat from monogastric animals than it does on that from ruminants, especially in terms of the FA profile (Rhee, 2000). More specifically, increasing the level of unsaturated FAs in the monogastric diet will typically relate to increased levels of these FAs in the meat (Wood et al., 2008). Such an increase in the diet of ruminants generally has a less marked effect, since a large proportion of unsaturated FAs (85–90%) will be converted to SFAs by the rumen microbes (Wood et al., 2008), and the proportion of SFAs thus normally exceeds that of PUFAs in the meat (as mentioned in section 2.6.1).

While deer and antelope are also ruminants, the aforementioned pattern is not necessarily evident in their meat composition. The dietary energy of wild game and cervids is largely dependent on the environment and the quantity and quality of the available vegetation. Season and region therefore play an important role in their diet and it cannot be guaranteed that these animals will continuously be on a good plain of nutrition (Von la Chevallerie, 1970; Hoffman et al., 2007b). Consequently, wild ungulates usually have little to no intramuscular and subcutaneous fat, which can represent an appealing characteristic for the health-conscious consumer (Hoffman & Cawthorn, 2012; Mostert & Hoffman, 2007). Even in cases where deer are farmed on natural pasture or provided supplementary concentrate diets, their intramuscular fat content normally does not exceed 1% (Daszkiewicz et al., 2015; Volpelli et al., 2003; Table 2.4). As eluded to in section 2.6.1, deer and game appear to incorporate larger proportions of dietary PUFA into their intramuscular fat in comparison with domestic livestock.

2.7. CONSUMER PREFERENCES AND PERCEPTIONS

2.7.1. Global trends

From what was originally a production-driven industry in the 1980s, the global red meat industry is now essentially a consumer-driven one (Dransfield, 2003; Schönfeldt & Jooste, 2015). Aside from those who for religious or ethnic reasons do not eat meat (mostly in Asia), the large majority of the world's more than 7 billion people are meat consumers (Harrington, 1994). Furthermore, the bulk of these individuals want to eat meat (from specific species) (Harrington, 1994), recognising it as a nutritious and important constituent of the diet (Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010). Today's increasingly discerning consumer forms expectations on the quality of a given meat product at the point of sale based on a set of cues, including intrinsic cues (colour, amount of fat, marbling, drip loss) and extrinsic cues (price, labelling, origin) (Grunert, Bredahl, & Brunsø, 2004). A consumer's expectations of a meat product also revolve around previous experiences of consumption. Experienced quality attributes are largely based on sensory characteristics, such as tenderness, flavour and juiciness (Font-i-Furnols & Guerrero, 2014), the importance of which is discussed in Section 2.5. Lastly, consumer preferences for meat products are also defined by credence qualities (e.g. healthiness or naturalness), which rather than being judged visually or experientially, are based on trust in the information provided on the product (Grunert et al., 2004). While all of these qualities contribute to a consumer's final choice of a meat product, there are a host of psychological factors (attitudes, beliefs, perceptions, values) that can result in negative or positive attitudes towards meat products and ultimately impact purchasing behaviour (Babicz-Zielińska, 2006; Berndsen & Van der Pligt, 2004).

Health considerations

Health appears to be the primary reason for changing meat consumption habits, particularly in terms of the reduction or avoidance of certain products altogether (Latvala et al., 2012). In this context, considerable public concern has been raised on the potential links between saturated animal fat, cholesterol and certain western diseases (Cross et al., 2007; Hu, Manson, & Willett, 2001; Kontogianni, Panagiotakos, Pitsavos, Chrysohoou, & Stefanadis, 2008). Specifically in South Africa, the high incidence of coronary heart disease (one in four people) has largely been attributed to red meat consumption (Radder & Le Roux, 2005; Schönfeldt & Gibson, 2008). Such concerns, coupled with those relating to calorie control, have consequently led to a progressive shift away from red meat derived from domestic livestock (e.g. beef and mutton) (Dransfield, 2003; Kearney, 2010; Radder & Le Roux, 2005). Nevertheless, while consumers are increasingly seeking low-fat meat products (Shongwe, Jooste, Hugo, Alemu, & Pelser, 2007), they are not always willing to compromise the favourable sensory attributes for the potential health benefits (Font-i-Furnols & Guerrero, 2014; Hoffman & Wiklund, 2006).

Health concerns relating to meat also extend to food safety, including animal disease outbreaks (e.g. bovine spongiform encephalopathy, foot-and-mouth disease, avian influenza), food poisoning (e.g. salmonella), residues (e.g. veterinary drugs) and contaminants (e.g. dioxin in poultry) (Font-i-Furnols & Guerrero, 2014). While the latter concerns are often related to specific incidents, an underlying uneasiness may remain and result in aversion to specific products (Harrington, 1994).

Ethical and environmental concerns

Primarily in more developed countries, there is growing consumer unease relating to animal welfare and often negative attitudes towards meat that is produced from animals in intensive systems or "factory farms" (Harrington, 1994; Ruby & Heine, 2012). In addition, a number of meat sectors have come under attack for their negative impacts on the environment, with the latter potentially including land degradation, greenhouse-gas emissions and water pollution (Steinfeld et al., 2006). These aspects, coupled with the previously mentioned safety concerns, have led to a consumer shift towards meat products that are considered "organic" or "free-range". Similarly, there is increasing interest in meat products that are derived from sustainable resources and that are produced in low-input systems (Dransfield, 2003; Hoffman & Wiklund, 2006).

Adventure-seeking and symbolism

Apart from the frequent negative perceptions relating to meat products, an emerging trend that appears to be positively affecting consumer choice is that of "adventure", expressed as a desire for new tastes and variety at a relatively low risk (Hoffman & Cawthorn, 2013; Schupp, Gillespie, &

Reed, 1998). This desire, which is particularly prevalent among the urban middle- and upper-class, is leading to an increased demand for "exotic" or "authentic" meat products (Smith, & Wevers, 2004). The consumption of exotic meats can provide an avenue to experience and identify with a different culture (Mak, Lumbers, Eves, & Chang, 2012). For instance, consumers may not only opt to eat game meat for its nutritional qualities, but also due to its association with the "Africa" experience (Hoffman, Crafford, Muller, & Schutte, 2003). Furthermore, the consumption of exotic meats may represent a symbol of social status or a means to mark consumers in certain ways (i.e. as sophisticated, educated, worldly, wise, cosmopolitan, etc.) (Heldke, 2003; Smith, & Wevers, 2004). In some cultures, wild meat is perceived as a symbol of luxury, prestige and even masculinity (Drury, 2011; Radder & Le Roux, 2005).

2.7.2. South African perspective

In comparison to game meat, South Africans eat considerably larger quantities of meat from domestic livestock species. As previously mentioned, game meat accounts for less than 20% of the total red meat consumed in the country, with consumption being highest in the *ca*. 3-month hunting season (SAMIC, 2009; Van der Merwe et al., 2011). Moreover, 85% of adult South African consumers report eating red meat (domestic species) two or more times a week, while only 4% appear to eat game meat as often (Radder & Le Roux, 2005). Surveys conducted with South Africans of various race groups (n = 100 black; n = 100 white; n = 100 coloured) revealed that local consumers do not regard game as a "regular" meat type, but instead as an "exotic" and seasonal product (Hoffman, Muller, Schutte, Calitz, & Crafford, 2005c). Additionally, some consumers perceive game meat as being too dark in colour or as tough and dry (Lawrie & Ledward, 2006a), with the latter potentially being attributable to the low fat content and/or incorrect cooking methods used (Hoffman, 2002; Hocquette et al., 2010).

Above all, the primary reason for the negative attitudes and/or low levels of game consumption in South Africa appears to stem from a poor understanding among locals on the positive attributes of such products, specifically in terms of their health benefits (Hoffman et al., 2005c; Radder & Le Roux, 2005). For instance, Hoffman et al. (2005c) found that only 25% of consumers based in Stellenbosch rated "healthiness" as the most positive attribute of game meat. This lack of understanding was also evident in a study conducted in the Eastern Cape of South Africa, in which consumers were asked to provide their opinions on the nutritional qualities of various meat products, rating these from excellent to poor (Radder & Le Roux, 2005). The results indicated that the majority of questioned consumers believed that fish, chicken, beef, lamb and pork were all healthier than venison (Fig. 2.2), with these misconceptions being in stark contrast to the nutritional reality. On the other hand, 40% of these consumers perceived game meat as a "luxurious meat" and 35% considered it as a meat for the high income class, indicating that game meat could be related to social status (Radder & Le Roux, 2005).

One potential reason for the poor understanding and promotion of game meat in South Africa may be due to the limited nutritional information that exists on this meat in comparison with that for domestic livestock species. Moreover, that information that is available on the composition of different game meat species is largely restricted to the loin muscle, which may not provide an adequate representation of the nutritional value of other marketable muscles.

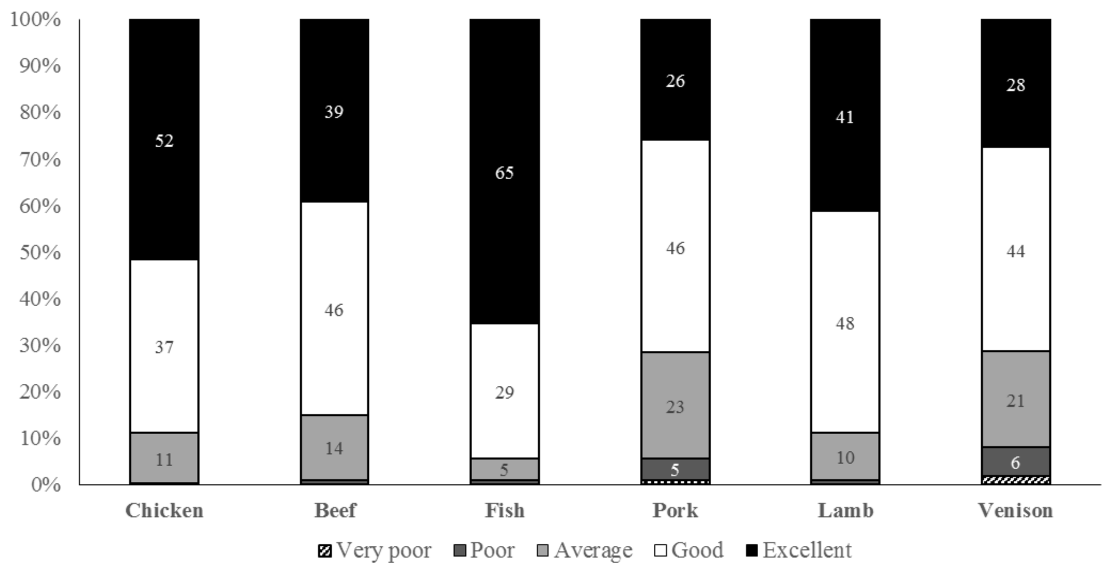

Figure 2.2 Percentage of South African consumers' beliefs about the nutritional qualities of game meat (venison) and other meats (adapted from Radder & Le Roux, 2005).

2.8. CONCLUSIONS

The South African game industry continues to grow, with meat representing an important by-product of biltong hunting, trophy hunting and culling/cropping activities. In spite of its potential to contribute to food security and generate revenue, the local and export market for game meat remains underdeveloped. This is especially true in terms of fallow deer, which although widespread and abundant in the country, do not contribute meaningfully to the local game meat industry. Such a situation is in stark contrast to that occurring in many other countries, where fallow deer are farmed in considerable numbers and the meat is readily accepted on the market. The meat from wild ungulates has many attributes that are considered important to modern consumers, including its favourable nutritional composition (high protein, low fat, desirable fatty acid profile), its “exotic” appeal, and its “natural” and “free range” status. Nonetheless, the domestic uptake of the meat appears to be hampered by misconceptions regarding its quality and composition. Consumers generally base their purchasing choices on knowledge that they have gained throughout their lives and, in the absence of reliable and up-to-date information, will likely continue basing decisions on past knowledge. It has been recognised that knowledge on meat products can have a marked influence on the choices of individuals, specifically on the likelihood of consuming certain types of meat (Guenther, Jensen, Batres-Marquez, & Chen, 2005). No information currently exists on the quality and composition of wild fallow deer meat in South Africa. Thus, in order to compete with domestic livestock products, the generation of credible scientific data on all the quality attributes (physical, chemical and sensorial) of South African fallow deer meat will likely be imperative for consumer education and the promotion of these products based on their unique benefits. Accordingly, the local meat industry requires information on the yields and cross-carcass quality variations of this species so that they are able to deliver consistent and desirable products to the consumer.

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CHAPTER 3

CARCASS COMPOSITION AND YIELDS OF WILD FALLOW DEER (*DAMA DAMA*) IN SOUTH AFRICA

ABSTRACT

The aim of this study was to determine the carcass characteristics, as well as the meat and offal yields, of wild fallow deer harvested in the Western Cape, South Africa. Live weights, warm carcass weights and cold carcass weights were significantly higher in male fallow deer (47.4 kg, 29.6 kg, 29.2 kg, respectively) versus females (41.9 kg, 25.2 kg, 24.7 kg, respectively), as well as in pregnant females (47.5 kg, 28.7 kg, 28.2 kg, respectively) versus non-pregnant females (32.5 kg, 19.7 kg, 19.3 kg, respectively). Similarly, dress-out percentages were significantly higher in males (61.5%) than females (59.0%), while being comparable to or higher than those found for other African antelope species and domestic livestock. Consumable offal (excluding stomach and intestines) contributed 9.6% and 8.9% to the live weights of males and females, respectively, with some significant gender and pregnancy effects on certain offal components. The individual weights of seven muscles (*longissimus thoracis et lumborum* [LTL], *infraspinatus* [IS], *supraspinatus* [SS], *biceps femoris*, [BF], *semimembranosis* [SM], *semitendinosus* [ST], *psoas major* [PM]) did not differ significantly between males and females, with the LTL and BF being the heaviest. Male fallow deer had significantly higher total meat and bone weights than females, however, no gender differences were observed for the meat-to-bone ratios.

3.1. INTRODUCTION

Within the next 35 years, it is projected that both the human population and the demand for animal protein will double on the African continent (Rosegrant & Thornton, 2008; UNPD, 2011). Meeting these escalating requirements for animal protein is not only expected to be hindered by climate change and water shortages (Carter & Gulati, 2014), but also by the limitations in suitable land available for the expansion of domestic livestock production (Hoffman, 2008). South Africa alone presently imports up to R 4 billion worth of meat annually (Dry, 2011), accounting for at least 10%

of the beef and 24% of mutton found on the local market (Fox, 2014). Nonetheless, these imports are still insufficient to fulfil the protein requirements of the country's people, with high-quality protein sources being particularly inaccessible to *ca*. 50% of the population that lives below the poverty line and remains mostly food insecure (Cooper & Van der Merwe, 2014; Lehohla, 2015; Shisana et al., 2013). Consequently, there is a growing need to increase the domestic production of alternative meat sources that can be supplied consistently and affordably (Cooper & Van der Merwe, 2014).

Since the 1960s, game meat production through wildlife ranching has been promoted as a potentially more feasible and profitable land use option compared to domestic livestock production in the dry regions of sub-Saharan Africa (Barnett, 2000; Berry, 1986; Dassman & Mossman, 1960). As a result, the last 50 years have seen *ca*. 25 million hectares of marginal agricultural land in South Africa being converted into wildlife ranches, much of which was previously used for cattle ranching, as well as an over 40-fold increase in the number of game animals in the country (Dry, 2011; Van Hoven, 2015). Of the estimated 21 million head of game in South Africa, it is thought that 16 million are kept on private land, compared to the 14 million cattle in the country (Van Hoven, 2015). The movement from domestic stock to wild game animals, which have naturally adapted to the harsh and dry conditions of South Africa, could contribute substantially to food security and economic growth in the region (Barnett, 2000; Cloete & Rossouw, 2014; Cooper & Van der Merwe, 2014). Of these wild animals, South African fallow deer (*Dama dama*), although not native, are abundant, adaptable and currently exploited more for hunting purposes than for meat production (Bothma, 2014; P. van Niekerk, 2015, Nelson Mandela Metropolitan University, South Africa, personal communication). Such hunting, if practised within legal bounds, could provide a viable source of meat and lower value offal for an established market (McCrindle, Siegmund-Schultze, Heeb, Zárate, & Ramrajh, 2013).

Fallow deer, in general, are medium-sized cervids, with males (buck) standing at 84–94 cm and weighing between 46 and 94 kg (Bothma, 2014), although these weights can reach up to 100 kg (Chapman & Chapman, 1997). The females (does) stand at approximately 73–91 cm and tend to weigh between 35 and 56 kg (Bothma, 2014). The farming of deer in South Africa is still a new concept, with less than five farmers using these animals for production (Hoffman & Wiklund, 2006). At present, the main wild game species used for production and export in South Africa are springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus pygargus phillipsi*) and greater kudu

(*Tragelaphus strepsiceros*), with wildebeest (*Connochaetes* spp.), impala (*Aepyceros melampus*) and gemsbok (*Oryx gazella*) contributing to a lesser degree (Hoffman & Cawthorn, 2014). This is in contrast to New Zealand and many European countries, where deer species are the main focus for venison production (Anonymous, 1994; Piasentier, 2005). Fallow deer are largely seen as pests to farmers in South Africa, as they were originally in New Zealand, due to their tendency to ring-bark trees, eat farm crops and break fences (Moore, Hart, Kelly, & Langton, 2000; Theunissen, 2001). Production opportunities are yet to be investigated and exploited in South Africa. One possible reason for this is the lack of demand due to a poorly established fallow deer meat market. Furthermore, little is known about the production potential of fallow deer in South Africa. Nonetheless, given the protein and micronutrient deficiencies in South Africa (Hoffman & Cawthorn, 2013; Steyn & Herselman, 2005), an opportunity exists to establish these animals as an additional nutrient source.

For an animal to be considered as a suitable meat producer, it must compete with recognised domestic stock in terms of production potential and information on the nutritional value and consumer acceptability of the meat should be available (Hoffman and Cawthorn, 2013; Hoffman, Muller, Schutte, Calitz, & Crafford, 2005). Since game meat is generally sold per animal or per kilogram (Hoffman & Wiklund, 2006), it is also essential to know which animals provide the highest dress-out percentages and meat yields (Issanchou, 1996). Furthermore, it is desirable to utilise as much of the edible portion of the carcass as possible, therefore knowledge on the yields of consumable organs should be generated. At present, none of the aforementioned data exist for wild fallow deer in South Africa. The aim of this study was thus to generate baseline data on the carcass characteristics and meat production potential of locally harvested fallow deer, while simultaneously assessing the yields of various organs that could represent an important food source in the country.

3.2. MATERIALS AND METHODS

3.2.1. Study and sampling design

The overall research design is illustrated in Figure 3.1, which shows the individual parameters measured in this study and the number of fallow deer included for each measurement.

