Factors influencing the flavour of the meat derived from South African game species

by

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Declaration

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Abstract

In South Africa, wild and free-living animal species that are dependent on the natural vegetation present in their habitat as food source, are referred to as 'game species'. Game species are utilised for live animal sales, trophy hunting, non-trophy recreational hunting and game meat production. The latter is of economic importance, as the export of game meat is a very lucrative industry for South Africa. However, only small quantities of fresh game meat is sold locally in South Africa, which is attributable to a lack of scientific information on the chemical composition and sensory quality of game meat that is required to enable proper marketing of game meat products.

Game meat is derived from female and male animals of various species, located throughout southern Africa. However, differences in the dietary regimes of game species between farm locations, in addition to species and gender differences could influence the composition and sensory quality of game meat. Differences in the fatty acid content and volatile compound profile could influence the aroma and flavour of meat, yet no research exists that has established the volatile compound profile of South African game meat.

The volatile compound profile of the *longissimus thoracis et lumborum* muscle of commonly consumed game species (springbok, *Antidorcas marsupialis*; blesbok, *Damaliscus pygargus phillipsi*; gemsbok, *Oryx gazella*; impala, *Aepyceros melampus*; red hartebeest, *Alcelaphus caama*; and kudu, *Tragelaphus strepsiceros*) from various farm locations was mainly lipid-derived, containing compounds such as aldehydes, alcohols and 2-pentylfuran. Farm location and gender had a significant influence on the fatty acid content and volatile compound profile of springbok and blesbok meat. Furthermore, the fatty acid content and volatile compound profile of game meat differed significantly between the six species, while gender differences were more species-specific.

Descriptive sensory analysis was used to establish the sensory profile of game meat in this study. The latter, in addition to physical measurements (thaw and cooking loss percentage, ultimate pH and Warner-Bratzler shear force) and the proximate composition (moisture, protein, intramuscular lipid and ash) were used to establish the sensory quality of game meat derived from different farm locations, species and genders. Farm location had a significant influence on the sensory quality of springbok meat, while this was not evident for blesbok meat. Selected physical, proximate and sensory attributes differed significantly between the six game species, however, when conducting multivariate analyses using all of the sensory attributes as variables it is clear that springbok meat illustrated a prominent gamey sensory profile and thus associated with a different set of sensory attributes than the other five game species. This study also indicated that gender differences in the sensory quality of game meat are more species-specific.

It is therefore recommended that the meat industry should take farm location (for springbok and not blesbok) and species into account during the marketing of game meat. As the influence of gender on the sensory profile of the game meat from the selected species in this study was of minor importance, it is recommended that this factor not be considered during the marketing of game meat derived from these six game species. However, the magnitude of the influence of species and gender on the sensory quality of game meat could change when other factors such as season and farm location come into play.

Opsomming

In Suid-Afrika word die spesies wat wild, vrylopend en afhanklik van die natuurlike plantegroei in hulle habitat as voedselbron is, verwys na as 'wild'. Wild word benut vir lewendige verkope, trofeejag, jag vir plesier (biltongjagter) en wildsvleisproduksie. Laasgenoemde is van groot ekonomiese waarde, aangesien die uitvoer van wildsvleis 'n baie winsgewende industrie is in Suid-Afrika. Ongelukkig, as gevolg van 'n tekort aan wetenskaplike inligting oor die chemiese samestelling en die sensoriese kwaliteit van wildsvleis, is vars wildsvleis nie so geredelik beskikbaar in Suid-Afrika nie; wat die bemarking daarvan negatief beïnvloed.

Vroulike en manlike diere vanaf verskeie spesies en van regoor suider Afrika word benut vir wildvleisproduksie. Die samestelling en sensoriese kwaliteit van vleis kan beïnvloed word deur verskille in die dieet van wildspesies tussen plase, asook deur verskille tussen spesies en geslagte. Verder kan die aroma en geur van vleis beïnvloed word deur die vetsuurinhoud en vlugtige komponente profiel. Ongelukkig bestaan daar geen navorsing wat al die vlugtige komponente profiel van Suid-Afrikaanse wildsvleis vasgestel het nie.