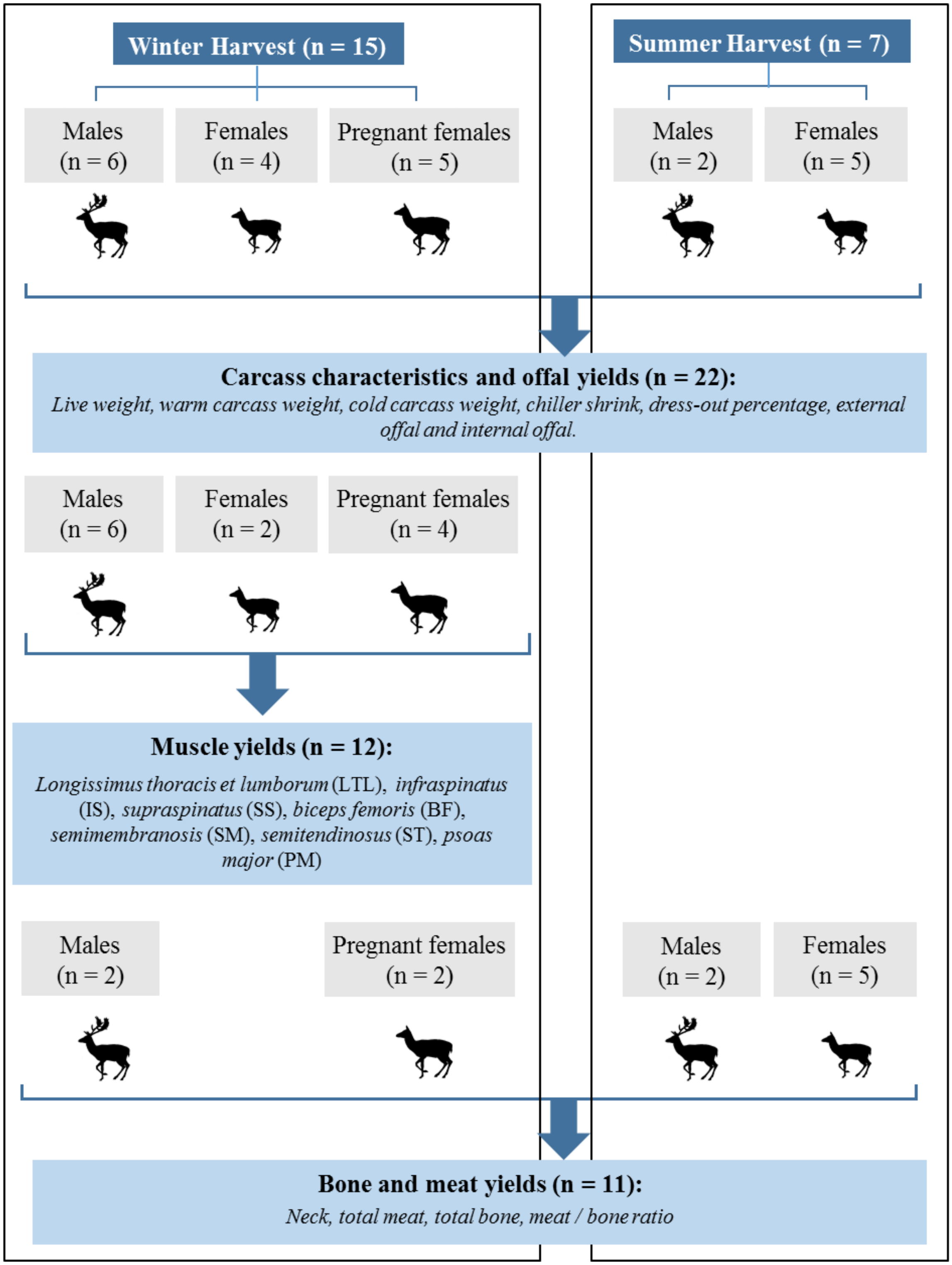

Figure 3.1 Overall study design, showing the number of fallow deer, per gender and life-cycle stage, included for each measured parameter.

3.2.2. Fallow deer harvesting

Ethical clearance (SU-ACUM000-44) was granted by the Stellenbosch University Animal Care and Use Committee prior to the initiation of field work. All the fallow deer were harvested on Brakkekuil farm (34°17'47.6"S; 20°49'28.0"E) near Witsand in the Western Cape of South Africa. This study area falls within the East Coast Renosterveld Bioregion, which forms part of the larger Fynbos Biome of South Africa (Rutherford, Mucina, & Powrie, 2006). No specific hunting season exists for fallow deer in South Africa. Cropping procedures were thus implemented for the control of fallow deer population size on finite land and were in line with the general management strategies of the farm.

The deer were harvested on two separate occasions, with adult animals preferably being targeted. The first group of 15 animals (n = 6 males, n = 4 non-pregnant females and n = 5 pregnant females) was harvested in August 2014 (winter) and the second group of seven animals (n = 2 males and n = 5 non-pregnant females) was harvested in February 2015 (summer) (Fig. 3.1). The duration of each harvesting period did not exceed 30 hours, with the majority of animals being harvested at night (spotlight cropping) by experienced and licensed huntsman using a procedure similar to that detailed by Hoffman and Laubscher (2010). Targeted animals were shot in the head, high neck or shoulder using high velocity rifles, followed immediately by exsanguination in the field using a sharp knife. The undressed fallow deer were then transported to the abattoir, where they were individually weighed (Mettler Toledo Hawk Scale, supplied by Microsep, Gauteng, South Africa) within 2-hours post mortem to determine the live weights.

External offal was removed directly thereafter following the procedures described by Ledger (1963). One modification to the aforementioned procedures related to the skinned tail, which was left on the dressed carcass. In brief, the unskinned head (including tongue and antlers, where applicable) was detached from the body at the atlas joint, with the incision running around the neck to behind the jaw bone. All four unskinned trotters were removed at the carpal (front limbs) and tarsal (hind limbs) joints. The hide, including the skin covering the tail, was carefully flayed from the carcass so as to leave minimal flesh and subcutaneous fat (where applicable) attached. The heads, trotters and hides were individually weighed on a Micro A12E scale (supplied by B&R Scale Services, Cape Town, South Africa), with results being expressed in kg and as a percentage of the respective live weights.

The carcasses were eviscerated and internal offal was removed following Ledger (1963). Organs were weighed on a Micro A12E scale or a Digi DS-673 scale (B&R Scale Services), with results being expressed in kg and as a percentage of the respective live weights. Briefly, the heart was separated by cutting the main veins and arteries entering or leaving the organ, followed by weighing without the pericardium. The spleen was removed and weighed separately, as was the case for the kidneys (kidney fat removed). The following organs were severed from their connections and were weighed together: lungs plus trachea; liver plus attached gall bladder; full stomachs (rumen, reticulum, omasum and abomasum combined) plus full intestines (small intestine, large intestine and caecum combined).

The dressed carcasses were then immediately re-weighed (Mettler Toledo Hawk Scale) to determine the warm carcass weights, followed by suspension by both Achilles tendons in an on-site cooler set at 4 °C. After a minimum of 16-hours post mortem, animals were removed from the cool room and the cold carcass weights were recorded (Mettler Toledo Hawk Scale). The cold carcass weights were compared to the corresponding warm carcass weights and live weights to calculate chiller shrink and dress-out percentages, respectively.

3.2.3. Muscle yields

Carcass deboning commenced with the removal of seven muscles (*longissimus thoracis et lumborum* [LTL], *infraspinatus* [IS], *supraspinatus* [SS], *biceps femoris,* [BF], *semimembranosis* [SM], *semitendinosus* [ST], *psoas major* [PM]). Twelve animals (n = 6 males, n = 6 females) were selected from the winter harvest for evaluation of muscle yields (Fig. 3.1). Each of the muscles (right and left side together) from each carcass were weighed separately (Digi DS-673 scale) and the weights were expressed as a percentage of the corresponding cold carcass weights.

3.2.4. Meat and bone yields

Following removal of the muscles, the remainder of the carcasses were deboned. The bones and meat from 11 animals (n = 4 males, n = 7 females; Fig 3.1) were weighed (Micro A12E scale) individually. In each case, the weights of the seven previously removed muscles were added back to the respective animal's total meat component. The neck was kept as an individual component and was not deboned. Finally, the total meat yields from each carcass were compared to the corresponding bone values to calculate overall meat-to-bone ratios.

3.2.5. Statistical analyses

Statistical analyses were performed using Statistica 12 (StatSoft, 2013). The values for carcass characteristics and offal yields (Table 3.1) were analysed using a one-way ANOVA, with gender as the main effect. The effect of pregnancy on the aforementioned parameters was evaluated using a one-way ANOVA, with Fisher LSD post hoc p-values being reported to indicate differences between pregnant and non-pregnant females. Muscle yields, total meat yields, total bone yields and meat-to-bone ratios were all analysed using one-way ANOVAs, with gender as the main effect. Differences were considered statistically significant at a level of 5% ($p < 0.05$).

3.3. RESULTS AND DISCUSSION

3.3.1. Harvesting

With no information currently available on the meat production potential of wild fallow deer in South Africa, the overarching aim of this study was to generate baseline data on the carcass characteristics and yields of these animals, which could provide the meat industry with a starting point to increase the utilisation of this resource. Nonetheless, cognisance is taken of a number of constraints and limitations in the current study (discussed below) that could warrant additional investigation and, where applicable, recommendations for further research are made.

Night cropping is recognised as the most effective (most humane, least stressful) method of harvesting wild ungulates (Hoffman, 2000; Hoffman & Laubscher, 2010) and was thus employed as far as feasible in this study. Nonetheless, due to the free-roaming and wild nature of the fallow deer targeted for this purpose, harvesting was required to run over extended periods. Three of the 22 animals were consequently shot during daylight hours in order to obtain the necessary animal numbers. Regardless of whether shot during the night or day, none of the fallow deer experienced unnecessary ante-mortem stress and the carcasses were all treated in the same manner in terms of timing and the order in which they were processed.

While adult animals were specifically targeted for this work, it is important to note that the free-roaming nature of the fallow deer in the study area places the animals under considerable hunting pressure, with adult mature males being hunted by choice. Indeed, it was observed during harvesting that high hunting pressure by surrounding farmers had reduced the number of mature fallow buck in the vicinity, thus the harvested males may have been younger than the females.

Pregnant females were shot in error as pregnancy was not easily detectable at the time of harvesting, particularly since the animals were mostly shot from a distance and at night. These pregnant females, however, appeared to be in early gestation as the foetuses weighed between 180 and 370 g (data not shown), with fallow deer fawns being born at approximately 4.5 kg (Wiklund, Hutchison, Flesch, Mulley, & Littlejohn, 2005).

As a result of the occasional necessity to shoot from extended distances, three female fallow deer were shot in the shoulder during the winter harvest. The shoulder is usually considerably more still than the head, which makes aiming from a distance easier and consequently increases the chances of hitting the intended target (Hoffman & Laubscher, 2009). This area of the body does have a number of vital organs in close proximity which is expected to lead to a rapid death, although the probability of damaging some of the edible meat is increased.

Although harvesting was conducted during both winter and summer months, season was not considered as a main effect in this study due to the fact that an unrepresentative sample of males (number and maturity) was obtained in the second harvest (Fig. 3.1). Muscle yields were determined for animals from a single season to avoid the potential influence of season on these parameters. Pregnancy was considered as an effect in the calculation of carcass and offal yields (Table 3.1). However, since three females from the first harvest experienced muscle damage associated with shoulder shots, non-pregnant and pregnant females were grouped for the analysis of muscle yields and subsequent determinations, with the numbers of each being too low to draw accurate statistical inferences on the effect of pregnancy on these parameters.

3.3.2. Carcass characteristics and offal yields

Fallow deer carcass characteristics, external offal yields and visceral organ yields are presented in Table 3.1. Live weights were found to be influenced by both gender and pregnancy. The mean live weight of the males (47.4 ± 4.37 kg) was significantly higher than that of the females (41.9 ± 1.96 kg) (Table 3.1). Although this result was expected, fallow deer are regarded as the most sexually dimorphic of all the cervid species, with male to female live weight ratios of 1.7–2.4 having been recorded (Carranza, 1996; Loison, Gaillard, Pélabon, & Yoccoz, 1999; McElligott et al., 2001). The considerably lower male to female live weight ratio in this study (*ca*. 1.1) can likely be attributed to the reduction in mature fallow buck in the study area and the probability that the males were younger than the females

Table 3.1 Mean (± standard error) carcass yields and offal contributions (kg and %) of fallow deer as influenced by gender (n=22) and pregnancy (n=9). Significant differences ($p < 0.05$) are indicated in bold.

Parameter		Effect = Gender			Effect = Pregnancy (winter harvest)		
		Male (n = 8)	Female (n = 14)	p-value	Female pregnant (n = 4)	Female (n = 5)	p-value
Live weight	**kg**	**47.4 ± 4.37**	**41.9 ± 1.96**	**0.023**	**47.5 ± 1.30**	**32.5 ± 3.04**	**0.002**
Warm carcass	**kg**	**29.6 ± 2.73**	**25.2 ± 1.15**	**0.006**	**28.7 ± 0.72**	**19.7 ± 1.50**	**0.002**
Cold carcass	**kg**	**29.2 ± 2.72**	**24.7 ± 1.13**	**0.006**	**28.2 ± 0.73**	**19.3 ± 1.36**	**0.002**
Chiller shrink (16h)[1]	**kg**	0.5 ± 0.04	0.5 ± 0.06	0.590	0.5 ± 0.08	0.5 ± 0.15	0.600
	%	1.6 ± 0.00	2.0 ± 0.00	0.244	1.8 ± 0.00	2.2 ± 0.01	0.411
Dress-out[2]	**%**	**61.5 ± 0.52**	**59.0 ± 0.57**	**0.006**	59.5 ± 0.97	59.7 ± 1.32	0.891
Skin[3]	**kg**	3.2 ± 0.44	3.0 ± 0.22	0.162	**3.3 ± 0.20**	**2.1 ± 0.30**	**0.006**
	%	6.6 ± 0.28	7.0 ± 0.29	0.543	7.0 ± 0.30	6.5 ± 0.39	0.259
Head (& antlers)[3]	**kg**	**2.6 ± 0.24**	**2.1 ± 0.09**	**0.013**	**2.4 ± 0.07**	**1.7 ± 0.12**	**0.014**
	%	5.4 ± 0.16	5.1 ± 0.11	0.289	5.1 ± 0.23	5.2 ± 0.18	0.651
Trotters[3]	**kg**	**1.6 ± 0.09**	**1.2 ± 0.04**	**0.000**	1.3 ± 0.07	1.1 ± 0.09	0.172
	%	3.4 ± 0.17	2.9 ± 0.09	0.058	**2.7 ± 0.12**	**3.3 ± 0.04**	**0.010**
Stomach & Intestine[3]	**kg**	7.9 ± 0.73	8.2 ± 0.51	0.813	**9.1 ± 0.60**	**6.4 ± 1.01**	**0.029**
	%	**16.7 ± 0.59**	**19.5 ± 0.74**	**0.020**	19.0 ± 1.01	19.2 ± 1.18	0.881
Liver & gall bladder[3]	**kg**	**0.8 ± 0.06**	**0.7 ± 0.02**	**0.001**	0.7 ± 0.03	0.6 ± 0.04	0.240
	%	1.8 ± 0.04	1.6 ± 0.07	0.501	**1.4 ± 0.06**	**1.8 ± 0.16**	**0.005**
Heart[3]	**kg**	**0.4 ± 0.02**	**0.3 ± 0.02**	**0.013**	**0.4 ± 0.02**	**0.3 ± 0.02**	**0.013**
	%	0.9 ± 0.05	0.8 ± 0.03	0.390	0.8 ± 0.04	0.9 ± 0.08	0.547
Lungs[3]	**kg**	**0.5 ± 0.03**	**0.4 ± 0.04**	**0.048**	0.4 ± 0.04	0.3 ± 0.03	0.165
	%	1.2 ± 0.08	1.0 ± 0.08	0.726	0.8 ± 0.07	0.4 ± 0.03	0.325
Kidneys[3]	**kg**	0.2 ± 0.01	0.1 ± 0.01	0.071	0.1 ± 0.01	0.1 ± 0.01	0.082
	%	0.3 ± 0.01	0.3 ± 0.01	0.405	**0.3 ± 0.01**	**0.4 ± 0.01**	**0.014**
Spleen[3]	**kg**	0.1 ± 0.01	0.1 ± 0.00	0.076	0.1 ± 0.01	0.1 ± 0.01	0.359
	%	0.3 ± 0.01	0.3 ± 0.02	0.463	**0.3 ± 0.01**	**0.4 ± 0.03**	**0.008**

[1] Cold carcass weight relative to warm carcass weight
[2] Cold carcass weight as percentage of live weight
[3] Parameters relative to live weight

The mean live weight of the pregnant females (47.5 ± 1.30 kg) was significantly higher than that of the non-pregnant females (32.5 ± 3.04 kg) (Table 3.1). Fallow does reach sexual maturity at 2-years old (Bothma, 2014), with this age group and older being targeted for this study. Nonetheless, the fact that harvesting took place at night and in some bushy areas meant that accurate appraisal of size and thus age was occasionally compromised. Consequently, the difference between live weights of the pregnant and non-pregnant females could have been the result of some non-pregnant females being slightly younger than the mature, pregnant females. It has been noted that feeding behaviour in fallow deer develops with age, with feeding selectivity and the time spent feeding increasing as animals get older (Bergvall, 2009). These aspects could have contributed to the heavier live weights for older pregnant females, as such behaviour would allow the animals to gain weight through a more substantial diet. Additionally, body condition and fertility are known to be correlated in the case of cervids, with lighter females having less chance of falling pregnant (Gerhart, Russell, van de Wetering, White, & Cameron, 1997). This could potentially explain why some of the mature females were not pregnant during the winter harvest. Gerhart et al. (1997) reported a correlation between the live weight and age of caribou (*Rangifer tarandus*), with younger females being lighter than older females. In this same study, pregnant caribou does were also found to have heavier live weights than non-pregnant or dry does.

With heavier live weights in males, it follows that the corresponding mean warm carcass weight in males (29.6 ± 2.73 kg) was significantly higher than that of the females (25.2 ± 1.15 kg) (Table 3.1). Likewise, the mean cold carcass weight of the males (29.2 ± 2.72 kg) was significantly higher than the cold carcass weight of the females (24.7 ± 1.13 kg). Also consistent with their higher live weights, pregnant females had significantly heavier mean warm carcass weights (28.7 ± 0.72 kg) and cold carcass weights (28.2 ± 0.73 kg) than non-pregnant females (19.7 ± 1.50 kg and 19.3 ± 1.36 kg, respectively) (Table 3.1). Neither, gender nor pregnancy had a significant effect on chiller shrinkage, with all analysed groups (males, females, pregnant females and non-pregnant females) showing chiller losses of approximately 500 g or 2% in weight (Table 3.1). In relation to wild ungulates, beef carcasses are generally expected to have a thicker layer of subcutaneous fat, which should reduce chiller shrink in the latter. Nonetheless, shrinkage of up to 2% in weight has similarly been reported for beef carcasses chilled overnight in conventional refrigeration systems (Kastner, 1981). Since chiller shrink decreases the profitable yield of a carcass, alternative systems such as spray chilling can be employed to reduce such evaporative losses (Savell, Mueller, & Baird, 2005).

Dress-out percentage is an important criterion when considering the meat production potential of an animal. In this study, dress-out percentage was significantly influenced by gender, but not by pregnancy. The mean dress-out percentage was significantly higher for male fallow deer (61.5 ± 0.52%) than for females (59.0 ± 0.57%). The former gender effect could be attributed to the difference in the contributions of the stomach and intestines, which made up *ca.* 19.5% of the live weight in females and a lower 16.7% in males (Table 3.1). While the males had significantly heavier (kg) heads than the females, no gender differences were seen in the percentage contribution of the heads to live weights, possibly since not all males had fully developed antlers. The dress-out percentage of the males in this study (61.5 ± 0.52%) corresponds with the *ca*. 61% reported for entire fallow buck in Australia (Mulley, English, Thompson, Butterfield, & Martin, 1996), but is higher than the dress-out percentages described for male red deer (*Cervus elaphus*; 57.1%) and wapiti (*Cervus canadensis*; 56.4%) in New Zealand (Drew & Hogg, 1990). In comparison with the females in this study, Wiklund et al. (2005) recorded slightly higher dress-outs of 60.5% for adult fallow does having been on pastures for 24 weeks, with such variations possibly being reflective of the different diets of the two groups. Lower dress-out percentages have also been reported for some African antelope species, namely for adult impala (male = 60.9%; female = 58.6%) and greater kudu (male = 58.3%; female = 55.9%) (Hoffman, Mostert, Kidd, & Laubscher, 2009), as well as for red hartebeest (*Alcelaphus caama*; male = 55.0%; female = 47.5%) (Hoffman, Smit, & Muller, 2010).

Several researchers have suggested that wild ungulates produce dress-out percentages similar to or higher than those of domestic livestock species, reportedly resulting from the higher proportion of muscle tissue in the former carcasses (Ledger, 1963; Skinner, 1984; Von la Chevallerie, 1970). Most notably, wild ungulates are thought to compete favourably with domestic livestock due to their capacity to attain mature weights at a comparatively younger age under harsh extensive farming conditions (Skinner, 1984). Indeed, compared to the fallow deer dress-outs obtained here, dress-outs of 50.3–53.8% have been documented for Nguni, Bonsmara and Angus cattle (Muchenje, Dzama, Chimonyo, Raats, & Strydom, 2008). Even lower dress-outs have been noted for South African mutton merinos (41.5%) and dormer sheep (44.2%) (Cloete, Hoffman, Cloete, & Fourie, 2004), likely since the skin (including wool) contributes more to the live weight in all sheep breeds (Van Zyl & Ferreira, 2004).

The fallow deer skin, kidneys and spleen did not differ significantly with regards to their respective weight (kg) or contribution to live weight (%) when gender was the main effect (Table 3.1). The head (and antlers), trotters, liver and gall bladder, heart and lungs were all significantly heavier (kg) in males than females, but the contribution of these components to total live weight (%) did not differ with gender. As previously mentioned, the contribution to live weight (%) of the stomach and intestines in the does was significantly higher than that of the bucks. In a study on sika deer (*Cervus nippon*) in Japan, female sika deer were found to have heavier stomach tissue, stomach and intestinal contents, as well as longer intestinal length, in relation to male sika deer (Jiang, Hamasaki, Takatsuki, Kishimoto, & Kitahara, 2009). It was further noted by Baker and Hobbs (1987) that female deer possess a longer intestine as well as greater capacity in the rumino-reticulum and large intestine, which allows for more efficient fermentation, extended retention time, and more complete digestion and absorption required for increased nutritional demands during lactation.

Given that the stomach and intestines were weighed with their contents, the significantly heavier (kg) values for these components in pregnant females compared with non-pregnant females could perhaps be attributed to increased dietary intake in the former (Table 3.1). Barboza and Bowyer (2000) suggested that gestation increases minimal energy requirements by 10% and it is thus anticipated that these needs would be met through increasing feed consumption. Pregnant females were also found to have significantly heavier (kg) skins, heads and hearts compared to the non-pregnant females (Table 3.1). However, the contributions of these components to live weight (%) did not differ significantly. Thus, the heavier weights of these components appear to be relative to a larger body size of the pregnant females. The kidneys, liver and gall bladder, and spleen did not differ significantly in weight (kg) between the pregnant and non-pregnant females. Conversely, the contribution of these organs to live weight (%) was significantly higher in non-pregnant females as a result of the lower live weight in the non-pregnant females.

The total weight of consumable offal (head [brain, cheeks, tongue], liver, heart, lungs and kidneys) was calculated as 4.5 kg for males (9.6% of live weight) and 3.7 kg for females (8.9% of live weight) (Table 3.1). The stomach and intestines were not included in these calculations since these were weighed with their contents, however, these components would also contribute to the weight of consumable offal. The combined weights of the cleaned omasum, stomach and intestines of male and female impala reported by Hoffman (2000) contributed 4.1% and 5.4% of the live weight, respectively. It is known that the internal organs of wild game animals are consumed by people throughout South Africa (McCrindle et al., 2013) and increasing the supply of these components could provide a low-cost means to offset the protein and micronutrient deficiencies existing in the country today (Hoffman & Cawthorn, 2013; Steyn & Herselman, 2005).

3.3.3. Muscle yields

The weights of the seven muscles removed from 12 fallow deer carcasses (n = 6 males; n = 6 females) are presented in Table 3.2. No significant gender differences were observed in the weights (kg) of any of the individual muscles under study. For both genders, the LTL and the BF were the heaviest (kg) of the muscles, while the IS, SS, ST and PM all had similar and lower weights (0.3–0.4 kg). The BF and PM did, however, contribute significantly more to the cold carcass weights (%) of the females in comparison with those of the males (Table 3.2).

Table 3.2 Mean (± standard error) contributions (kg and %) of seven muscles (combined right and left sides) from fallow deer (n = 12) as influenced by gender. Significant differences ($p < 0.05$) are indicated in bold.

		Effect = gender		
Muscle		**Male (n = 6)**	**Female (n = 6)**	**p-value**
***Longissimus thoracis et lumborum* (LTL)**	**kg**	1.9 ± 0.10	2.0 ± 0.09	0.639
	%[1]	7.5 ± 0.20	7.8 ± 0.36	0.498
***Infraspinatus* (IS)**	**kg**	0.3 ± 0.03	0.4 ± 0.04	0.261
	%[1]	1.3 ± 0.13	1.5 ± 0.07	0.243
***Supraspinatus* (SS)**	**kg**	0.3 ± 0.03	0.3 ± 0.02	0.230
	%[1]	1.1 ± 0.09	1.3 ± 0.03	0.134
***Biceps femoris* (BF)**	**kg**	1.6 ± 0.12	1.7 ± 0.11	0.533
	%[1]	**6.1 ± 0.05**	**6.5 ± 0.14**	**0.025**
***Semimembranosis* (SM)**	**kg**	1.4 ± 0.08	1.4 ± 0.07	0.931
	%[1]	5.2 ± 0.07	5.2 ± 0.13	0.811
***Semitendinosus* (ST)**	**kg**	0.4 ± 0.03	0.4 ± 0.02	0.783
	%[1]	1.6 ± 0.03	1.6 ± 0.03	0.369
***Psoas major* (PM)**	**kg**	0.3 ± 0.03	0.4 ± 0.01	0.121
	%[1]	**1.3 ± 0.07**	**1.5 ± 0.07**	**0.048**

[1] Muscle weight relative to cold carcass weight

It is known that mature female ruminants concentrate more of their muscle development in the hindquarter (relative to whole carcass weight) compared with males (Ledger, 1963), which could be the reason for these two hindquarter muscles showing a higher contribution to the cold carcass weights in the females. While mature males are expected to develop comparatively more in the forequarter region (Jones, 2014; Ledger, 1963), the fact that no gender differences were found in the weights (kg) or contributions (%) of the forequarter muscles could be reflective of the potentially younger (less mature) status of the males.

3.3.4. Bone and meat yields

The total bone and meat yields from 11 fallow deer (n = 4 males; n = 7 females) are presented in Table 3.3. The weights (kg) of the neck (not deboned), total meat and total bone were all significantly higher in the males in relation to the females (Table 3.3), which can be attributed to the higher live and cold carcass weights of the males (Table 3.1). Nonetheless, no significant gender differences were seen in the percentage contributions of the aforementioned components to cold carcass weights. This indicates that, relative to their size, both males and females deliver similar meat and bone percentages. The observation of heavier neck weights for the males is consistent with data reported for impala (Hoffman, 2000), where the necks of the males were almost double the weight of those from females. Likewise, the heavier values for total meat (kg) and total bone (kg) in the male fallow deer are analogous to the findings reported for male and female red deer and Père David's deer (*Elaphurus davidianus*) hybrids (Goosen, Fennessy, & Pearse, 1999).

Lastly, there was no significant difference in the meat-to-bone ratios of the male (2.2 ± 0.04) and female (2.3 ± 0.02) fallow deer in this study. The aforementioned values are, however, considerably lower than the meat-to-bone ratios recorded for various cattle breeds by Warriss (2000), which ranged from 3.5 to 4.3. These difference could be associated with cattle being bred domestically for increased meat production (Hoffman & Cawthorn, 2013). Additionally, some of the animals in this study were determined to potentially be sub-adult upon measuring live weights; therefore these animals might not have deposited as much muscle as adult animals. This could thus cause the aforementioned animal to have more bone in relation to muscle, due to muscle developing later in life than bone (Warriss, 2000).

Table 3.3 Mean (± standard error) bone and meat contributions (kg and %) from fallow deer (n = 11) as influenced by gender. Significant differences ($p < 0.05$) are indicated in bold.

Parameter		Effect = Gender		
		Male (n = 4)	**Female (n = 7)**	**p-value**
Neck	**kg**	**2.4 ± 0.48**	**1.5 ± 0.12**	**0.038**
	%[1]	6.7 ± 0.67	5.6 ± 0.33	0.120
Total meat	**kg**	**20.4 ± 2.14**	**16.0 ± 0.49**	**0.028**
	%[1]	57.9 ± 1.33	60.5 ± 0.93	0.139
Total bone	**kg**	**9.1 ± 0.46**	**6.9 ± 0.35**	**0.005**
	%[1]	26.2 ± 1.70	26.1 ± 1.08	0.934
Meat / bone ratio		2.2 ± 0.04	2.3 ± 0.02	0.617

[1] Parameters as a percentage of cold carcass weight

3.4. CONCLUSIONS

This is the first study to shed light on the carcass yield potential of wild fallow deer found in South Africa. The generated data is expected to be of value to the meat industry in forecasting the potential meat and offal yields, as well as the economic viability of these derived products. Furthermore, these results may provide the impetus for the local agricultural sector to view these animals as an economically viable resource rather than a pest, while potentially facilitating any considerations pertaining to the commercial farming of the species for meat production. On the basis of the present results, South African fallow deer appear to have similar or higher dress-out percentages in comparison with other African game species and domestic livestock. Moreover, edible meat contributes *ca*. 58-60% of the cold carcass weights in locally harvested fallow deer, with no differences between males and females in terms of meat-to-bone ratios. All indications are that fallow deer can provide a valuable source of offal to serve as a food source. However, since organs can potentially carry a high microbial load, strict standard operating procedures for processing and handling should be followed if such offal is to be used for human consumption. While this work has generated baseline data on South African fallow deer carcass yields, further research is required with larger sample sizes to evaluate and quantify the effects of other extrinsic factors (e.g. season, diet and slaughter age) on the measured parameters. In addition, data on both the physical and chemical qualities of the meat derived from these locally harvested animals will be imperative to promote the uptake of such products on the local market.

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CHAPTER 4

PHYSICAL MEAT QUALITY ATTRIBUTES OF WILD FALLOW DEER (*DAMA DAMA*) IN SOUTH AFRICA

ABSTRACT

The aim of this study was to evaluate the physical quality attributes of the meat from wild fallow deer (n = 6 males; n = 6 females) harvested in South Africa, as affected by muscle and gender. Ultimate pH (pH_u), drip loss, cooking loss, Warner-Bratzler shear force (tenderness) and colour measurements were conducted on six different muscles, namely the *longissimus thoracis et lumborum* (LTL), *biceps femoris* (BF), *semimembranosis* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS). The pH_u, drip loss, cooking loss and shear force values were significantly ($p < 0.05$) influenced by muscle, but not by gender. Mean pH_u values ranged from 5.4 to 5.6 in the six muscles, whereas drip loss and cooking loss values ranged from 1.3–1.6% and 29.4–36.1%, respectively. Shear force values were significantly lowest in the LTL (31.3 N) and BF (36.0 N), while being highest in the ST (61.9 N). The colour of the fallow deer muscles was characterised by L* < 40, high a* and low b* values, which are generally the values considered desirable by venison meat consumers. All the measured colour parameters (L*, a*, b*, chroma, hue-angle) differed significantly ($p < 0.05$) between muscles, while gender had a significant ($p < 0.05$) effect on only the a* values of the LTL, SS and ST (females > males) and chroma values of the LTL (females > males). This study represents the first attempt to quantify the physical quality of wild South African fallow deer meat, the results of which will be imperative for the marketing and promotion of such products.

4.1. INTRODUCTION

Game ranching in South Africa is well established (Hoffman, Kritzinger, & Ferreira, 2005), with the springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus pygargus phillipsi*) and greater kudu (*Tragelaphus strepsiceros*) being the primary species harvested for the commercial meat supply (Hoffman & Cawthorn, 2014). Fallow deer (*Dama dama*) are not native to South Africa, having been introduced by the British in the 19th century for hunting purposes (Chapman & Chapman, 1980). These cervids have, however, adapted well to South African conditions and the population numbers of the species have increased ever since (Bothma, 2014; Curry, Hohl, Noakes, & Kohn, 2012). In spite of their abundance and adaptability, fallow deer still contribute very little to the South African game meat industry. This is also exemplified by the small number (<5) of deer farmers in the country (Hoffman & Wiklund, 2006). In light of the growing interest and establishment of deer farms around the world, as well as the low input systems utilised for such operations (Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003), fallow deer could play a more prominent role as meat producers and contributors to food security in South Africa. In this respect, it is important to note that modern consumers are showing increasing concern relating to the environmental impacts of meat production, and there is also a growing demand for free-range or "organic" meat products (Hoffman & Wiklund, 2006; Tešanović et al., 2011). Fallow deer meat from South Africa could satisfy the aforesaid consumer desires in that commercial deer farming is recognised as an environmentally sustainable food production method (Volpelli et al., 2003), and as the fallow deer in the country are currently wild and free-roaming. Nonetheless, before the meat production potential of these animals can be fully realised, the physical meat quality characteristics of locally harvested fallow deer should be well understood.

From a consumer perspective, the physical quality of meat is judged by those properties that are perceived by the senses. These properties include visual attributes (colour, amount of visible water, amount of fat and textural appearance) and palatability attributes (tenderness and flavour) (Brewer, Lan, & McKeith, 1998; Brewer, Zhu, Bidner, Meisinger, & McKeith, 2001; Nollet, 2012). The colour of meat is particularly important as this is the first quality cue observed by the consumer at the point of sale, often being used as an indicator of product freshness and acceptability (Hoffman, 2002; Mancini, 2009; Troy & Kerry, 2010). This colour is primarily attributed to the quantity and quality of the myoglobin pigment in the meat (Mancini & Hunt, 2005; Lawrie & Ledward, 2006), as well as its propensity to be oxidised to metmyoglobin (Ruiz de Huidobro, Miguel, Onega, & Blázquez, 2003). Meat products are generally expected to be bright pink or red in colour (Warriss, 2000), with those that are too pale or too dark frequently being rejected (Issanchou, 1996; Viljoen, De Kock, & Webb, 2002). On the other hand, tenderness is recognised as the most important palatability attribute of meat and also the consumer's principal determinant of eating quality (Brewer, & Novakofski, 2008; Huffman et al., 1996). The properties of animal skeletal muscles that are known to affect meat tenderness include contractile protein integrity, sarcomere length, connective tissue content, endogenous protease activity, and to some extent the levels of intramuscular fat (Juárez et al., 2012).

Although intrinsic features (species, breed, gender, age) and environmental factors (season, diet) may alter the physical quality of meat, it is well established that the ante-mortem experiences of the animal and the early post-mortem treatment of the carcass have an equal or greater impact (Arana, 2012; Hoffman, Kroucamp, & Manley, 2007; O'Halloran, Troy, & Buckley, 1997). In particular, the rate and magnitude of post-mortem pH decline, a direct consequence of muscle glycogen concentrations and stress levels preceding slaughter, influences the colour, water-holding capacity, tenderness and shelf life of meat (Hughes, Oiseth, Purslow, & Warner, 2014; Wiklund, Manley, & Littlejohn, 2004). More specifically, post-mortem pH values dictate the effectiveness of the enzymatic tenderisation process (Dransfield, 1992; Yu & Lee, 1986), while increases in ultimate pH (pH_u) values from *ca*. 5.5–6.0 generally manifest in decreased tenderness due, in part, to decreased sarcomere length in this pH range (Purchas, 1990; Watanabe, Daly, & Devine, 1996). Moreover, abnormally high pH_u values (pH_u>6) can result in dark, firm and dry (DFD) meat, a condition often associated with game meat if harvested under stressful conditions (Daszkiewicz et al., 2015; Hoffman, 2000; Wiklund et al., 2004).

While a great deal has been done to measure and quantify the physical meat quality attributes of domestic livestock species (Devine et al., 2006; Farouk et al., 2007; Fletcher, 2002; Kim, Warner, & Rosenvold, 2014; Lloveras et al., 2008; Muchenje et al., 2009; Terlouw, 2005), as well as that of indigenous antelope species (Hoffman, 2000; 2004; Hoffman & Laubscher, 2009; 2010; Hoffman et al., 2007; Hoffman, Mostert, Kidd, & Laubscher, 2009), no such work has been conducted for fallow deer in South Africa. Assurance of consistent quality in terms of visual, eating and technological parameters is nevertheless imperative if the market for fallow deer is to grow and become economically viable. Limited knowledge on the variations in physical quality from animal to animal, as well as from cut to cut, will not only prevent the game meat industry from marketing its produce according to quality (Mullen, Murray, & Troy, 2000), but may also result in the consumer gaining a negative perception of the meat if encountering an inferior portion. The aim of this study was thus to shed new light on the physical (tenderness, colour) and technological (pH, drip loss, cooking loss) quality attributes of wild fallow deer harvested in South Africa, as affected by muscle and gender.

4.2. MATERIALS AND METHODS

4.2.1. Harvesting and slaughtering of animals

Ethical clearance (SU-ACUM000-44) for this study was issued by the Stellenbosch University Animal Care and Use Committee prior to the commencement of field work. Twelve wild fallow deer (n = 6 males, n = 6 females) were harvested on Brakkekuil farm (34°17'47.6"S; 20°49'28.0"E) near Witsand in the Western Cape, South Africa, during August 2014 (winter). Animals within the adult category were specifically targeted for this study. There is no defined hunting season for fallow deer in South Africa and cropping was conducted for the purpose of controlling the population size of the species on the farm. Most of the animals were harvested at night (spotlight cropping) by experienced and licensed hunters, following a similar procedure to that described by Hoffman and Laubscher (2010). All twelve fallow deer were shot with a single shot to the head or upper neck region using high velocity rifles, where after they were immediately exsanguinated by cutting the throat with a sharp knife. The carcasses were tagged with an identification number and subsequently transported to an on-site slaughtering facility, where skinning and evisceration was performed in accordance with the guidelines of Van Schalkwyk and Hoffman (2010). The dressed carcasses were transferred to an on-site cool room (± 4 °C) and hung by both Achilles tendons overnight.

4.2.2. Removal of muscles

At approximately 16-hours post mortem, the dressed carcasses were taken from the cool room for deboning. Six different muscles were removed entirely from the left side of each animal, namely the *longissimus thoracis et lumborum* (LTL), *biceps femoris*, (BF), *semimembranosis* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS). Each muscle was individually vacuum packed (Multivac C200, Multivac, Gauteng, South Africa) for overnight refrigerated storage (± 4 °C) and subsequent chilled transport to the laboratory facilities at the Stellenbosch University. Physical analyses (pH, drip loss, cooking loss, Warner-Bratzler shear force and colour) commenced 36-hours post mortem.

4.2.3. Physical analysis

Ultimate pH

pH readings were taken for each of the six muscles from the 12 fallow deer, with these pH_{36} readings being considered as pH_u values. The portable pH meter (Crison PH 25 with a glass electrode, Crison Instruments SA, Spain) was calibrated using pH 4 and pH 7 buffer solutions at room temperature. An incision (*ca*. 3 cm deep) was made into each muscle, with readings being taken at the position of the last rib of the thoracic region of the LTL and approximately mid-way in length for the remaining muscles.

Drip loss

A single steak (2.0–2.5 cm thick) was cut from the centre of each of the six muscles (perpendicular to the longitudinal axis) and was used for the determination of drip loss. The initial weight (W_1) of each steak was recorded using a Digi DS-673 scale (supplied by B&R Scale Services, Cape Town, South Africa). Each steak was suspended inside an inflated polyethylene bag (ensuring no contact with the side of the bag), followed by incubation in a walk-in refrigerator set at 2 °C for 24 h. The steaks were thereafter removed from the bags, gently blotted dry with absorbent paper and individually re-weighed (W_2). Drip loss was calculated as a percentage of the initial weights of the steaks (Honikel, 1998):

$$\text{Drip loss (\%)} = \left(\frac{W_1 - W_2}{W_1}\right)100$$

Cooking loss

Duplicate samples were used for cooking loss determinations. Two steaks of similar size (*ca*. 2.5 cm) were removed from caudally adjacent positions along each muscle as described by Honikel (1998). All steak samples were weighed (Digi DS-673 scale) to determine the initial weights (W_1), following by placement in separate polyethylene bags and cooking in a water bath set at 80 °C for 60 min. The bagged samples were subsequently cooled in a refrigerator (4 °C), where after the samples were removed from the bags, blotted dry with absorbent paper and individually re-weighed (W_2). Cooking loss was calculated as a percentage of the initial weights of the uncooked steaks (Honikel, 1998):

$$\text{Cooking loss (\%)} = \left(\frac{W_1 - W_2}{W_1}\right) 100$$

Warner-Bratzler shear force

Samples used for cooking loss (described above) were used for the shear force measurements. A core borer was used to remove six cylindrical cores (1.27 cm diameter) from the steaks of each muscle, cutting parallel to the muscle fibre direction. Care was taken to ensure that no visible connective tissue was included in the core. Shear force values were determined using an Instron Universal Testing Machine (Model 4444, supplied by Advanced Laboratory Solutions, Gauteng, South Africa), fitted with a Warner-Bratzler shear attachment. Tenderness was measured as the maximum force required to shear the cylindrical cores of cooked meat (perpendicular to the muscle fibre direction) at a crosshead speed of 200 mm/min. Mean values of the six measurements in Newtons (N) were determined for each muscle from each animal.