Die vlugtige komponente profiel van die *longissimus thoracis et lumborum* spier vanaf verskeie algemeen benutte wildspesies (springbok, *Antidorcas marsupialis*; blesbok, *Damaliscus pygargus phillipsi*; gemsbok, *Oryx gazella*; rooibok, *Aepyceros melampus*; rooihartebees, *Alcelaphus caama*; en koedoe, *Tragelaphus strepsiceros*) geoes van verskeie plaasliggings, was hoofsaaklik afgelei van lipiede en het komponente soos aldehiede, alkohole en 2-pentielfuraan bevat. Die vetsuurinhoud en vlugtige komponente profiel van springbok- en blesbokvleis was betekenisvol beïnvloed deur plaasligging en geslag. Verder het die vetsuurinhoud en vlugtige komponente profiel van wildsvleis betekenisvol verskil tussen die ses spesies, maar die invloed van geslag op laasgenoemde was spesies-spesifiek.

Die sensoriese profiel van wildsvleis is bepaal deur 'n beskrywende sensoriese analitiese metode. Die algehele sensoriese kwaliteit van wildsvleis is bepaal deur die sensoriese profiel, fisiese kwaliteit (ontdooi- en kookverlies persentasie, finale pH en Warner-Bratzler instrumentele taaiheid) en die benaderde chemiese samestelling (vog, proteïen, intramuskulêre lipiede en as) vas te stel. Die sensoriese kwaliteit van springbokvleis is betekenisvol beïnvloed deur plaasligging, maar laasgenoemde faktor het nie 'n betekenisvolle invloed op blesbokvleis gehad nie. Verskeie fisiese kwaliteit-, benaderde chemiese samestelling en sensoriese eienskappe was betekenisvol verskillend tussen die vleis verkry vanaf die ses wildspesies. Die gebruik van meerveranderlike analises, met alle sensoriese eienskappe ingesluit as veranderlikes, het getoon dat springbokvleis 'n prominente 'wilde' sensoriese profiel het en dus geassosieer was met 'n ander stel sensoriese eienskappe, in vergelyking met die vyf ander wildspesies. Die invloed van geslag op die sensoriese kwaliteit van wildsvleis vanaf die ses wildspesies was ook meer spesies-spesifiek.

Die vleisindustrie word dus aangeraai om plaasligging (vir springbok, maar nie vir blesbok nie) en spesie in ag te neem met die bemarking van wildsvleis. Verder was die invloed van geslag op die sensoriese profiel van wildsvleis minimaal en word daar aangeraai dat geslag nie in ag geneem word met die bemarking van wildsvleis soos verkry vanaf die ses wildspesies nie; alhoewel die invloed van spesie en geslag op die sensoriese kwaliteit van wildsvleis kan verander indien ander faktore soos bv. seisoen en plaasligging in ag geneem word.

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"A good deed is never lost; he who sows courtesy reaps friendship, and he who plants kindness gathers love." – *Saint Basil*

Notes

This thesis is presented in the format prescribed by the Department of Food Science, Stellenbosch University. The structure is in the form of one or more research chapters (papers prepared for publication) and is prefaced by an introduction chapter with the study objectives, followed by a literature review chapter and culminating with a chapter for elaborating a general discussion and conclusions. Language, style and referencing format used are in accordance with the requirements of the *International Journal of Food Science and Technology*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, therefore, been unavoidable.

Results from this dissertation that have been submitted for publication in the following journal:

- Neethling, J., Hoffman, L.C. & Muller, M. (2016). Factors influencing the flavour of game meat: A review. *Meat Science*, **114**, 139-153.

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Table of Contents

Chapter 1

Introduction

The various game species found in Africa are of great economic and ecological importance, especially in southern Africa (Pollock, 1969). These species are conserved by means of game ranching, tourism and live animal sales (privately or at auctions), in addition to the sustainable utilisation through trophy hunting and hunting for private (biltong hunter) or commercial game meat production (Grobler & Van Der Bank, 1992; Cloete *et al.,* 2015). Game ranching, "the scientific management of many species of wild animals in their natural habitat" (Pollock, 1969), is aimed at building healthy animal populations, as well as conserving and maintaining natural habitats (Bothma, 2002). However, the majority of game species in South Africa are present in fenced-in areas (Grobler & Van Der Bank, 1992). A maximum ecological carrying capacity can therefore be reached, after which the surplus of animals should be removed (Bothma, 2002). These surplus animals are often utilised for private or commercial game meat production. Unfortunately, South Africa does not have a well-established local market for the sale of fresh game meat as only 8% of game meat is sold locally (Cloete *et al.,* 2015). The latter low percentage of sales can be attributed to consumer perceptions of game meat (often negative) and the legislation regulating the slaughtering processes and meat safety, restricting the development of the local game meat market (Cloete *et al.,* 2015). Consequently, game meat produced on a commercial scale has predominantly been exported from South Africa (Hoffman & Wiklund, 2006).