Surface colour

Fresh steaks (2.0–2.5 cm thick) were cut from each muscle (perpendicular to the fibre direction) and were allowed to bloom (oxygenate) for a period of 45 min. Colour measurements were taken at five different locations on each steak using a Color-Guide 45°/0° colorimeter (catalogue number 6801; BYK-Gardner GmbH, Geretsried, Germany; aperture size of 11 mm; illuminant/observer of D65/10°), which was pre-calibrated with the standards provided (BYK-Gardner GmbH). The results were expressed by the L* (lightness), a* (green-red) and b* (yellow-blue) co-ordinates of the CIELab colorimetric space (Honikel, 1998). The a* and b* values were subsequently used to calculate the chroma (saturation/colour intensity) and hue angle (colour definition) values, as represented below (AMSA, 2012):

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

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

The mean values of the five measurements for each attribute were determined for each muscle from each animal, with these values being used for statistical analyses.

4.2.4. Statistical analyses

Statistical analyses were performed with Statistica 12 (StatSoft, 2013). Mixed model repeated measures Analysis of Variance (ANOVA) was used as measurements were done on different muscles (i.e. repeated measurements) from the same animal. Muscle and gender were treated as fixed effects and the animals were treated as a random effect. For post hoc analysis, Fisher least significant difference (LSD) tests were used. Differences were considered significant at a level of 5% ($p < 0.05$).

4.3. RESULTS AND DISCUSSION

4.3.1. Harvesting

Night (spotlight) cropping was conducted as far as was feasible in this study, since this is considered the most humane and effective means of reducing stress on the animals during harvesting (Hoffman, 2000; Hoffman & Laubscher, 2010; Lewis, Pinchin, & Kestin, 1997). However, due to the wild and free-roaming nature of the targeted fallow deer, two of the 12 animals were harvested during the day in order to obtain the required numbers. Irrespective of the time of harvesting, none of the animals experienced unnecessary ante-mortem stress and all carcasses were treated in the same manner in terms of the timing and order of processing. The male and female fallow deer harvested for this work had mean (± standard error) live weights of 45.5 ± 2.97 kg and 44.0 ± 2.84 kg, respectively (data not shown). Fallow deer are, however, expected to show high levels of sexual size dimorphism, with male to female live weight ratios of 1.7–2.4 being previously recorded (McElligott et al., 2001). Although adult animals were targeted in the study, it was observed that hunting pressure by neighbouring farmers had reduced the number of mature buck in the fallow deer population under investigation, thus providing a potential explanation for the similar live weights between the males and females (ratio ≈ 1:1).

4.3.2. Interactions and main effects

No significant muscle by gender interactions (muscle × gender) were observed for any of the measured parameters (pH_u, drip loss, cooking loss, shear force, L*, a*, b*, chroma and hue-angle). The main effect of gender did not significantly ($p > 0.05$) influence the pH_u, drip loss, cooking loss and shear force values (Table 4.1), thus only the effect of muscle is discussed in terms of the aforementioned parameters. Both muscle and gender influenced ($p < 0.05$) the colour parameters to differing degrees (Table 4.2), thus these main effects are described independently in the proceeding sections.

4.3.3. Ultimate pH

Venison pH values determined from 12 to 96 hours post mortem should ideally be between 5.4 and 5.6 (Winkelmayer et al., 2005). In this study, the mean pH_u values measured on the six muscles fell precisely into this range (5.4–5.6), although some significant differences were seen between individual muscles (Table 4.1). Variations in the pH_u of different muscles are to be expected, given that these differ in their functions and activity levels. More specifically, skeletal muscles comprise heterogeneous combinations of red and white muscle fibres that store lower and higher amounts of glycogen, respectively, which can in turn lead to deviations in the rate and extent of post-mortem pH decline (Cassens & Cooper, 1971; Kohn, Hoffman, & Myburgh, 2007; Taylor, 2004). It should, however, be noted that while the mean pH_u values of the IS and SS were significantly higher than the other four muscles from a statistical viewpoint, this would not necessarily translate to biologically significant differences, especially given that all pH values were within the aforementioned “ideal” range. The relatively low mean pH_u results measured in this work correspond with those values reported for wild fallow deer in Poland (Daszkiewicz et al., 2015), as well as with values for other wild cervids (Daszkiewicz, Janiszewski, & Wajda, 2009; Daszkiewicz, Kubiak, Winarski, & Koba-Kowalczyk, 2012). On the other hand, higher pH_u values ($pH_u>6$) have been recorded for over 50% of meat samples from farmed fallow deer in Poland and New Zealand (Daszkiewicz et al., 2015; Wiklund et al., 2004), which consequently increases the risk for dark, firm and dry (DFD) meat. High pH_u values in the meat from ruminants have generally been ascribed to pre-slaughter handling stress and/or the poor nutritional status of the animals (Gregory, 1996; Warriss, 1990; Warriss, Kestin, Brown, & Wilkins, 1984; Wiklund et al., 2004). The fact that no values of $pH_u>6$ were documented in this study is both reflective of the minimal ante-mortem stress experienced by the animals during harvesting and the finding of no DFD meat cuts.

4.3.4. Drip loss

Drip loss, defined as the formation of exudates from meat (excluding thawing loss) without application of external forces (Hamm, 1986), is generally considered undesirable from both an economic and consumer acceptability perspective (Huff-Lonergan & Lonergan, 2005; Troy & Kerry, 2010). The mean drip loss results attained from the current study are presented in Table 4.1, which indicates some significant ($p < 0.05$) differences between muscles. The ST showed the highest drip loss (1.6 ± 0.10%), while the values for the BF (1.3 ± 0.09%) and IS (1.3 ± 0.07%) were the lowest. Nonetheless, these drip loss values can generally be considered low in comparison with the values reported for red deer (*Cervus elaphus*; *ca*. 2.9%) (Daszkiewicz et al., 2009), greater kudu (*T. strepsiceros*; 3.7–4.5%) (Mostert & Hoffman, 2007) and impala (*Aepyceros melampus*; 2.9–4.2%) (Kritzinger, Hoffman, & Ferreira, 2003), but are similar to those documented for various sheep breeds (1.3–1.5%) (Ekiz et al., 2009).

Table 4.1 Mean (± standard error) physical meat quality measurements for six muscles from fallow deer (n = 12), as influenced by muscle and gender.

Parameter	Muscle	Total Group	p-value	Gender		p-value
		(n = 12)	Muscle	Male (n = 6)	Female (n = 6)	Gender
pH_u	LTL	$5.4^{a} \pm 0.05$	0.0001	5.5 ± 0.05	5.4 ± 0.08	0.1476
	BF	$5.5^{a} \pm 0.03$		5.5 ± 0.05	5.4 ± 0.03	
	SM	$5.4^{a} \pm 0.03$		5.5 ± 0.06	5.4 ± 0.02	
	ST	$5.4^{a} \pm 0.03$		5.5 ± 0.03	5.3 ± 0.04	
	IS	$5.6^{b} \pm 0.04$		5.6 ± 0.06	5.6 ± 0.05	
	SS	$5.6^{b} \pm 0.04$		5.6 ± 0.05	5.5 ± 0.06	
Drip loss (%)	LTL	$1.4^{cb} \pm 0.04$	0.0041	1.4 ± 0.07	1.4 ± 0.05	0.3550
	BF	$1.3^{c} \pm 0.09$		1.1 ± 0.05	1.4 ± 0.18	
	SM	$1.5^{ab} \pm 0.05$		1.5 ± 0.06	1.6 ± 0.08	
	ST	$1.6^{a} \pm 0.10$		1.5 ± 0.11	1.7 ± 0.16	
	IS	$1.3^{c} \pm 0.07$		1.2 ± 0.05	1.3 ± 0.12	
	SS	$1.4^{cb} \pm 0.10$		1.5 ± 0.18	1.2 ± 0.05	
Cooking loss (%)	LTL	$29.4^{d} \pm 0.25$	0.0000	29.5 ± 0.40	29.3 ± 0.35	0.4263
	BF	$32.4^{c} \pm 0.32$		32.5 ± 0.36	32.2 ± 0.57	
	SM	$35.2^{b} \pm 0.39$		35.5 ± 0.50	34.9 ± 0.61	
	ST	$37.2^{a} \pm 0.19$		37.2 ± 0.33	37.3 ± 0.24	
	IS	$28.5^{d} \pm 0.70$		28.9 ± 0.99	28.1 ± 1.04	
	SS	$36.1^{b} \pm 0.19$		36.3 ± 0.19	35.9 ± 0.33	
Shear Force (N)	LTL	$31.3^{e} \pm 1.41$	0.0000	30.2 ± 2.22	32.4 ± 1.81	0.1315
	BF	$36.0^{de} \pm 2.06$		33.9 ± 2.01	38.1 ± 3.59	
	SM	$37.2^{d} \pm 1.58$		36.6 ± 1.92	37.8 ± 2.67	
	ST	$61.9^{a} \pm 2.56$		59.8 ± 3.60	63.9 ± 3.77	
	IS	$43.1^{c} \pm 2.19$		38.7 ± 2.63	47.5 ± 2.55	
	SS	$52.7^{b} \pm 1.76$		51.6 ± 2.75	53.8 ± 2.35	

Abbreviations: LTL = *Longissimus et thoracis lumborum;* BF = *Biceps femoris*; SM = *Semimembranosus*; ST = *Semitendinosus*; IS = *Infraspinatus*; SS = *Supraspinatus.*
Different superscripts within a column for a specific parameter indicate significant differences ($p < 0.05$) among individual muscles.

Drip loss can be attributed to the loss of water from the myofibrils themselves, as well as from the interfilamental spaces (Hamm, 1986). The condition is known to be highly influenced by pH and to occur maximally at the isoelectric point of meat, this generally being at a pH_u of 5.4 or 5.5 (Lawrence, Fowler, & Novakofski, 2009). For this reason, it is expected that some drip loss will occur in all game meat that is not DFD. Conversely, protein denaturation rates are anticipated to be lower at higher pH_u values, enabling more water to be bound and resulting in little or no exudate (Daszkiewicz et al., 2015; Kritzinger et al., 2003). In spite of this general pattern, the results of this study do not appear to fully support this explanation. Although the muscles with the highest pH_u values (IS and SS) had of the lowest drip loss percentages, similar results were found for muscles with lower pH_u values.

4.3.5. Cooking loss

Cooking loss can generally be used as a measure of the juiciness of meat, with low cooking losses being associated with greater retention of meat fluids (water and/or lipid) and thus with enhanced juiciness of the final product (Sebsibe, 2008; Smith & Carpenter, 1974). In this study, cooking loss was found to be influenced ($p < 0.05$) by the main effect of muscle. Cooking loss was highest in the ST (37.2 ± 0.19%) and lowest in the IS (28.5 ± 0.70%) and LTL (29.4 ± 0.25%), potentially indicating that the latter two muscles would represent the juicier cuts.

Cooking loss is known to be associated with the ultimate pH and water holding capacity of meat, such that a low pH_u and low water-holding capacity (high drip loss) generally translates to a high cooking loss (Aaslyng, Bejerholm, Ertbjerg, Bertram, & Andersen, 2003). Although the pH_u values of all evaluated muscles fell within the ideal range of 5.4 to 5.6 (section 4.3.3), a trend was noted between the drip loss and cooking loss percentages for some of the individual muscles. Specifically, the SM and ST showed the highest drip loss percentages, as well as comparatively high cooking losses. The LTL, BF and IS were among the muscles with the lowest drip losses, while also showing the lowest cooking losses. An exception to this trend pertained to the SS muscle, which had of the lowest drip loss percentages, but of the highest cooking loss percentages.

4.3.6. Shear force (tenderness)

In general, the meat from game animals is considered more tender than that from domestic livestock (Jansen van Rensburg, 2002; Ledger, 1963). Nonetheless, variations are known to exist in muscle tenderness at slaughter and during post-mortem storage as a result of various interrelated factors, including the pH, anatomical position, muscle fibre composition, amount of connective tissue, intramuscular fat content, proteolytic enzyme activity and age of the animal (Hoffman et al., 2007; Lawrie & Ledward, 2006; North, Frylinck, & Hoffman, 2015; Swatland, 1994a).

Indeed, from the Warner-Bratzler shear force results presented in Table 4.1, it is clear that these values differed significantly among the individual muscles evaluated. The lowest mean shear force values were recorded for the LTL (31.3 ± 1.41 N) and BF (36.0 ± 2.06 N), followed by the SM (37.2 ± 1.58 N), with the last mentioned not differing significantly from the BF. As a comparison, shear force values of 40–45 N are generally considered to be indicative of tender beef (ASTM, 2011; Devine et al., 2006), while Destefanis, Brugiapaglia, Barge, and Dal Molin (2008) suggested that values exceeding 52.68 N indicate tough beef. The LTL is known to be an inherently tender muscle owing largely to its low content of connective tissue (Astruc, 2014), which is reflected by the results of this study. The BF and SM are among the main extensor muscles in the hip, with the tenderness of the former being relatively uniform, while that of the latter decreases from the pelvic portion of the muscle outward (Frandson, 1966; Swatland, 1994b; Wiklund, Finstad, Johansson, Aguiar, & Bechtel, 2008).

The highest mean shear force values in this study was found for the ST (61.9 ± 2.56 N), which has similarly been classified as a tough muscle in beef carcasses (Sullivan & Calkins, 2007). The ST, located in the centre of the posterior thigh muscles (Frandson, 1966), has fewer muscle fibres with similar diameter per primary muscle fibre bundle compared to more tender muscles (e.g. LTL) and has a less desirable texture. Rhee, Wheeler, Shackelford, and Koohmaraie (2004) reported larger variations in sarcomere length in the ST than in 10 other muscles studied, with this length increasing from the proximal to the distal end. Herring, Cassens, and Briskey (1965) further found a correlation between sarcomere length, fibre diameter and tenderness, such that as sarcomere length decreased, the fibre diameter increased and tenderness decreased.

In terms of the influence of pH on tenderness, it is known that shear force values tend to increase with increasing pH_u and that a low pH_u is generally required to achieve optimal tenderness. Devine et al. (2006) suggested that significant variations in meat tenderness become apparent at $pH_u > 5.75$, while Bouton, Carroll, Fisher, Harris, and Shorthose (1973) reported maximum toughness at intermediate pH values of 5.8–6.0. On the other hand, tenderness may be increased at $pH_u > 6.3$ (Devine, Graafhuis, Muir, & Chrystall, 1993) due to the enhanced activity of proteolytic enzymes (Yu & Lee, 1986), although the shelf life of such meat (pH > 6) would be expected to be reduced (Devine et al., 1993). Since all the pH_u values measured in the muscles in this study fell between 5.4 and 5.6, this would be expected to give rise to optimum tenderness in the meat. Nonetheless, it should be noted that heightened pre-slaughter stress levels experienced by game animals during harvesting might potentially lead to higher pH_u values that fall within the aforementioned intermediate range, which could in turn increase the propensity for tough, DFD meat.

4.3.7. Colour

Venison typically has a darker red-and-brown colour when compared with the meat from domestic livestock, which can predominantly be attributed to the higher content of myoglobin in the former (Young & West, 2001). Such elevated myoglobin concentrations are correspondingly associated with the muscles of free-roaming wild ungulates being subject to a greater activity load than those of domestic animals (Daszkiewicz et al., 2012; Ruiz de Huidobro et al., 2003). A darker colour in venison may also be related to the low intramuscular fat content (Janicki, 1963) or be the indirect result of a high pH_u, where the latter is characteristic of pre-slaughter stress, the depletion of glycogen reserves and the consequent occurrence of DFD meat (Hoffman, 2000; Wiklund et al., 2004). Furthermore, venison colour can be affected by the gunshot wound localisation, as well as the intensity and variability in carcass bleeding (Dominik, Saláková, Buchtová, & Steinhauser, 2012). According to Volpelli et al. (2003), the dark red colour of venison that is normally attractive to consumers is characterised by an L* value of below 40, a high a* value and a low b* value.

The L*, a*, b*, chroma and hue-angle values obtained from the six fallow deer muscles evaluated in this study are given in Table 4.2. Significant differences were found between the different muscles in terms of all the colour parameters measured. Such a result could be expected due to different muscles having different haem pigment concentrations, pH values, and ratios of red to white muscle fibre types (Brewer et al., 2001). Gender appeared to exert a significant effect on only the a* and chroma values.

The LTL, BF and SM had significantly lower L* values compared with the other three muscles, thus showing a darker colour. The L* values found for the LTL (29.7 ± 0.69) and SM (29.5 ± 0.67) in this work are somewhat lower than those reported for the LTL (33.2–34.6) and SM (35.2–36.3) in a study comparing age and supplementary feeding of fallow deer in Italy (Volpelli et al., 2003). Similarly, Bureš, Bartoň, Kotrba, and Hakl (2014) found higher L* values (33.2) in the LTL of fallow deer in the Czech Republic. Such discrepancies in the L* values of the meat from European and South African animals may have arisen due to differences in diet (altered glycogen storage and/or antioxidant accumulation) (Mancini & Hunt, 2005), variations in bleeding or due to differences in the post-mortem pH and/or temperature of the muscles (Morgan Jones, 1995).

Table 4.2 Mean (± standard error) colour data for six muscles from fallow deer (n = 12), as influenced by muscle and gender.

Parameter	**Muscle**	**Total Group**[†] (n = 12)	**p-value Muscle**	**Gender**[#] Male (n = 6)	Female (n = 6)	**p - value Gender**
CIE *L**[1]	**LTL**	29.7[a] ± 0.69	**0.0000**	29.7 ± 1.12	29.6 ± 0.91	0.1210
	BF	30.1[a] ± 0.53		31.1 ± 0.74	29.1 ± 0.55	
	SM	29.5[a] ± 0.67		30.5 ± 1.00	28.4 ± 0.72	
	ST	33.4[b] ± 0.59		33.8 ± 0.49	32.9 ± 1.11	
	IS	31.6[c] ± 0.56		32.8 ± 0.57	30.3 ± 0.68	
	SS	33.1[b] ± 0.84		34.4 ± 1.02	31.9 ± 1.18	
CIE *a**[2]	**LTL**	13.8[a] ± 0.38	**0.0392**	13.0 ± 0.31 [a]	14.6 ± 0.53 [b]	**0.0390**
	BF	13.3[b] ± 0.17		13.3 ± 0.19 [a]	13.4 ± 0.29 [a]	
	SM	14.2[a] ± 0.20		14.3 ± 0.22 [a]	14.2 ± 0.36 [a]	
	ST	14.3[a] ± 0.60		13.5 ± 0.87 [a]	15.0 ± 0.77 [b]	
	IS	14.5[a] ± 0.21		14.3 ± 0.37 [a]	14.7 ± 0.22 [a]	
	SS	14.5[a] ± 0.37		13.6 ± 0.50 [a]	15.4 ± 0.21 [b]	
CIE *b**[3]	**LTL**	9.7[cb] ± 0.46	**0.0003**	9.0 ± 0.58	10.3 ± 0.64	0.4087
	BF	8.8[c] ± 0.18		9.0 ± 0.35	8.6 ± 0.11	
	SM	10.5[ab] ± 0.26		10.4 ± 0.46	10.5 ± 0.29	
	ST	11.3[a] ± 0.63		10.9 ± 0.71	11.7 ± 1.09	
	IS	10.3[ab] ± 0.10		10.5 ± 0.09	10.1 ± 0.13	
	SS	10.9[a] ± 0.33		10.9 ± 0.34	11.0 ± 0.60	
Chroma[4]	**LTL**	16.9[cb] ± 0.55	**0.0032**	15.9 ± 0.54 [a]	17.9 ± 0.79 [b]	**0.0432**
	BF	16.0[c] ± 0.20		16.1 ± 0.30 [a]	15.9 ± 0.28 [a]	
	SM	17.7[ab] ± 0.28		17.7 ± 0.42 [a]	17.7 ± 0.41 [a]	
	ST	18.2[a] ± 0.84		17.4 ± 1.09 [a]	19.1 ± 1.26 [a]	
	IS	17.8[ab] ± 0.17		17.7 ± 0.28 [a]	17.8 ± 0.23 [a]	
	SS	18.2[a] ± 0.32		17.5 ± 0.31 [a]	19.0 ± 0.36 [a]	
Hue-angle°[5]	**LTL**	34.9[cd] ± 0.77	**0.0001**	34.5 ± 1.34	35.2 ± 0.86	0.3066
	BF	33.5[d] ± 0.52		34.1 ± 0.91	32.9 ± 0.47	
	SM	36.3[cb] ± 0.57		36.1 ± 0.94	36.6 ± 0.71	
	ST	38.2[a] ± 0.74		38.8 ± 0.81	37.6 ± 1.27	
	IS	35.4[c] ± 0.51		36.3 ± 0.82	34.4 ± 0.31	
	SS	37.1[ab] ± 1.21		38.8 ± 1.69	35.4 ± 1.56	

[1] lightness (0 = black; 100 = white); [2] green-red (-60 – 0 = green; 0 – 60 = red); [3] yellow-blue (-60 – 0 = blue; 0 – 60 = yellow); [4] dull (grey) or saturated (vivid/clear); [5] purity of colour

Abbreviations: LTL = *Longissimus et thoracis lumborum;* BF = *Biceps femoris*; SM = *Semimembranosus*; ST = *Semitendinosus*; IS = *Infraspinatus*; SS = *Supraspinatus.*

[†] Total group: different superscripts within a column for a specific parameter indicate significant differences among individual muscles.

[#] Gender: different superscripts within a row for a specific parameter indicate significant differences between genders.

Light scattering from a meat surface (which affects L* values) is known to be influenced by muscle structure and the extent of protein denaturation, with the latter being largely influenced by post-mortem pH (Morgan Jones, 1995). DFD meat, in which protein denaturation is expected to be minimal, generally shows low L* values, as exemplified by Hoffman's (2000) report of a wounded (stressed) male impala having very dark meat with a high pH_u and L* value of *ca*. 25. Conversely, light scattering tends to increase when the pH of the meat is low and protein denaturation is increased (Swatland, 2008). The low pH_u values obtained for the fallow deer muscles in the current study (5.4–5.6) could thus explain the higher degree of light scattering (higher L* values of 29.5–33.4) found in comparison with the values reported for DFD meat by Hoffman (2000). In addition, all the L* values measured in this work were within the range suggested by Volpelli et al. (2003) to be desirable to venison meat consumers (i.e. L* < 40).

In terms of the a* values, the BF exhibited significantly lower values (13.3 ± 0.17) than the other five muscles. The a* values for the LTL, SM, ST, IS and SS did not differ significantly from one another, and could be regarded as having a brighter or more intense red colour in relation to the BF. When considering gender, the females had significantly higher a* (more red) values than the males in the LTL, ST and SS, while the a* values did not differ significantly with gender in the remaining muscles. The a* value of meat is known to be correlated with its myoglobin content, such that higher a* values are related to higher myoglobin content (Bekhit & Faustman, 2005; Kim et al., 2010; Vestergaard, Oksbjerg, & Henckel, 2000). It could accordingly be postulated that the BF of the fallow deer in this study, as well as the LTL, ST and SS of the males, contained lower levels of myoglobin compared with the other muscles and with the LTL, ST and SS of the females, respectively. Nonetheless, such a proposition would undoubtedly require corroboration through the direct measurement of myoglobin concentrations in the muscles. As previously mentioned, meat with a brighter red colour (higher a* value) is considered desirable by the consumers (Volpelli et al., 2003). Moreover, Wiklund, Stevenson-Barry, Duncan, and Littlejohn (2001) suggest that an a* value ≥12 in meat is the lower limit for consumer acceptability. The a* values measured in all of the fallow deer muscles exceeded the aforementioned threshold (Table 4.2) and thus would likely be deemed acceptable by the consumer in this respect.

The b* values measured in the fallow deer muscles ranged from 8.8 to 11.3, with the values for the ST (11.3 ± 0.63) and SS (10.9 ± 0.33) being significantly higher (more yellow) than those for the LTL (9.7 ± 0.46) and BF (8.8 ± 0.18) (Table 4.2). No significant gender effects were seen for the muscles in terms of the b* values. With reference to the consumer desire for meat with lower b* (less yellow) values, it is important to note that the b* values measured for the fallow deer LTL in this study were lower than those documented for various beef breeds (Du Plessis & Hoffman, 2007), boer-cross goat wethers and intact males (Solaiman et al., 2011), and reindeer (*Rangifer tarandus*) in Alaska (Wiklund et al., 2008).

Significant differences were found between muscles in terms of chroma, with the values in the two smaller muscles (ST and SS) being the highest and indicating a more saturated or vivid colour. The lowest chroma value was observed for the BF (16.0 ± 0.20), which could consequently be accepted to have the least saturated or most dull (grey) colour. Since chroma values are calculated using a* and b* values, it follows that a muscle with a significantly lower a* and b* value (such as the BF) will have a lower chroma value, and vice versa for the two small muscles (ST and SS). It thus further follows that the significantly higher chroma values seen for the LTL in females may be reflective of both the higher a* values (significant) and b* values (not significant) recorded in females for this muscle.

Hue-angle measurements provide a good indication of discolouration in meat (Young & West, 2001), with larger values indicating less redness and more metmyoblobin formation (Howe, Gullett, & Usborne, 1982). The high concentrations of myoglobin and pro-oxidants (e.g. iron and copper) in venison increase the probability of metymyoglobin formation in the meat, which can consequently give rise to a dull, brown colour that is undesirable to the consumer (Farouk et al., 2007; Young & West, 2001). In this study, significant differences were observed between muscles in terms of hue-angle, with the lowest mean value (most red hue) being found for the BF (33.5 ± 0.52°) (Table 4.2). Conversely, the highest mean hue-angle values were found in the ST (38.2 ± 0.74°) and SS (37.1 ± 1.21°), indicating a shift in these muscles towards the yellow part of the colour spectrum. The calculation of hue angle [$\tan^{-1}$(b*/a*)] takes into account both the a* and b* values, with the aforementioned results reflecting the higher b* values found for these two muscles (Table 4.2). Since it has been suggested that brown meat colour only becomes noticeable to the consumers when *ca*. 60% of the myoglobin is converted to metmyoglobin (Lawrie & Ledward, 2006), it is questionable whether the differences found in the hue-angle values of the different muscles in this study would be apparent to the consumer. Moreover, compared with the hue-angle values measured for the different muscles in the current work (33.5–38.2°), King, Shackelford, and Wheeler (2011) reported values of 36.8–41.6° for the steaks taken from 14 beef muscles on the first day of placement on retail display. Such a comparison suggests that fallow deer meat cuts would not be inferior to retail beef in terms of the hue-angle (discolouration) parameter.

4.4. CONCLUSIONS

This study represents the first attempt to quantify the physical quality of the meat from wild fallow deer in South Africa, the outcomes of which will be indispensable for the marketing and promotion of such products. Since consumers place a strong focus on the visual, eating and technological parameters of meat, generating data of this kind is imperative if the market for fallow deer is to grow and become economically viable. The results of this study suggest that fallow deer meat from South Africa compares well with that of other commonly consumed game species, as well as with some domestic livestock species. The generated data further indicate that all the measured parameters (pH_u, drip, cooking loss, shear force and colour) are influenced by the individual muscle analysed, which should prove beneficial to the meat industry in deciding which muscles to market as the prime cuts and which are more suitable for further processing. Gender, on the other hand, appears to have a less pronounced effect on the meat quality. The present investigation has also shown that the method used for fallow deer cropping (i.e. mostly night harvesting) does not appear to have detrimental effects on the physical meat quality attributes when such activities do not alarm and stress the animals. No DFD meat was observed in any of the fallow deer muscles, reflected also by the low pH_u measurements. Rather, fallow deer meat colour was characterised by values generally considered desirable by venison meat consumers, thus there is no reason to believe that this would not be readily accepted by such consumers. While baseline data has been presented on the physical attributes of South African fallow deer meat, further research on the chemical and nutritional value will undoubtedly contribute to the consumer acceptance and commercial uptake of such meat.

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CHAPTER 5

PROXIMATE, FATTY ACID AND MINERAL COMPOSITION OF MEAT FROM WILD FALLOW DEER (*DAMA DAMA*) IN SOUTH AFRICA

ABSTRACT

The aim of this study was to determine the chemical composition of the meat from wild fallow deer in South Africa, as affected by muscle and gender. Proximate analyses were conducted on six muscles (*longissimus thoracis et lumborum* [LTL], *biceps femoris* [BF], *semimembranosis* [SM], *semitendinosus* [ST], *infraspinatus* [IS] and *supraspinatus* [SS]), while fatty acid and mineral analyses were conducted on the LTL and BF. The proximate composition of the six muscles ranged from 73.3–76.2% moisture, 20.4–23.1% protein, 2.2–3.2% lipid and 1.1–1.5% ash. Proximate composition was significantly ($p < 0.05$) influenced by muscle, but not by gender. Polyunsaturated fatty acids (PUFAs) were the predominant class of fatty acids (FAs) present in the fallow deer muscles, followed by saturated FAs (SFAs) and monounsaturated FAs (MUFAs). However, the PUFA content was significantly ($p < 0.05$) affected by muscle (BF > LTL), the MUFA content was significantly ($p < 0.05$) affected by gender (female > male), and a significant ($p < 0.05$) muscle × gender interaction was observed for the SFAs. Overall, the fallow deer muscles had favourable PUFA/SFA (> 0.4) and omega-6/omega-3 (< 4) ratios and could be regarded as healthy lipid sources. The primary essential macro- and micro-minerals determined in the LTL and BF were potassium, phosphorus, sodium and magnesium, as well as iron, zinc and copper, with seemingly more variation in the concentrations occurring with muscle than with gender. The minerals in the muscles found to contribute most notably to the human recommended dietary requirements were potassium, iron, copper and zinc.

5.1. INTRODUCTION

The nutritional value and quality of meat is largely defined by its basic chemical composition (moisture, protein, lipid and mineral content), with the latter being strongly influenced by both intrinsic (genetic) and extrinsic (environmental) factors (Guerrero, Velandia Valero, Campo, &

Sañudo, 2013; Lorenzo et al., 2014). Of these basic components, the lipid content is generally regarded as the most variable in meat (Hocquette et al., 2010; Purchas, 2012; Sebranek, 2014). Variations in the lipid component between animals are mostly attributed to species, diet and maturity (Keeton, Ellerbeck, & Núñez de González, 2014). In particular, notable differences exist in the lipid composition of meat from monogastric and ruminant animals due to their different digestive strategies. Whereas monogastric animals break down dietary fats into their parent fatty acids and incorporate these into their tissues in a relatively unchanged form, ruminants deposit considerably greater proportions of saturated fat as a result of fatty acid biohydrogenation in the rumen prior to absorption (Wood et al., 2008a). In addition, intramuscular lipid concentrations can vary considerably at different anatomical locations within a specific animal. The aforementioned variations can largely be ascribed to differences in muscle fibre type composition across the carcass, which in turn is related to the function and activity levels of the muscles (Astruc, 2014; Hocquette et al., 2010). Red muscle fibres (type I, “slow twitch”) are used for continuous motions and function aerobically (oxidative metabolism). These muscle fibres are characterised by high quantities of myoglobin and mitochondria, a rich supply of blood capillaries and a high lipid content, the last mentioned representing the main fuel source during prolonged activities. Conversely, white muscle fibres (type IIB, “fast twitch”) are used for rapid movements and predominantly function anaerobically (glycolytic metabolism), being characterised by higher glycogen and protein contents but lower lipid contents (Lawrie & Ledward, 2006; Warriss, 2000). Muscles with higher proportions of red fibres are thus expected to have higher intramuscular fat levels, with the relative amounts of moisture and protein fluctuating accordingly.

Consumers nowadays are increasingly discerning and place a large focus on the nutritional composition of the foods they purchase (Resurreccion, 2004; Font-i-Furnols & Guerrero, 2014). In general, there is a growing trend towards the selection of products that are authentic and flavoursome, while being high in protein and low in fat (Hoffman & Cawthorn, 2012; Paleari, Moretti, Beretta, Mentasti, & Bersani, 2002). Specifically, concerns relating to the reported links between the intake of saturated fat and cholesterol and the occurrence of certain western diseases have resulted in a gradual shift away from red meats from domestic livestock species, such as beef and mutton (Dransfield, 2003; Kearney, 2010; Resurreccion, 2004). Such a shift has additionally been fuelled by the high prices of the aforementioned commodities, the negative consumer perceptions associated with intensive animal production (e.g. animal welfare, administration of veterinary drugs and stimulants, carbon and water footprints), as well as other affiliated food safety concerns (e.g. foot-and-mouth disease, bovine spongiform encephalopathy in cattle) (Hoffman, Muller, Schutte, Calitz, & Crafford, 2005; Kanerva, 2013; Taljaard, Jooste, & Asfaha, 2006). On the other hand, the meat from wild African ungulates, loosely referred to as 'game meat', is growing in popularity among modern consumers, being an increasingly sought-after item on the menus of local restaurants and game lodges, as well as for the export market (Hoffman, Mostert, Kidd, & Laubscher, 2009). This increasing popularity can largely be ascribed to the novelty of game meat, its proposed health benefits, its association with the 'Africa experience', along with its natural and 'free range' origin (Hoffman & Wiklund, 2006).

Game ranching in South Africa has been steadily expanding over the last 50 years, with such operations being substantially boosted by the profits accruing through biltong hunting, trophy hunting and ecotourism (Cooper & Van der Merwe, 2014; Van der Merwe, Saayman, & Rossouw, 2014). The number of game in the country has consequently risen by more than 40-fold during this time period, with the meat from surplus animals increasingly making its way into both local and international markets (Dry, 2011; Van Hoven, 2015). At present, the indigenous antelope contributing most notably to the South African game meat industry include springbok (*Antidorcas marsupialis*), greater kudu (*Tragelaphus strepsiceros*) and blesbok (*Damaliscus pygargus phillipsi*), while wildebeest (*Connochaete*s spp.), impala (*Aepyceros melampus*) and gemsbok (*Oryx gazella*) are harvested in smaller numbers (Hoffman & Cawthorn, 2014).

On the other hand, fallow deer (*Dama dama*) are non-native cervids that were introduced into the country for hunting purposes in the 19th century (Chapman & Chapman, 1980). Although fallow deer have adapted well to South African conditions and their population numbers continue to intensify, these animals currently contribute little to the local game meat industry. Conversely, fallow deer are farmed in substantial numbers in continental Europe and Oceania, where their meat is a highly marketed commodity (Hudson, Drew, & Baskin, 1989). Like the meat from African antelope species, venison from deer is renowned for its high protein (> 20%) and low fat (< 3%) content (Hoffman & Cawthorn, 2012; Volpelli, Valusso, Morgante, Pittia, & Piasentier, 2003) and thus could represent a healthy meat source for a generally protein-deficient nation. Nonetheless, Hoffman et al. (2005) reported that South African consumers are frequently ill informed on the positive health attributes associated with game meat consumption. One potential reason for this may be due to the limited nutritional information that exists on game meat/venison in comparison with that for domestic meat species, which in turn may hamper consumer education and the marketing of these products based on their dietary benefits (Issanchou, 1996). Furthermore, where information is available on the composition of game meat, this is generally restricted to the loin muscle, which may not provide an adequate representation of the nutritional value of other marketable skeletal muscles. The aim of this study was thus to generate baseline data on the proximate, fatty acid and mineral composition of the meat from wild fallow deer harvested in South Africa, as affected by muscle and gender.

5.2. MATERIALS AND METHODS

5.2.1. Harvesting and slaughtering

Ethical clearance for this study was granted by the Stellenbosch University Animal Care and Use Committee (No.: SU-ACUM000-44) prior to the initiation of field work. Twelve wild fallow deer (n = 6 males; n = 6 females) were harvested in August 2014 (winter) on Brakkekuil farm (34°17'47.6"S; 20°49'28.0"E), close to Witsand in the Western Cape of South Africa. This study area forms part of the East Coast Renosterveld Bioregion, which falls within the greater Fynbos Biome of South Africa (Rutherford, Mucina, & Powrie, 2006). Cropping was conducted for the purpose of controlling the fallow deer population size on the farm.

The majority of fallow deer were harvested at night (spotlight cropping) in accordance with Hoffman and Laubscher (2010), since this is regarded as the most humane and effective means of minimising stress on the animals during such operations. As a result of the wild and free-roaming nature of the targeted fallow deer, however, a small number of animals (n = 2) were harvested during daylight hours so as to obtain the required numbers. Regardless of the harvesting time, none of the animals experienced unnecessary ante-mortem stress associated with the harvesting procedure. All 12 animals were harvested with a single shot to the head or upper neck area by experienced and licensed hunters using high velocity rifles, followed by immediate exsanguination in the field. The carcasses were subsequently tagged with unique identification numbers and transported to an on-site slaughtering facility, where individual live weights were documented (Mettler Toledo Hawk Scale, supplied by Microsep, Gauteng, South Africa) within 2-hours post mortem. Skinning and evisceration was conducted following the guidelines of Van Schalkwyk and

Hoffman (2010), where after the dressed carcasses were suspended by both Achilles tendons in a cool room (± 4 °C) for a period of 16 hours.

Although adult animals were targeted for this study, it should be noted that hunting pressure by surrounding farmers was observed to have reduced the number of mature fallow deer buck in the study area. The live weights of the harvested males and females were thus relatively similar, with mean (± standard error) values of 45.5 ± 2.97 kg and 44.0 ± 2.84 kg, respectively (data not shown).

5.2.2. Removal of muscles

Upon the 16-hour mark, the dressed carcasses were taken from the cool room and six muscles were excised entirely from the right-hand side of each animal: *longissimus thoracis et lumborum* (LTL), *biceps femoris*, (BF), *semimembranosis* (SM), *semitendinosus* (ST), *infraspinatus* (IS) and *supraspinatus* (SS). The excised muscles were individually vacuum packed (Multivac C200, Multivac, Gauteng, South Africa), labelled and refrigerated (± 4 °C) overnight. All muscle samples were subsequently transported under chilled conditions to the laboratory at the Department of Animal Sciences, Stellenbosch University, where they were frozen at -20 °C to await further analyses.

5.2.3. Sample preparation

Prior to homogenisation, all muscle samples were allowed to thaw overnight in their packaging at ± 4 °C. Each muscle sample was then individually homogenised (Dampa CT-35N Bowl Cutter, Mason Gray Strange, Kilkenny, South Australia), adding any exuded moisture to the homogeniser in each case to compensate for thawing loss. The homogenised content was subsequently divided, vacuum packed (Multivac C200), labelled and stored at -20 °C to await the various chemical analyses. Prior to the analyses, the homogenised samples were thawed (± 4 °C, 24 h), with thorough mixing of each muscle homogenate to incorporate exuded moisture.

5.2.4. Proximate analysis

Moisture

The moisture contents (% wet weight) of 2.5-g homogenised meat samples were analysed in duplicate for all six muscles by drying for 24 h at 100 °C, following official method 934.01 of the Association of Official Analytical Chemists (AOAC, 2002a).

Total protein

The total crude protein contents of dried, defatted and ground meat samples were determined in duplicate in accordance with the AOAC 992.15 Dumas combustion method (AOAC, 2002b). Sub-samples (0.1 g) from each muscle homogenate were encapsulated in a Leco^{TM} foil sheet and were subsequently analysed in a Leco Nitrogen/Protein analyser (FP – 528, Leco Corporation, St. Joseph, Michigan, USA). The Leco analyser was calibrated with ethylene-diamine-tetra-acetic acid (EDTA) (Leco Corporation) prior to the analysis of each batch of samples. The accuracy and recovery rate of the method was ensured by running a calibration sample of known protein content after every 10 test samples. The results obtained as % nitrogen (N) were multiplied by a conversion factor of 6.25 in order to determine the total crude protein (%) values.

Total lipid

The total lipid contents (% wet weight) of 5-g homogenised muscle samples were analysed in duplicate by means of the chloroform-methanol extraction gravimetric method described by Lee, Trevino, and Chaiyawat (1995). A 1:2 (v/v) chloroform/methanol solution was used for extraction as the samples were expected to contain less than 5% lipid.

Ash

The ash content (% wet weight) of the dried meat samples (from the moisture analysis described above) was determined in duplicate by ashing at 500 °C for 6 h, following the procedures detailed in AOAC 942.05 (AOAC, 2002c).