The well-established game meat export industry of South Africa was lost in 2011 due to the outbreak of foot-and-mouth disease, which resulted in a ban on the export of game meat to the European Union (Cloete *et al.,* 2015; Gyton, 2015; Mokhema, 2015). According to Oberem (2015 as cited by Cloete *et al.,* 2015) the international game meat export market is valued at approximately R2.5 billion per annum. Prior to 2011, South Africa exported game meat to the estimated value of R200 – R400 million per annum (Mokhema, 2015; Oberem, 2015 as cited by Cloete *et al.,* 2015). Nonetheless, South Africa has regained its foot-and-mouth disease free status in 2014, although the trade restrictions on game meat are still effective (Cloete *et al.,* 2015). It is estimated that the latter will be removed at the end of 2015 (Cloete *et al.,* 2015) and that South Africa could export five times more game meat in the future (Mokhema, 2015).

Although strict regulations exist for the harvesting[1] procedures of South African game species for meat production destined for export (Van Schalkwyk & Hoffman, 2010; Van Der Merwe, 2012), various game species are harvested from different farm locations and no preference is given towards the selection of male and female animals. Various researchers have established the influence of diet on the chemical composition (especially the fatty acid content) and volatile compound profile of meat (Larick & Turner, 1990; Wood *et al.,* 1999; Young & Baumeister, 1999; Geay *et al.,* 2001; Wiklund *et al.,* 2001; Priolo *et al.,* 2002; Wiklund *et al.,* 2003; Elmore *et al.,* 2004, 2005; Vasta & Priolo, 2006; Phillip *et al.,* 2007; Almela *et al.,* 2010; Resconi *et al.,* 2010; Vasta *et al.,* 2011; Hutchison *et al.,* 2012; Resconi *et al.,* 2012; Tansawat *et al.,* 2013; Watkins *et al.,*

[1]Harvesting refers to the indiscriminate shooting of animal as they are encountered whereas culling refers to the shooting of selected (on basis of age, gender, other characteristics) animals

2013). However, the majority of these studies are focused on the influence of grass vs. grain or concentrate-based diets on the composition of the meat derived from domesticated species (beef, lamb and selected deer species). Moreover, the influence of gender on the composition and sensory quality of the meat derived from selected South African game species have also been established (Hoffman *et al.*, 2005, 2007a, 2007b, 2007c, 2007d; Mostert & Hoffman, 2007; Hoffman *et al.*, 2008, 2009a, 2009b, 2009c; Neethling *et al.*, 2014a, 2014b), however, results are contradicting. These contradictions have been partially explained by the authors postulating that diet could also be responsible for these changes, although it should be borne in mind that the meat is derived from different species and the same factors that are known to influence the quality parameters of different livestock species (e.g. bovine vs. ovine) are also applicable when comparing different game species.

South Africa has a rich variety of game species distributed throughout a wide variety of vegetation types (Hoffman & Wiklund, 2006). These vegetation types are grouped into different biomes, which are regions that are characterised according to their climatic conditions and vegetation characteristics (Mucina & Rutherford, 2006). The majority of South African game ranches are found in the Limpopo Province (49.0%), along with the Northern Cape Province (19.5%) and the Eastern Cape Province (12.3%) (Hoffman, 2007). These provinces contain eight of the nine biomes: Fynbos; Succulent Karoo; Desert; Nama-Karoo; Grassland; Savanna; Albany Thicket; and Forest biome (Indian Ocean Coastal Belt not included) (Mucina & Rutherford, 2006). Game species located on game ranches in different regions or provinces of South Africa will most likely have differences in their dietary regimes, as a result of differences in the naturally occurring vegetation types.