5.2.5. Intramuscular fatty acids

The fatty acid (FA) profiles of the LTL and BF muscles from each fallow deer carcass were determined independently. The fat from a 2-g sample of raw muscle homogenate was extracted using a 2:1 (v/v) chloroform:methanol solution (Folch, Lees, & Sloane-Stanley,1957), which contained 0.01% butylated hydroxytoluene (BHT) as an antioxidant. The samples were homogenised in the extraction solvent for 30 secs using a polytron mixer (WiggenHauser D-500 Homogeniser, fitted with a standard shaft 1, speed setting D). Heptadecanoic acid (C17:0) was employed as an internal standard (catalogue number H3500, Sigma-Aldrich, Gauteng, South

Africa) to quantify the individual fatty acids present in each muscle sample. A 250-µL sub-sample of the extracted lipids was subsequently transmethylated at 70 °C for 2 h using 2 mL of a 19:1 (v/v) methanol:sulphuric acid solution as the transmethylating agent. After allowing the resultant mixtures to cool to room temperature, the fatty acid methyl esters **(FAME)** were extracted with water and hexane. Following separation of the distilled water and FAME-containing hexane fluids, the top hexane layer was transferred to a spotting tube and dried under nitrogen. Fifty µL hexane was then added to each dried FAME sample, of which 1 µL was injected into the gas chromatograph. The FAMEs were analysed using a Thermo TRACE 1300 series gas-chromatograph (Thermo Electron Corporation, Milan, Italy) equipped with a flame-ionisation detector, using a 30 m TR-FAME capillary column with an internal diameter of 0.25 mm and a 0.25 µm film (Cat. No. HY260M142P, Anatech, Cape Town, South Africa) and a run time of *ca*. 40 mins. The following oven temperature settings were utilised: initial temperature of 50 °C (maintained for 1 min) and final temperature of 240 °C attained after three ramps (initial increase at a rate of 25 °C/min until a temperature of 175 °C was reached; thereafter an immediate increase at a rate of 1.5 °C/min to reach 200 °C and maintenance of this temperature for 6 min; lastly an increase at a rate of 10 °C/min to reach 240 °C and maintenance of this temperature for a minimum of 2 min). The injector temperature was set at 240 °C and the detector temperature at 250 °C. The hydrogen gas flow rate was 40 mL/min. The FAME of each sample was identified by comparing the retention times with those of a standard FAME mixture (Supelco™ 37 Component FAME mix, Cat no. 47885-U, Supelco, USA), with results being expressed as mg fatty acid/g meat.

5.2.6. Minerals

Mineral analyses were performed on 5-g samples of raw muscle homogenates from the LTL and BF of each fallow deer. From each sample, 0.5 g was accurately weighed and digested on a MARS 240/50 microwave digester (CEM Corporation, Mathews, North Carolina) using 6.5 mL ultra-pure nitric acid (HNO_3) and 0.5 mL hydrochloric acid (HCl) (Merck Suprapur®) at elevated pressure (800 psi) and temperature (200 °C) in order to solubilise the acid-extractable elemental content. After cooling, the extracts were made up to a volume of 50 mL with deionised water in acid-cleaned Falcon tubes and were subsequently analysed for 26 elements. Major elements (calcium [Ca], magnesium [Mg], phosphorus [P], potassium [K] and sodium [Na]) were analysed on a Thermo ICap 6200 inductively coupled plasma atomic emission spectroscopy (ICP-AES) instrument

(Thermo Fisher Scientific, Waltham, Massachusetts, USA), after calibration with NIST-traceable standards (catalogue no. IV-28, supplied by Inorganic Ventures Inc., Christiansburg Virginia, USA), and validation using a multi-element standard (catalogue no. 1105800100, supplied by Merck Millipore, Darmstadt, Germany).

Trace elements (*aluminium* [Al], antimony [Sb], arsenic [As], barium [Ba], boron [B], cadmium [Cd], chromium [Cr], cobalt [Co], copper [Cu], iron [Fe], lead [Pb], manganese [Mn], mercury [Hg], molybdenum [Mo], nickel [Ni], selenium [Se], silicon [Si], strontium [Sr], titanium [Ti], vanadium [V] and zinc [Zn]) were analysed on an Agilent 7700 quadrupole inductively coupled plasma mass spectrometry (ICP-MS) instrument (Agilent Technologies, Santa Clara, California, USA). The instrument was tuned to optimise sensitivity and minimise oxides (<1% CeO/Ce ratio). Analysis was done using the Agilent patented HMI functionality to minimise matrix effects and drift, using helium (He) as collision cell gas for interference removal. Similar calibration (NIST-traceable standards, catalogue no. IV-28, Inorganic Ventures) and validation (multi-element standard, catalogue no. 1105800100, Merck Millipore) procedures were performed as for ICP-AES. Results were corrected to account for the dilution factors resulting from the digestion procedure, being expressed as mg/kg meat on a wet-weight basis.

5.2.7. Statistical analyses

Statistical analyses were performed using Statistica 12 (StatSoft, 2013). Linear mixed model repeated measures Analysis of Variance (ANOVA) was employed as measurements were conducted on different muscles (i.e. repeated measurements) from the same animal. Muscle, gender and muscle by gender interaction (muscle × gender) were treated as fixed effects, while the animals were treated as a random effect. For post hoc analysis, Fisher least significant difference (LSD) tests were utilised. Where applicable, Pearson's correlations were calculated for the various parameters. Differences were considered statistically significant at a level of 5% ($p < 0.05$).

5.3. RESULTS AND DISCUSSION

Although the composition of meat is known to be influenced by a wide range of factors (Guerrero et al., 2013), extrinsic factors (e.g. diet, season and environment) were assumed to have little effect on the chemical composition of the fallow deer meat in this study, as all the animals were harvested over a short time period from the same location, during the same season and under very similar conditions. Rather, the effects of intrinsic factors (muscle and gender) on the chemical composition of fallow deer meat were investigated.

5.3.1. Proximate composition

The proximate composition (g/100 g [%]) of six fallow deer muscles is presented in Table 5.1. No significant interactions were observed between the main effects (muscle and gender). When considering the main effects separately, gender did not have a significant influence on any of the proximate components, thus only the effect of muscle will be considered further in this section.

Broadly speaking, mammalian muscle is considered to comprise *ca*. 75% water, 19% protein, 2.5% intramuscular fat and 3.5% miscellaneous soluble non-protein components (Lawrie & Ledward, 2006). In comparison, the concentrations of the proximate components of the six fallow deer muscles analysed in this study ranged from 73.3–76.2% moisture, 20.4–23.1% protein, 2.2–3.2% lipid and 1.1–1.5% ash. Significant differences were found between the different muscles (total group) in terms of all the proximate components (moisture, protein, lipid and ash) measured. Such results could be expected since different muscles differ in their function and activity levels, which in turn is reflected by differences in their constituent muscle fibre types, intramuscular fat levels and connective tissue contents (Astruc, 2014; Kauffman, 2001).

In terms of moisture, significantly higher values were found in the SS (76.2 ± 0.16%), IS (76.1 ± 0.16%) and ST (75.8 ± 0.28%) compared with the other muscles, while the SM (73.3 ± 0.21%) and LTL (73.8 ± 0.22%) had the lowest moisture contents (Table 5.1). It is well established that a close relationship exists between the moisture content and the levels of lipid and protein in mammalian muscles, with increasing moisture content relating to a decreasing content of lipid and/or protein (Sales, 1995; Sebranek, 2014). Such a relationship was observed in this study and is discussed in further detail below.

With regards to protein, the highest levels were found in the SM (23.1 ± 0.23%) and LTL (22.7 ± 0.20%), while the lowest levels were found in the SS (20.4 ± 0.17%) and ST (20.9 ± 0.33%) (Table 5.1). A negative correlation between protein and moisture values was calculated for all the muscles, namely LTL (r = -0.49), BF (r = -0.62), SM (r = -0.84), ST (r = -0.77), IS (r = -0.58) and SS (r = -0.57). It has previously been reported that moisture and protein typically exist in raw meat in a ratio of 3.6 : 1 to 3.8 : 1 (Sebranek, 2014). In the current study, this ratio was found to range from 3.2 : 1 to 3.7 : 1 in the various muscles, with these lower values possibly being reflective of the higher protein concentrations in the fallow deer meat in relation to other meat products.

Table 5.1 Mean (± standard error) proximate composition in g/100 g (%) of six different muscles from fallow deer (n = 12), as influenced by muscle and gender.

Parameter (g/100 g)	Muscle	Total Group[†] (n = 12)	p-value Muscle	Gender Male (n = 6)	Gender Female (n = 6)	p-value Gender
Moisture	**LTL**	$73.8^{a} \pm 0.22$	**<0.0001**	74.2 ± 0.36	73.4 ± 0.18	0.1187
	BF	$74.5^{b} \pm 0.20$		74.8 ± 0.29	74.2 ± 0.23	
	SM	$73.3^{a} \pm 0.21$		73.4 ± 0.25	73.3 ± 0.36	
	ST	$75.8^{c} \pm 0.28$		75.5 ± 0.36	76.0 ± 0.44	
	IS	$76.1^{c} \pm 0.16$		76.2 ± 0.19	75.9 ± 0.25	
	SS	$76.2^{c} \pm 0.16$		76.6 ± 0.11	75.9 ± 0.22	
Protein	**LTL**	$22.7^{a} \pm 0.20$	**<0.0001**	22.6 ± 0.35	22.7 ± 0.23	0.9636
	BF	$21.9^{b} \pm 0.24$		21.8 ± 0.27	22.0 ± 0.43	
	SM	$23.1^{a} \pm 0.23$		23.1 ± 0.30	23.0 ± 0.39	
	ST	$20.9^{cd} \pm 0.33$		21.1 ± 0.50	20.6 ± 0.45	
	IS	$21.3^{c} \pm 0.15$		21.3 ± 0.10	21.4 ± 0.30	
	SS	$20.4^{d} \pm 0.17$		20.2 ± 0.24	20.6 ± 0.24	
Lipid	**LTL**	$2.8^{a} \pm 0.16$	**<0.0001**	2.5 ± 0.09	3.0 ± 0.26	0.2967
	BF	$3.2^{b} \pm 0.20$		3.4 ± 0.36	3.1 ± 0.19	
	SM	$2.9^{ab} \pm 0.10$		3.0 ± 0.19	2.9 ± 0.11	
	ST	$2.7^{a} \pm 0.12$		2.4 ± 0.11	2.9 ± 0.17	
	IS	$2.2^{c} \pm 0.08$		2.1 ± 0.06	2.3 ± 0.14	
	SS	$2.8^{a} \pm 0.15$		2.8 ± 0.22	2.9 ± 0.22	
Ash	**LTL**	$1.1^{a} \pm 0.02$	**0.0003**	1.1 ± 0.02	1.1 ± 0.03	0.7267
	BF	$1.2^{a} \pm 0.03$		1.2 ± 0.05	1.2 ± 0.03	
	SM	$1.4^{bc} \pm 0.08$		1.3 ± 0.06	1.5 ± 0.13	
	ST	$1.5^{c} \pm 0.07$		1.4 ± 0.07	1.5 ± 0.12	
	IS	$1.3^{ab} \pm 0.05$		1.3 ± 0.07	1.2 ± 0.08	
	SS	$1.4^{bc} \pm 0.06$		1.4 ± 0.10	1.4 ± 0.09	

Abbreviations: LTL = *Longissimus et thoracis lumborum;* BF = *Biceps femoris*; SM = *Semimembranosus*; ST = *Semitendinosus*; IS = *Infraspinatus*; SS = *Supraspinatus.*

[†] Total group: different superscripts within a column for a specific parameter indicate significant differences ($p < 0.05$) among individual muscles.

Game meat is considered to be higher in protein than the meat from domestic livestock (Jansen van Rensburg, 2002) and indeed the protein values found in this study (20.4–23.1%) exceed those approximated for mammalian muscle in general (19%) (Lawrie & Ledward, 2006). The present protein values further compare well with or surpass those reported for the meat of indigenous African antelope species, namely for blesbok (*D. pygargus phillipsi*; 22.18–22.45%; Hoffman, Smit, & Muller, 2008), springbok (*A. marsupialis*; 18.80–21.16%; Hoffman, Kroucamp, & Manley, 2007a) and greater kudu (*T. strepsiceros*; 22.18–22.77%; Hoffman et al., 2009). Wild fallow deer meat from South Africa thus appears to represent a protein-dense meat source, with a 100-g portion being capable of contributing between 38% and 43% of the daily protein requirement for a 65-kg adult (FAO/WHO, 2007). Moreover, in accordance with the South African food labelling legislation (DoH, 2010), fallow deer meat could be considered to be 'high in protein' since the mean values for this nutrient exceeded 10 g protein/100 g final product for all the muscles analysed.

While venison is generally considered to contain < 3% intramuscular fat (Hoffman & Cawthorn, 2012), the lipid fraction is recognised as being a highly variable component between the muscles of a specific animal (Hocquette et al., 2010; Purchas, 2012; Sebranek, 2014). In this study, the lipid content of the fallow deer muscles ranged from 2.2–3.2% (Table 5.1), which is similar to the values found in the LTL of fallow deer in Hungary (2.5%; Zomborszky, Szentmihalyi, Sarudi, Horn, & Szabo, 1996). The current lipid values are, however, somewhat higher than those reported in the LTL of fallow deer buck in Poland (0.24–0.50%; Daszkiewicz et al., 2015) and Italy (0.56–0.72%; Volpelli et al., 2003), as well as being higher than those reported for red hartebeest (*Alcelaphus caama*; 0.6%; Hoffman, Smit, & Muller, 2010), greater kudu (1.5%; Hoffman et al., 2009) and common duiker (*Sylvicapra grimmia*; 2.1%; Hoffman & Ferreira, 2004) in South Africa. Compared to domestic livestock, the present values are similar to the lipid values reported for pork (2.1%, Kim et al., 2008) and goat meat (2.5%; Arain et al., 2010), but are considerably lower than those found in mutton (9%, Schönfeldt, Van Heerden, Sainsbury, & Gibson, 2011) and grain-fed beef (5.6%, Cordain et al., 2002). Significant differences were observed in the lipid content of the different muscles, with the highest values being recorded in the BF and the lowest values being found for the IS (Table 5.1). A negative correlation between lipid and moisture was calculated for the LTL (r = -0.47), SM (r = -0.66), IS (r = -0.29) and SS (r = -0.24), but little correlation between these components was determined for the ST (r = -0.03) and BF (r = 0.03). Overall, the correlations between lipid and moisture were weaker than those found between protein and moisture. Although this is an opposite trend to that generally found in most meat cuts, similar results have been reported for the muscle of blesbok (Du Buisson, 2006;

Neethling, Hoffman, & Britz, 2014). It was suggested by Neethling et al. (2014) that, with the low fat content in the muscles of game species, stronger negative correlations between moisture and protein can be expected in the meat of these animals.

In terms of the ash content, the highest levels were observed in the ST (1.5 ± 0.07%) and lowest in the LTL (1.1 ± 0.02%) and BF (1.2 ± 0.03%) (Table 5.1). Most comparative studies assessing the proximate composition of game species have tended to focus on the LTL, with similar mean ash values of 1.2% being reported in this muscle for blesbok, greater kudu, impala and red hartebeest in South Africa (Hoffman et al., 2008; 2009; 2010), while values of 1.1% have been reported in the LTL of red deer (*Cervus elaphus*), fallow deer and roe deer (*Capreolus capreolus*) in Hungary (Zomborszky et al., 1996). Lower ash values have, however, been documented in the LTL of domestic livestock, namely 0.99% for pigs (Kim et al., 2008) and 1.04% for cattle (Moreira, de Souza, Matsushita, do Prado, & do Nascimento, 2003).

5.3.2. Fatty acids (FAs)

The LTL and BF were selected for FA analysis as both are considered valuable cuts, with the former representing the loin and the latter forming part of the silverside (Wiklund, Finstad, Johansson, Aguiar, & Bechtel, 2008; USDA, 2015). The impacts (p-values) of the main effects (muscle and gender) and their interactions (muscle × gender) on the FA composition (mg/g meat) of fallow deer meat are presented in Table 5.2. The average (mean ± standard error), minimum and maximum values for the FAs of fallow deer meat are additionally shown in Table 5.2 in order to provide an indication of the relative proportions of each FA. Given the low intramuscular lipid content of the fallow deer muscles (Table 5.1), some of the FAs were present at very low concentrations (< 1.0 mg/g meat). These FAs will thus not be discussed in detail, with the exception of those that are regarded as important to human health.

With reference to the average values in Table 5.2, polyunsaturated fatty acids (PUFAs) were found to be the predominant class of FAs in the fallow deer meat (13.57 ± 0.669 mg/g meat), followed by saturated FAs (SFAs; 10.20 ± 0.616 mg/g meat) and monounsaturated FAs (MUFAs; 6.46 ± 0.439 mg/g meat). A similar pattern (PUFA > SFA > MUFA) has also been determined in the LTL of roe deer buck in Lithuania (Razmaitė, Šiukščius, Pileckas, & Švirmickas, 2015) and pasture-fed fallow deer buck in Italy (Volpelli et al., 2003). Even though fallow deer are considered ruminants (Chapman & Chapman, 1997) and are therefore expected to biohydrogenate a large proportion of dietary unsaturated FAs to SFAs in the rumen (Jenkins, 1993; Polan, McNeill & Tove, 1964; Wood et al., 2008a), previous research has demonstrated that considerable differences exist in the FA composition of the tissues of wild and domestic ruminants (Crawford, 1986; Crawford, Gale, & Woodford, 1969; Crawford, Gale, Woodford, & Casped, 1970). More specifically, the muscle tissue of domestic ruminants tends to have higher proportions of SFAs and MUFAs relative to PUFAs, whereas PUFA proportions are typically higher in the muscle of wild ruminants (Cordain et al., 2002). One prominent reason for these differences in the muscle FA profiles of domestic and wild ruminants appears to lie in the total amount of fat occurring therein (Crawford et al., 1970; Miller, Field, Riley, & Williams, 1986). As mentioned in Section 5.3.1, domestic ruminants (particularly sheep and grain-fed cattle) generally deposit higher concentrations of intramuscular fat (marbling) compared with their wild counterparts. With the increase in muscle lipids due to triacylglycerol infiltration, the relative proportion of cellular structural lipids (i.e. phospholipids) diminishes and the muscle FA profile changes to reflect that of the major lipids present (i.e. triacylglycerols) (Cordain et al., 2002). Since wild ruminants deposit comparatively less total intramuscular fat, the FA profile of their meat tends to reflect that of the phospholipids, in which the proportion of PUFAs is higher (Crawford, Hare, & Whitehouse, 1984). In addition, the phospholipids in the lean tissue of wild ruminants are reportedly richer in essential PUFAs and long-chain essential PUFA derivatives than those of domestic ruminants (Crawford et al., 1970; 1984). It should further be noted that differences in the muscle FA profiles of domestic and wild ruminants could also arise from differences in rumen microbial populations (Christie, 1981), as well as differences in passage rates associated with varying rumen sizes, resulting in contrasting biohydrogenation efficiencies.

In descending order of concentration, the main FAs found in the meat were linoleic acid (LA; C18:2n6; 5.53 ± 0.243 mg/g meat), stearic acid (C18:0; 5.00 ± 0.248 mg/g meat), palmitic acid (C16:0; 4.49 ± 0.361 mg/g meat) and arachidonic acid (AA; C20:4n6; 3.63 ± 0.171 mg/g meat) (Table 5.2). These have also been reported to be the four main FAs detected in the LTL of pasture-fed male fallow deer in Italy (Volpelli et al., 2003). Linoleic, palmitic and stearic acids were similarly found to dominate in the LTL of blesbok (Hoffman et al., 2008), greater kudu (Mostert & Hoffman, 2007) and springbok (Hoffman, Kroucamp, & Manley, 2007b), although the levels of oleic acid (C18:1n9c) were higher than those of AA in the aforementioned studies.

Table 5.2 P-values indicating the impact of the main effects (muscle and gender) and their interaction (muscle × gender [M×G]) on the fatty acid composition (mg/g) of fallow deer (n = 12) meat, as well as the average, minimum and maximum values (mean ± standard error) calculated for each fatty acid.

	p-values			mg/g meat		
	M×G	**Muscle†**	**Gender**	**Average#**	**Minimum**	**Maximum**
C14:0	0.203	0.774	0.161	0.23 ± 0.029	0.05	0.50
C15:0	0.118	0.893	0.218	0.13 ± 0.014	0.03	0.26
C16:0	0.058	0.766	0.113	4.49 ± 0.361	2.19	8.14
C18:0	**0.036**	0.206	0.992	5.00 ± 0.248	3.30	7.58
C20:0	0.513	0.574	0.602	0.04 ± 0.003	0.02	0.07
C21:0	0.440	**0.022**	0.078	0.28 ± 0.015	0.18	0.46
C22:0	0.317	0.982	0.071	0.04 ± 0.002	0.02	0.06
C23:0	---	---	---	---	---	---
C24:0	---	---	---	---	---	---
C14:1	0.393	0.371	0.186	0.11 ± 0.016	0.05	0.32
C15:1	0.223	0.930	**0.010**	3.11 ± 0.198	1.84	5.15
C16:1n7	0.103	0.202	0.128	0.51 ± 0.037	0.28	0.89
C17:1	**0.019**	0.067	**0.003**	0.26 ± 0.035	0.12	0.73
C18:1n9c	**0.036**	0.669	0.141	2.23 ± 0.202	0.99	4.54
C18:1n9t	0.192	0.264	0.410	0.08 ± 0.005	0.05	0.12
C20:1n9	---	---	---	---	---	---
C22:1n9	---	---	---	---	---	---
C24:1n9	0.358	**0.005**	0.140	0.15 ± 0.008	0.11	0.24
C18:2n6c	0.485	**0.007**	0.297	5.53 ± 0.243	3.76	8.38
C18:2n6t	---	---	---	---	---	---
C18:3n3	0.241	**0.012**	**0.014**	2.42 ± 0.149	1.67	4.20
C18:3n6	---	---	---	---	---	---
C20:3n3	---	---	---	---	---	---
C20:3n6	0.386	**0.007**	0.156	0.29 ± 0.014	0.21	0.47
C20:4n6	0.416	**0.002**	0.928	3.63 ± 0.171	2.28	5.49
C20:5n3	0.353	**0.006**	0.070	1.28 ± 0.087	0.83	2.27
C22:2n6	---	---	---	---	---	---
C22:6n3	0.246	**0.007**	**0.008**	0.40 ± 0.032	0.24	0.76
SFA	**0.045**	0.659	0.284	10.20 ± 0.616	6.08	15.30
MUFA	0.055	0.931	**0.024**	6.46 ± 0.439	3.98	11.23
PUFA	0.361	**0.005**	0.158	13.57 ± 0.669	9.67	21.60
PUFA:SFA	0.119	**0.035**	0.138	1.40 ± 0.073	0.68	1.97
n-6 PUFA	0.450	**0.004**	0.476	9.47 ± 0.424	6.28	14.36
n-3 PUFA	0.269	**0.009**	**0.021**	4.10 ± 0.265	2.87	7.23
(n-6)/(n-3)	**0.007**	0.617	**0.018**	2.38 ± 0.075	1.79	3.02

Abbreviations: c = cis; t= trans; total saturated fatty acids (SFA); total monounsaturated fatty acids (MUFA); total polyunsaturated fatty acids (PUFA); total omega-3 polyunsaturated fatty acids (n-3 PUFA); total omega-6 polyunsaturated fatty acids (n-6 PUFA); polyunsaturated to saturated fatty acid ratio (PUFA:SFA); omega-6 to omega-3 polyunsaturated fatty acid ratio (n-6:n-3).
† Pooled muscle p-values (*longissimus thoracis et lumborum* and *Biceps femoris*) irrespective of gender.
# Averages were calculated irrespective of main effects (muscle and gender) or interactions [M×G].
Dashed lines = not detected.
Significant differences ($p < 0.05$) are indicated in bold typescript.

The main FAs detected in the fallow deer muscles appear to more or less reflect those FA profiles found in the diet. Most grasses and forbs contain fairly low concentrations of FAs, however, PUFAs generally predominate in the form of essential LA and α-linolenic acids (ALA; C18:3n3), while palmitic acid forms a more minor but noteworthy proportion (Clapham, Foster, Neel, & Fedders, 2005; Dewhurst, Scollan, Youell, Tweed, & Humphreys, 2001; Glasser, Doreau, Maxin, & Baumont, 2013). It was suggested by Doreu and Ferlay (1994) that the extent of biohydrogenation in ruminants is greater for ALA (85–100%) than for LA (70–95%). This means that less of the former is available for incorporation into muscle tissues, potentially explaining the higher levels of LA detected in the muscles compared with ALA. The majority of LA is known to be located in muscle phospholipid molecules (Wood et al., 2008a), as are its long-chain FA products (e.g. AA). The relatively high proportions of AA found in the fallow deer muscles may be attributed to the action of fatty acid desaturase enzymes, which are responsible for synthesising this long chain PUFA from LA (Wood et al., 2008a).

The individual FAs that were significantly influenced by the muscle × gender interaction are shown in Table 5.3. The concentration of stearic acid (C18:0) was higher ($p < 0.05$) in the male BF than in the male LTL, but the former did not differ from the female LTL or female BF. The female LTL had significantly higher levels of oleic acid (C18:1n9c) and SFA than the male LTL, whereas the former muscle did not differ from the male BF or female BF. Both female muscles had significantly higher n-6/n-3 ratios compared with those of the males, while this ratio was also significantly higher in the male LTL than in the male BF. A significant muscle by gender interaction was also observed for heptadecenoic acid (C17:1), but this FA was present at very low concentrations (<0.5 mg/g meat).

Table 5.3 The means (± standard errors) of the fatty acids (mg/g) in fallow deer (n = 12) meat significantly influenced ($p < 0.05$) by the interaction (M×G) between muscle and gender.

Fatty acid (mg/g meat)	LTL		BF	
	Male (n = 6)	Female (n = 6)	Male (n = 6)	Female (n = 6)
C18:0	$4.15^{a} \pm 0.160$	$5.25^{ab} \pm 0.432$	$5.86^{b} \pm 0.656$	$4.76^{ab} \pm 0.375$
C17:1	$0.15^{a} \pm 0.007$	$0.49^{b} \pm 0.104$	$0.18^{a} \pm 0.021$	$0.27^{a} \pm 0.034$
C18:1n9c	$1.62^{a} \pm 0.150$	$3.04^{b} \pm 0.578$	$2.27^{ab} \pm 0.374$	$2.14^{ab} \pm 0.346$
SFA	$8.12^{a} \pm 0.513$	$11.90^{b} \pm 1.733$	$11.02^{ab} \pm 1.366$	$10.04^{ab} \pm 0.881$
(n-6)/(n-3)	$2.18^{a} \pm 0.086$	$2.65^{c} \pm 0.113$	$2.09^{b} \pm 0.102$	$2.63^{c} \pm 0.140$

Abbreviations: LTL = *Longissimus thoracis et lumborum;* BF = *Biceps femoris*; c = cis; t= trans; total saturated fatty acids (SFA); omega-6 to omega-3 polyunsaturated fatty acid ratio (n-6:n-3).
Different superscripts across individual rows indicate significant ($p < 0.05$) differences.

The FAs that were significantly influenced by the main effect of muscle are shown in Table 5.4. Muscle was found to have a significant influence on only one of the SFAs (C21:0; heneicosanoic acid) and one of the MUFAs (C24:1n9; nervonic acid), both being higher in the BF but being present at very low concentrations (< 0.5 mg/g meat). Muscle was, however, seen to have a much more marked effect on the concentrations of the PUFAs. All of the PUFAs that were influenced ($p < 0.05$) by muscle were present at higher concentrations in the BF, including LA and ALA, as well as the long-chain (C20 – C22) PUFAs eicosatrienoic acid (C20:3n6), AA, eicosapentaenoic acid (EPA; C20:5n3) and docosahexaenoic acid (DHA; C22:6n3). This pattern was, in turn, reflected in the significantly higher total content of PUFA, n-6 PUFA, n-3 PUFA, and the PUFA/SFA ratio, in the BF in comparison with the LTL (Table 5.4).

Table 5.4 The means (± standard errors) of the fatty acids (mg/g) in fallow deer (n = 12) meat significantly influenced ($p < 0.05$) by muscle.

Fatty acid (mg/g meat)	LTL	BF
C21:0	0.24 ± 0.009	0.31 ± 0.024
C24:1n9	0.12 ± 0.004	0.17 ± 0.011
C18:2n6c	4.81 ± 0.163	6.19 ± 0.350
C18:3n3	2.06 ± 0.074	2.75 ± 0.246
C20:3n6	0.25 ± 0.008	0.33 ± 0.022
C20:4n6	3.05 ± 0.124	4.17 ± 0.210
C20:5n3	1.04 ± 0.036	1.51 ± 0.135
C22:6n3	0.32 ± 0.018	0.47 ± 0.052
PUFA	11.54 ± 0.339	15.43 ± 0.980
PUFA:SFA	1.29 ± 0.126	1.50 ± 0.073
n-6 PUFA	8.12 ± 0.279	10.70 ± 0.579
n-3 PUFA	3.42 ± 0.119	4.73 ± 0.429

Abbreviations: LTL = *Longissimus thoracis et lumborum;* BF = *Biceps femoris*; c = cis; total polyunsaturated fatty acids (PUFA); polyunsaturated to saturated fatty acid ratio (PUFA:SFA); total omega-3 polyunsaturated fatty acids (n-3 PUFA); total omega-6 polyunsaturated fatty acids (n-6 PUFA).

The LTL of domestic species (e.g. cattle and pigs) and wild ungulates (e.g. fallow deer and springbok) has been reported to be composed predominantly of white (type II) fast glycolytic muscle fibres (Aalhus, Robertson, & Ye, 2009; Curry, Hohl, Noakes, & Kohn, 2012; Hunt & Hedrick, 1977; Johnston, Moody, Boling, & Bradley, 1981; Karlsson, Klont, & Fernandez, 1999; Kirchofer, Calkins, & Gwartney, 2002), which typically use glycogen as the primary fuel source and contain lower PUFA concentrations in relation to red muscle fibres (Wood, Enser, Richardson, & Whittington, 2008b).

Histochemical studies on the muscle fibre types in the BF of wild game and cervid species are comparatively limited. While the BF of cattle has been classified as "white" (Kirchofer et al., 2002), Beecher, Cassens, Hoekstra, and Briskey (1965) reported that the BF of pigs had distinct "red" and "white" portions on the inside and outside of the muscle, respectively. If a similar phenomenon to the latter were to occur in the BF of fallow deer, this could perhaps explain the higher PUFA content in the BF when compared with the LTL. Further research is undoubtedly required to better understand the fibre type composition of the different fallow deer muscles and the degree to which this influences the composition.

The main effect of gender on the fatty acid composition of fallow deer meat is depicted in Table 5.5. The muscles of the females were found to have a significantly higher concentration of cis-10-pentadecenoic acid in relation to the males, likely accounting for the higher ($p < 0.05$) total MUFA content in the former. Contrasting results have been reported for the LTL of springbok by Hoffman et al. (2007b), where the proportions of MUFA were found to be higher in the males relative to the females. The concentrations of ALA and DHA in this study were, however, significantly higher in the muscles of the males when compared to the females. As anticipated from the aforementioned finding, the males also had a higher total n-3 PUFA content and lower n-6/n-3 ratio in their muscles relative to the females.

Table 5.5 The means (± standard errors) of the fatty acids (mg/g) in fallow deer (n = 12) meat significantly influenced ($p < 0.05$) by gender.

Fatty acid (mg/g meat)	Male (n = 6)	Female (n = 6)
C15:1	2.55 ± 0.134	3.72 ± 0.296
C17:1	0.17 ± 0.012	0.37 ± 0.059
C18:3n3	2.73 ± 0.230	2.08 ± 0.130
C22:6n3	0.47 ± 0.045	0.32 ± 0.035
MUFA	5.44 ± 0.401	7.56 ± 0.676
n-3 PUFA	4.61 ± 0.411	3.55 ± 0.253
(n-6)/(n-3)	2.14 ± 0.065	2.64 ± 0.088

Abbreviations: total monounsaturated fatty acids (MUFA); total omega-3 polyunsaturated fatty acids (n-3 PUFA); omega-6 to omega-3 polyunsaturated fatty acid ratio (n-6:n-3).

From a human health perspective, substantial evidence has been presented to indicate that the replacement of dietary SFA with PUFA influences blood lipoprotein cholesterol concentrations and lowers the risk of coronary heart disease (CHD) (FAO/WHO, 2010; Micha & Mozaffarian, 2010; Wijendran & Hayes, 2004). It should, however, be noted that a recent systematic review reported insufficient evidence to link the intake of SFA with CHD (Mente, de Koning, Shannon, & Anand, 2009). Nonetheless, a reduction in dietary SFA has become a pillar of international dietary guidelines, with recommendations that SFA should contribute < 10% of the total caloric intake, whereas PUFA should account for 6–11% of this intake (FAO/WHO, 2010). When assessing the nutritional quality of the fallow deer intramuscular lipid fraction by considering the PUFA/SFA ratios (Tables 5.2), it was observed that the average ratio in the muscles (1.40) was well above the minimum level of 0.4 recommended to be appropriate for human health (COMA, 1994), while falling within the range (1.0–1.5) that is seen as beneficial in meat products (Maid-Kohnert, 2002; Pedrosa, Tecelão, & Gil, 2014). The PUFA/SFA ratios determined in this study further exceed those reported for beef (0.1), lamb (0.2), pork (0.3–0.6), springbok (0.9–1.0), roe deer (1.1) and horsemeat (1.2), while being lower than those found for pasture-fed fallow deer in Italy (1.8) (Enser, Hallett, Hewitt, Fursey, & Wood, 1996; Hoffman et al., 2007b; Jakobsen, 1999; Razmaitė et al., 2015; Schmid, 2011; Volpelli et al., 2003).

As scientific knowledge on the effects of dietary fats on human health has continued to advance, it has been increasingly realised that individual FAs within the conventional FA classes have different effects on human health status and disease risk (Vannice & Rasmussen, 2014). With cognisance of this realisation and with specific reference to PUFAs, the considerable proportions of LA (5.53 ± 0.243 mg/g meat) and ALA (2.42 ± 0.149 mg/g meat) in the fallow deer muscles (Table 5.2) can be considered beneficial as these essential FAs cannot by synthesised by humans, play prominent roles in different organs and can be saturated and elongated in the human body to form a series of long-chain FA products (i.e. AA, EPA and DHA) (FAO/WHO, 2010). Arachidonic acid, which was the fourth most abundant FA in the fallow deer muscles (3.63 ± 0.171 mg/g meat; Table 5.2), is the most important of the n-6 FAs as it is the primary precursor for health-promoting n-6 derived eicosanoids (FAO/WHO, 2010).

Moreover, it is well established that the consumption of n-3 FAs, particularly EPA and DHA, holds numerous health benefits, including promoting normal growth and development, reducing inflammation and protecting against heart- and degenerative-diseases (FAO/WHO, 2010; Simopoulos, 2008). A daily minimum intake of 0.25 g DHA plus EPA has been advised for adults to prevent deficiencies (FAO/WHO, 2010), although slightly higher daily combined levels of 0.3–0.4 g per day have been recommended by Simopoulos (1989). From the values in Table 5.2, it can be calculated that a 100-g portion of fallow deer meat could contribute *ca*. 67% of the aforementioned daily minimum requirement. In addition, given the mean total n-3 PUFA value for the fallow deer muscles (4.10 ± 0.265 mg/g meat) (Table 5.2), these could be considered to be 'very high in omega-3 fatty acids' since a 100-g raw portion could meet the stipulations for this parameter (> 300 mg/serving) in the South African food labelling regulations (DoH, 2010). With respect to the n-6 FAs, while these indeed have specific vital modulatory functions in the human body, excessive consumption and high ratios of n-6/n-3 in the diet may promote the pathogenesis of several diseases (FAO/WHO, 2010; Simopoulos, 2008). An n-6/n-3 ratio of less than 4.0 has been recommended to be optimal for human health (COMA, 1994; Simopoulos, 2004). Although the usefulness of the aforementioned ratio has more recently been challenged (Griffin, 2008; Harris, 2006; Stanley et al., 2007), it is noteworthy that the n-6/n-3 ratios in the fallow deer muscle (2.38) (Table 5.2) is well below the previously recommended level of 4.0. Nonetheless, compared to the aforementioned ratio in fallow deer muscle, higher n-6/n-3 ratios have been reported in the LTL of roe deer buck (2.99; Razmaitė et al., 2015) and pasture-fed fallow deer buck in Italy (3.3; Volpelli et al., 2003), whereas lower ratios have been found in the LTL of pasture-fed beef cattle (1.95; Rule et al., 2002).

5.3.3. Mineral composition

The mineral composition of the fallow deer LTL and BF muscles is presented in Table 5.6. Since no significant interactions were observed between the main effects (muscle and gender), the two main effects are discussed separately.

Muscle tissue, particularly red meat, is regarded as an important source of essential macro-minerals, containing high levels of K and P, moderate levels of Na and Mg, but relatively low levels of Ca (Keeton et al., 2014; Ortega-Barrales & Fernández-de Córdova, 2015). It further represents a valuable source of essential micro-minerals (e.g. Fe, Cu, Zn, Co, Mn, Se, Mo), many of which are exclusively present in muscle tissue or have higher bioavailability compared with those in plant tissues (Ortega-Barrales & Fernández-de Córdova, 2015).

As anticipated, the predominant macro-minerals determined in the two fallow deer muscles in this study, in descending order of concentration, were K (3.622–3.743 g/kg meat), P (2.246–2.302 g/kg meat), Na (0.433–0.435 g/kg meat) and Mg (0.259–0.273 g/kg meat), with lower levels of Ca (0.035–0.037 g/kg meat) (Table 5.6). The levels of K, P and Mg in the fallow deer muscles are higher than those previously summarised by Ortega-Barrales and Fernández-de Córdova (2015) for beef, lamb and chicken, while the present Na and Ca levels are lower than those reported for the aforementioned domestic livestock species. Compared with indigenous African antelope, the levels of K, P and Mg in the fallow deer muscles are also higher than those determined in the muscles of male blesbok (Smit, 2004), springbok (Kroucamp, 2004), black wildebeest (*Connochaetes gnou*; Van Schalkwyk, 2004) and mountain reedbuck (*Redunca fulvorufula*; Van Schalkwyk, 2004).

The primary essential micro-minerals measured in the fallow deer muscles were Fe (38.294–43.196 mg/kg meat) and Zn (14.955–20.844 mg/kg meat), followed by Cu (1.942–2.014 mg/kg meat) and lower levels (<1.0 mg/kg meat) of Mn, Se and Co (Table 5.6). The latter Fe and Cu concentrations are also higher than those previously reported for beef, pork and chicken (Ortega-Barrales & Fernández-de Córdova, 2015). The minerals detected in the fallow deer muscles that have undefined functions or can represent environmental contaminants included silicon (Si; 5.506–6.233 mg/kg meat) and aluminium (Al; 3.170–5.763 mg/kg meat), as well as lower levels of lead (Pb; 0.009–0.044 mg/kg meat) (Table 5.6).

The mineral composition of muscle tissue is known to be influenced by both intrinsic and extrinsic factors (Doyle, 1980), however, this can also vary at different anatomical locations of the body (Zarkadas et al., 1987). The latter variations can be attributed to differences in muscle fibre type, muscle activity levels, as well as to the various biological functions of minerals within the muscles (Knochel & Cronin, 1984; Raiymbek, Faye, Serikbaeva, Konuspayeva, & Kadim, 2013). In this study, the concentrations of seven of the 17 detected minerals were found to be significantly influenced by muscle (Table 5.6). The BF contained significantly higher concentrations of the macro-minerals Mg, P and K compared with the LTL, while the LTL contained higher concentrations of Ca. Of the aforementioned minerals, Ca and K are known to be directly involved in the contraction of living muscles, while Ca and Mg play a role in post-mortem muscle fibre contraction (Keeton et al., 2014). The differences in the levels of these minerals in the two muscles could perhaps be related to differences in their contractile processes, as well as in their muscle fibre type composition.

Table 5.6 Mean (± standard error) mineral composition (mg/kg meat) of fallow deer (n = 12) *longissimus thoracis et lumborum* and *biceps femoris*, as influenced by muscle (total group) and gender (male and female).