The dietary regimes of game species differ, as they can be selective or generalists in their feeding habits, in addition to being classified as grazers, browsers or mixed feeders (graze and browse) (Liversidge & Van Eck, 1994; Bothma, 2002). The springbok (*Antidorcas marsupialis*) is the most well-known and extensively harvested game species in South Africa and Namibia (Hoffman *et al.*, 2004; Hoffman & McMillin, 2009). Blesbok (*Damaliscus pygargus phillipsi*), impala (*Aepyceros melampus*) and kudu (*Tragelaphus strepsiceros*) are some of the most popular game species for game ranching in South Africa (Cloete *et al.*, 2015). Gemsbok (*Oryx gazella*) and red hartebeest (*Alcelaphus buselaphus caama*) are two of the popular game species harvested and utilised for game meat production in Namibia (Van Schalkwyk *et al.*, 2012). In addition, red hartebeest have an enormous potential for meat production in South Africa (Hoffman *et al.*, 2010).

Springbok are classified as selective, mixed feeding herbivores (Van Zyl, 1965; Hofmann *et al.*, 1995; Bothma *et al.*, 2010a). In addition, the foraging behaviour of springbok is generally seasonal (Van Zyl, 1965; Novellie, 1978), as the quality and quantity of their food sources vary seasonally. Springbok tend to graze during the wet season when grasses are highly digestible and green (Bigalke & Van Hensbergen, 1990), but they prefer forbs, shrubs and leaves from bushes and trees (browsing) during the dry season (Van Zyl, 1965; Bigalke, 1972). Furthermore, springbok feed more selectively during the dry season, as a higher proportion of the day is dedicated to foraging for widely distributed food sources (Novellie, 1978). Blesbok are not found as widely distributed throughout southern Africa as springbok, as the former predominantly occur in the South

West Arid and grassland subregion of the southern Savanna (Meester, 1965). Blesbok are very selective, grazing herbivores, preferring short grass species (Du Plessis, 1972; Bothma *et al.*, 2010b). However, blesbok often lower their plane of selection during the dry season when the quality and quantity of grass species are lower (Novellie, 1978). The variation in the rainfall patterns and vegetation types throughout the regions of southern Africa (Mucina & Rutherford, 2006; Kruger, 2007; Hanks, 2009) will therefore most likely result in variations in the 'seasonality' of the forage selection by springbok and blesbok, as the quality and quantity of the vegetation types preferred by these two species will differ between regions (Bigalke, 1972; Liversidge, 1972). Similar to springbok, impala are classified as selective, mixed feeding herbivores (Monro, 1980; Bothma, 2002; Wronski, 2003; De Garine-Wichatitsky *et al.*, 2004). This species prefers grazing when grasses are green and palatable as after rainfall, while mainly browsing edible herbs and shrubs in the dry season (Young, 1972; Rodgers, 1976; Monro, 1980). In addition, impala tend to concentrate in the areas that are rich in *Acacia* savanna, especially during the dry season (Monro, 1980). Gemsbok and red hartebeest are classified as mixed feeders, with approximately 75% of their diets consisting of grazing and 25% of browsing (Van Zyl, 1965; Bothma, 2002; Cerling *et al.*, 2003; Bothma *et al.*, 2010a). Unfortunately little is known about the seasonality of the diets of gemsbok and red hartebeest. Kudu are classified as selective, browsing herbivores (Bothma, 2002; De Garine-Wichatitsky *et al.*, 2004; Bothma *et al.*, 2010a). The browsing strategies of kudu change between the wet and dry seasons, as this species will feed less selectively during the wet season, while more selectively during the dry season (Simpson, 1972; Owen-Smith, 1994; De Garine-Wichatitsky *et al.*, 2004).

Internationally, significant differences have been found in the sensory quality of the meat derived from different species (Rødbotten *et al.*, 2004; Rincker *et al.*, 2006; Bureš *et al.*, 2014), however, research on the influence of species, especially South African game species, on the sensory quality of game meat is lacking. Hoffman *et al.* (2009b) found that game derived from two well-known South African game species, impala and kudu, had distinct fatty acid and sensory profiles (aroma, flavour and texture attributes). Consequently, these authors suggested that impala and kudu meat are unique in their overall aroma and flavour and should be marketed as such (Hoffman *et al.*, 2009b). Marketing game meat according to species-specific flavour profiles could definitely enhance export, but also the sale of game meat within South Africa, thereby expanding the South African game industry.