Mineral (mg/kg meat)	Total group[†] (n = 12)		p - value	Gender[#] Male (n = 6)		Female (n = 6)		p - value
	LTL	BF	Muscle	LTL	BF	LTL	BF	Gender
Aluminium (Al) [1]	**5.763 ± 0.379**	**3.170 ± 0.55**	**0.0033**	5.516 ± 0.585	2.696 ± 0.913	6.010 ± 0.514	3.644 ± 0.623	0.3111
Antimony (Sb) [1]	---	---		---	---	---	---	
Arsenic (As) [1]	---	---		---	---	---	---	
Barium (Ba) [2]	0.014 ± 0.002	0.010 ± 0.001	0.0727	0.018 ± 0.003	0.010 ± 0.002	0.011 ± 0.002	0.009 ± 0.001	0.1048
Boron (B) [1]	---	---		---	---	---	---	
Cadmium (Cd) [2]	---	---		---	---	---	---	
Calcium (Ca) [3]	**37.143 ± 0.720**	**34.810 ± 0.656**	**0.0168**	36.809 ± 1.190	34.793 ± 1.109	37.478 ± 0.905	34.826 ± 0.817	0.7733
Chromium (Cr) [2]	0.058 ± 0.019	0.071 ± 0.028	0.7038	0.037 ± 0.015	0.104 ± 0.053	0.078 ± 0.034	0.037 ± 0.016	0.7043
Cobalt (Co) [4]	0.003 ± 0.001	0.002 ± 0.000	0.3357	0.004 ± 0.002	0.001 ± 0.001	0.002 ± 0.000	0.002 ± 0.001	0.4963
Copper (Cu) [4]	1.942 ± 0.071	2.014 ± 0.055	0.1181	1.944 ± 0.132	2.008 ± 0.089	1.939 ± 0.069	2.020 ± 0.074	0.9762
Iron (Fe) [4]	**43.196 ± 1.954**	**38.294 ± 1.352**	**0.0023**	**38.414^{ab} ± 1.811**	**34.788^{a} ± 1.045**	**47.978^{c} ± 2.093**	**41.800^{b} ± 1.426**	**0.0019**
Lead (Pb) [1]	0.044 ± 0.029	0.009 ± 0.006	0.3958	0.011 ± 0.004	0.014 ± 0.011	0.020 ± 0.011	0.003 ± 0.003	0.3729
Magnesium (Mg) [3]	**259.402 ± 1.353**	**272.992 ± 2.072**	**0.0001**	256.985 ± 1.758	271.213 ± 2.261	261.818 ± 1.621	274.771 ± 3.536	0.1609
Manganese (Mn) [4]	0.201 ± 0.008	0.218 ± 0.008	0.0618	0.202 ± 0.012	0.203 ± 0.008	0.200 ± 0.013	0.233 ± 0.010	0.3038
Mercury (Hg) [1]	---	---		---	---	---	---	
Molybdenum (Mo) [4]	---	---		---	---	---	---	
Nickel (Ni) [1]	---	---		---	---	---	---	
Phosphorus (P) [3]	**2245.846 ± 18.126**	**2301.909 ± 20.857**	**0.0208**	2256.688 ± 26.579	2313.660 ± 26.152	2235.003 ± 26.308	2290.158 ± 34.278	0.5307
Potassium (K) [3]	**3622.478 ± 33.775**	**3743.060 ± 50.492**	**0.0004**	**3670.861^{a} ± 34.042**	**3852.473^{b} ± 45.258**	**3574.096^{a} ± 54.076**	**3633.647^{a} ± 66.186**	**0.0446**
Selenium (Se) [4]	0.146 ± 0.007	0.139 ± 0.007	0.3232	**0.139^{ab} ± 0.011**	**0.122^{a} ± 0.004**	**0.153^{b} ± 0.007**	**0.155^{b} ± 0.008**	**0.0208**
Silicon (Si) [1]	6.233 ± 0.316	5.506 ± 0.345	0.1599	6.522 ± 0.507	5.686 ± 0.669	5.944 ± 0.388	5.325 ± 0.254	0.3500
Sodium (Na) [3]	435.319 ± 8.105	432.910 ± 9.621	0.7496	419.832 ± 11.758	426.394 ± 16.299	450.806 ± 7.408	439.427 ± 11.165	0.1841
Strontium (Sr) [2]	0.019 ± 0.003	0.014 ± 0.002	0.2003	**0.024 ± 0.005**	**0.017 ± 0.004**	**0.014 ± 0.003**	**0.013 ± 0.002**	0.0586
Titanium (Ti) [1]	---	---		---	---	---	---	
Vanadium (V) [1]	---	---		---	---	---	---	
Zinc (Zn) [4]	**20.844 ± 0.630**	**14.955 ± 0.499**	**0.0000**	21.700 ± 0.843	14.521 ± 0.481	19.988 ± 0.862	15.390 ± 0.888	0.6644

Abbreviations: LTL = *Longissimus et thoracis lumborum;* BF = *Biceps femoris.*
[†] Total group: bold text across rows indicates significant differences between muscles.
[#] Gender: different superscripts across individual row indicate significant ($p < 0.05$) differences between males and females.
[1] Minerals with undefined functions or environmental contaminations; [2] Non-essential micro-minerals; [3] Essential macro-minerals; [4] Essential micro-minerals.
Dashed lines = not detected

Although the fallow deer LTL is reported to comprise mostly type II muscle fibres (Curry et al., 2012), attributing the aforementioned differences to variations in muscle fibre composition is complicated by a lack of data on the histochemical properties of the fallow deer BF. As previously mentioned, Beecher et al. (1965) found that the BF of pigs was composed of distinct “red” (inside) and “white” (outside) portions, however, it is not currently known if the same pattern exists in the fallow deer BF. While red muscle fibres are considered to contain higher concentrations of Ca than white muscle fibres (Pearson & Young, 2012), Du Buisson (2006) similarly reported higher mean Ca concentrations in the LTL of blesbok compared with the BF. Phosphorus, on the other hand, forms an important constituent of adenosine triphosphate (ATP) and creatine phosphate (CP) in the muscles, with both of the latter compounds being expected to occur at higher concentrations in white muscle (Pearson & Young, 2012). The levels of K have also been reported to be higher in the white muscle of pigs relative to red muscle (Beecher, Kastenschmidt, Cassen, Hoekstra, & Briskey, 1968). The LTL was further found to contain higher concentrations of the essential micro-minerals Fe and Zn, as well as the potential contaminant Al, relative to the BF. The Fe content is generally anticipated to be higher in muscles with more red muscle fibre and thus a higher myoglobin content (Lawrie & Ledward, 2006). Moreover, Zn is thought to occur at higher levels in muscles that are used more actively during movement (Doornenbal & Murray, 1982).

Ortega-Barrales and Fernández-de Córdova (2015) suggested that gender does not represent a determining factor in the levels of macro-minerals in meat products. Indeed, K was found to be the only macro-mineral that differed with gender, being significantly higher in the BF of the males (3852.473 mg/kg meat) than the females (3633.647 mg/kg meat) (Table 5.6). Of the essential micro-minerals, the concentrations of Se were higher in the BF of the females (0.155 mg/kg meat) than the males (0.122 mg/kg meat), whereas the concentrations of Fe were higher in both the female LTL (47.978 mg/kg meat) and BF (41.800 mg/kg meat) relative to the male LTL (38.414 mg/kg meat) and BF (34.788 mg/kg meat) (Table 5.6). The differences in the K and Fe content could potentially have been related to differences in the ages of the male and female fallow deer. The concentrations of K in muscle tissue are known to decrease with increasing age, while those of Fe are reported to increase with increasing age (Doornenbal & Murray, 1982; Kotula & Lusby, 1982). As previously mentioned, high hunting pressure was observed to have reduced the number of large fallow deer buck in the study area during harvesting. This could have meant that the harvested females were somewhat older than the males, potentially explaining the lower K and higher Fe contents of the female muscles.

In order to better relate the current mineral values to human health, Table 5.7 compares the levels of selected elements in the fallow deer muscles with the relevant recommended dietary allowance (RDA) or adequate intake (AI) values, or with the maximum intake levels in the case of potential contaminants. From this comparison, it appears that the greatest contribution that a 100-g portion of fallow deer meat could make in meeting the RDA or AI requirements would be through the supply of P, Fe, Cu and Zn, and to a lesser extent via the supply of K and Mg.

Table 5.7 Mean (mg/kg ± standard error) mineral levels found in fallow deer (n = 12) *longissimus thoracis et lumborum* and *biceps femoris* muscles compared with relevant dietary recommendations or maximum intake levels.

Essential macro- and micro-minerals

Element	LTL (mg/kg meat)	BF (mg/kg meat)	RDA/AI (i) (mg/day)	RDA/AI met by 100 g LTL	RDA/AI met by 100 g BF
Calcium (Ca)	37.143 ± 0.720	34.810 ± 0.656	1000–1200	0.31–0.37%	0.29–0.35%
Copper (Cu)	1.942 ± 0.071	2.014 ± 0.055	0.9	21.6%	22.4%
Iron (Fe)	43.196 ± 1.954	38.294 ± 1.352	8–18	24–54%	21.3–47.9%
Magnesium (Mg)	259.402 ± 1.353	272.992 ± 2.072	310–400	6.5–8.4%	6.8–8.8%
Manganese (Mn)	0.201 ± 0.008	0.218 ± 0.008	1.8–2.3	0.9–1.1%	0.9–1.1%
Potassium (K)	3622.478 ± 33.775	3743.060 ± 50.492	4700	7.7%	8.0%
Phosphorus (P)	2245.846 ± 18.126	2301.909 ± 20.857	700	32.1%	32.9%
Sodium (Na)	435.319 ± 8.105	432.910 ± 9.621	1500	2.9%	2.9%
Zinc (Zn)	20.844 ± 0.630	14.955 ± 0.499	8–11	18.9–26.1%	13.6–18.7%

Minerals with undefined functions or environmental contaminants

Element	LTL (mg/kg meat)	BF (mg/kg meat)	Maximum level
Aluminium (Al)	5.763 ± 0.379	3.170 ± 0.55	1 mg/kg bw/week (TWI) (i)
Lead (Pb)	0.044 ± 0.029	0.009 ± 0.006	0.1 mg/kg (in meat) (ii)
Silicon (Si)	6.233 ± 0.316	5.506 ± 0.345	ND (iii)

Abbreviations: LTL = *Longissimus et thoracis lumborum;* BF = *Biceps femoris*; RDA = Recommended dietary allowance; AI = adequate intake; ND = Not determined; bw = body weight

(i) EFSA, 2008.

(ii) CEC, 2006.

(iii) Otten, Hellwig, & Meyers, 2006.

In terms of the potential contaminants in the meat, it is clear that the levels of lead measured in the fallow deer LTL (0.044 mg/kg meat) and BF (0.009 mg/kg meat) were well below the maximum levels specified for this element in meat (0.1 mg/kg) according to European Union regulations (CEC, 2006). With respect to aluminium, the European Food Safety Authority (EFSA) has set a tolerable weekly intake (TWI) for this element of 1 mg/kg body weight/week (EFSA, 2008), which would equate to *ca*. 70 mg per week for a 70-kg individual. Although the levels of Al measured in the fallow deer LTL (5.763 mg/kg) and BF (3.170 mg/kg) were relatively high compared to other potential contaminants (Table 5.7), similar or higher levels (5–10 mg/kg) have been determined in bakery products, some vegetables, seafood, dairy products, processed meats, tea leaves, herbs, spices and cocoa products (EFSA, 2008). While there is currently insufficient data to establish an upper limit for Si, no evidence exists to suggest that the levels naturally occurring in foods present adverse effects on human health (Otten, Hellwig, & Meyers, 2006) and thus the Si levels are likely to be of limited concern in fallow deer meat.

5.4. CONCLUSIONS

This study is the first to evaluate the chemical composition and nutritional value of the meat from wild fallow deer harvested in South Africa, the results of which will prove important for food product labelling, consumer education and the marketing of such products. The current data will also be valuable for those involved in the further processing of the meat, since the composition is recognised to affect an array of product qualities, including colour, flavour, juiciness, structure and oxidative stability. Although some compositional differences were evident between muscles and to a lesser extent genders (summarised in Table 5.8), comparison of the present results with relevant dietary guidelines and data for alternative species indicates that fallow deer meat can be considered as a protein-dense foodstuff, with a low lipid content and favourable fatty acid and mineral composition. All indications are thus that fallow deer could serve as a healthy meat source and contribute meaningfully to food security in South Africa, especially given that most of the fallow deer harvested in the country are surplus animals. Nonetheless, while this research has generated baseline data on the meat composition of South African fallow deer, further work may be required to assess the potential effects of extrinsic factors (i.e. season, diet, slaughter age) on the evaluated chemical properties.

Table 5.8 Summary of the two main effects (muscle and gender) and their interaction (muscle×gender) on the individual chemical components of fallow deer meat.

		Muscle	Gender
Proximate components			
Moisture	(g/100g meat)	Significant effect: Highest in SS, IS, ST; Lowest in SM, LTL	No significant effect
Protein	(g/100g meat)	Significant effect: Highest in SM, LTL; Lowest in SS, ST	No significant effect
Lipid	(g/100g meat)	Significant effect: Highest in BF and SM; Lowest in IS	No significant effect
Ash	(g/100g meat)	Significant effect: Highest in ST; Lowest in LTL and BF	No significant effect
Fatty acids			
SFA	(mg/g meat)	Significant muscle×gender interaction	Significant muscle×gender interaction
MUFA	(mg/g meat)	No significant effect	Significant effect (female>male)
PUFA	(mg/g meat)	Significant effect (BF>LTL)	No significant effect
n-6 PUFA	(mg/g meat)	Significant effect (BF>LTL)	No significant effect
n-3 PUFA	(mg/g meat)	Significant effect (BF>LTL)	Significant effect (male>female)
PUFA:SFA		Significant effect (BF>LTL)	No significant effect
n-6:n-3		Significant muscle×gender interaction	Significant effect (female>male)
Minerals	(mg/kg meat)	Significant effect (LTL>BF): Al, Ca, Fe, Zn Significant effect (BF>LTL): Mg, P, K No significant effect: Ba, Cr, Co, Cu, Pb, Mn, Se, Si, Na, Sr	Significant effect for LTL: Fe (female>male) Significant effect for BF: K (male>female); Fe, Se (female>male) No significant effect: Al, Ba, Ca, Cr, Co, Cu, Pb, Mg, Mn, P, Si, Na, Sr, Zn

Abbreviations: LTL = *Longissimus et thoracis lumborum;* BF = *Biceps femoris*; SM = *Semimembranosus*; ST = *Semitendinosus*; IS = *Infraspinatus*; SS = *Supraspinatus*; SFA = total saturated fatty acids; MUFA = total monounsaturated fatty acids; PUFA = total polyunsaturated fatty acids; n-6 PUFA = total omega-6 polyunsaturated fatty acids; n-3 PUFA = total omega-3 polyunsaturated fatty acids; PUFA:SFA = polyunsaturated to saturated fatty acid ratio; n-6:n-3 = omega-6 to omega-3 polyunsaturated fatty acid ratio.

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CHAPTER 6

GENERAL DISCUSSION AND CONCLUSIONS

Humankind currently faces a momentous challenge at the nexus of food security and sustainable development, as it becomes increasingly clear that our demand for food may indeed be at odds with the ability of the planet to supply it (Hanson, 2013). This challenge is particularly pronounced in Africa, where both human populations and animal protein demands are forecast to double by 2050 (Rosegrant & Thornton, 2008; UNPD, 2011). The future situation will almost certainly be exacerbated by global warming, land limitations and resource shortages. The uncertainty, however, lies in whether a mere handful of domesticated species will be able to meet the protein requirements of this growing population. Although the need to better utilise alternative species is widely realised, the meat from these species generally remains grossly undervalued, partly as a result of inadequate information and perceptions that this is of a poorer quality and nutritional value in relation to domestic livestock (Cawthorn & Hoffman, 2014).

This study focused on one such alternative species – the wild fallow deer (*Dama dama*) in South Africa – which although abundant in the country, has largely been overlooked as a potential meat source and contributor to local food security. The outcomes of the study, however, indicate that these fallow deer could represent efficient meat producers and deliver products with many of the features that are important to modern consumers. For one, South African fallow deer differ from deer farmed in many other parts of the world, as they are free-roaming and mostly unaffected by human interventions. Accordingly, their meat can prospectively be promoted as “free-range” and “natural”. The results of the current work show that South African fallow deer, particularly males, can deliver dress-out percentages that parallel or surpass those of other African antelope and domestic livestock. Edible meat appears to comprise 58–60% of the cold carcass weights of local fallow deer, with bone-to-meat ratios of 2.2–2.3 being found. However, given that some of the animals in this study were potentially sub-adult, the aforementioned values could well be higher in more mature animals. Edible offal (excluding stomach and intestines) made up approximately 9% of the fallow deer live weights. Since game offal constitutes a part of the traditional diet of South Africans, fallow deer offal could provide an affordable and nutritious supplementary food source for an established market, provided that adequate food safety controls are in place.

The present results suggest that the physical meat quality of local fallow deer compares favourably with that of other commonly consumed indigenous antelope and domestic livestock. Nevertheless, the physical quality parameters (drip loss, cooking loss, shear force and colour) appear to vary considerably with individual muscle, and to lesser extent with gender. The former variations need to be taken into account by the meat industry when determining which muscles should be marketed as prime cuts and which are more suitable for further processing. Three of the six fallow deer muscles evaluated had shear force values falling within the range considered to be indicative of tender beef (40–45 N), while drip loss values in all of the muscles were lower than those found in some other deer and antelope species. Overall, the *longissimus thoracis et lumborum* (LTL) stood out as the muscle with the lowest shear force value (most tender), having of the lowest drip and cooking loss values and, like all the muscles evaluated, having colour characteristics that are reportedly desirable to venison consumers ($L^* < 40$, $a^* \geq 12$, low b^* values).

The meat from South African fallow deer generally appears to have a high protein (20.4–23.1%) and relatively low lipid (2.2–3.2%) content. While the aforementioned lipid content is slightly higher than those reported for several indigenous antelope and fallow deer abroad, this may well indicate that local fallow deer meat could represent a comparatively more tender and juicy product. It should simultaneously be noted that the lipid content of meat is known to be highly variable and influenced by both intrinsic and extrinsic factors. Since the current lipid determinations were conducted on a limited number of animals from a single region and season (winter), further research using larger sample sizes from different regions and seasons could provide a more representative and accurate depiction of the variations in lipid levels in these deer throughout the country. Although influenced by muscle and to a lesser extent by gender, this lipid content was found to be predominantly comprised of polyunsaturated fatty acids (PUFAs), followed by saturated fatty acids (SFAs) and monounsaturated fatty acids (MUFAs). These proportions were also reflected in the favourable PUFA/SFA ratio in fallow deer meat (> 0.4), which can be regarded as beneficial to human health given the current nutritional advice to reduce dietary SFAs and increase PUFAs. In conjunction with the favourable omega-6/omega-3 ratio (< 4), relatively high content of essential linoleic and α-linolenic acids, and valuable contribution of long-chain PUFAs, South African fallow deer meat can be regarded as a healthy lipid source. In addition, the concentrations of potassium, iron, copper and zinc in the fallow deer meat appear to contribute notably to the human recommended dietary requirements.

Concluding remarks and recommendations

All indications are that fallow deer from South Africa could serve as a good-quality, healthy meat source and contribute meaningfully to food security and economic stability in the country, especially given that most of the fallow deer harvested in the country are surplus animals. Moreover, the products of these animals could satisfy multiple income classes through the provision of prime cuts, sub-optimal cuts for processed products, as well as affordable offal. While this study has generated baseline data on the yields, physical meat quality and nutritional composition of South African fallow deer, cognisance is taken of a number of limitations in the current work, thus underpinning the requirement for further research. Firstly, and as previously eluded to, the yields and meat quality attributes can be influenced by a broad array of factors. It may thus be of value to replicate the current study on a larger sample size of animals, while additionally taking into account the influence of production region, season, diet and slaughter age. Moreover, in order to fully appreciate the acceptability of the meat among locals, sensory analyses with trained and consumer panels would likely prove beneficial. With respect to the considerable variation seen among the different muscles in terms of their chemical composition, in-depth studies on the fibre types comprising these muscles may provide a better understanding on such variations. Lastly, the safety of the meat and by-products would also need to be evaluated, especially in terms of their microbial load. Nevertheless, there is no reason to expect that fallow deer meat would differ from that of other antelope species in terms of its susceptibility to microbial contamination, if harvested humanely and handled under hygienic conditions.

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