The aim of this study was therefore to establish whether farm location (indirectly the dietary regime), gender and species had a significant influence on the chemical composition and sensory quality, i.e. the aroma, flavour, taste and texture profile of the meat derived from well-known and readily consumed South African game species. This knowledge will allow the game meat industry to take cognisance on whether the above-mentioned factors should be taken into account when harvesting game species for meat production purposes. In addition, the results will also influence the marketing of game meat, as more information on the sensory quality of selected game species will be available.

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Chapter 2

Literature review:

Factors influencing the flavour of game meat: A review[2]

Abstract

Flavour is a very important attribute contributing to the sensory quality of meat and meat products. Although the sensory quality of meat includes orthonasal and retronasal aroma, taste, as well as appearance, juiciness and other textural attributes, the focus of this review is primarily on flavour. The influence of species, age, gender, muscle anatomical location, diet, harvesting conditions, ageing of meat, packaging and storage, as well as cooking method on the flavour of game meat are discussed. Very little research is available on the factors influencing the flavour of the meat derived from wild and free-living game species. The aim of this literature review is thus to discuss the key ante- and post-mortem factors that influence the flavour of game meat, with specific focus on wild and free-living South African game species.

Keywords: Game meat; Fatty acids; Volatile compounds; Grass fed; Browse

2.1 Introduction

The meat industry is capable of producing meat products derived from domestic species that is consistent in meat quality, especially with regard to meat appearance, nutrition, safety and overall sensory quality (Troy & Kerry, 2010). This is, however, not as easy to achieve with the production of game meat and game meat products (Kritzinger *et al.*, 2003), as there is very little control of the key ante-mortem factors, as well as the slaughter processes known to influence game meat quality (Table 2.1). Although few of these have been researched, standard operating procedures (SOPs) for the commercial harvesting of game species have been compiled (Van Schalkwyk & Hoffman, 2010).

Factors that determine the overall quality of meat includes its microbiological safety, ethical production practices (animal welfare), in addition to healthiness (intramuscular lipid content and composition) and the sensory profile (aroma, flavour, taste and overall eating quality) (Wood *et al.*, 1999; Barendse, 2014). Sensory or eating quality of meat initially includes the appearance (raw and cooked), followed by the cooked attributes such as texture/tenderness, juiciness, orthonasal and retronasal aroma, as well as taste and flavour. Retronasal aroma refers to the sensation experienced when food is consumed, whereby molecules travel from the mouth area to the nasal cavity, while orthonasal aroma is only experienced through the nasal cavity by means of the external nares (Roberts & Acree, 1995). Aroma therefore refers to orthonasal aroma, whereas flavour refers to a combination of taste (experienced on the tongue) and retronasal aroma. Odour-active volatile compounds are often assessed by use of dynamic headspace-solid phase extraction (DHS-SPE) and gas chromatographic-

[2]Neethling, J., Hoffman, L.C. & Muller, M. (2016). Factors influencing the flavour of game meat: A review. *Meat Science*, **114**, 139-153.

olfactometric (GC-O) analysis (Resconi *et al.*, 2012). However, to our knowledge no such research has been conducted on game meat, particularly the meat derived from South African game species.

Table 2.1 Factors influencing the meat quality of the meat derived from domestic vs. game species (controllable vs. uncontrollable)

	Controllable	**Uncontrollable**	
Factor	**Domestic species**	**Game species**	**Explanation**
Species	Yes	Yes	Although there are many game species harvested, these are easily identifiable.
Age	Yes	Random	Mature game species are selected for harvesting.
Gender	Yes	Species-specific	With some game species the males are easily recognisable e.g. horns (kudu, *Tragelaphus strepsiceros*), while with other game species this proves more difficult, particularly with night harvesting (black wildebeest, *Connochaetes gnou*).
Ante-mortem stress	Yes	Difficult	Influenced by terrain, species, mating season, day vs. night harvesting and harvesting method (rifle vs. helicopter).
Method of killing	Yes	Partly	The major objective is killing with head shot using a free bullet; however, this is not always possible due to the ante-mortem stress factors.
Abattoir processes	Yes	No	All 'dirty' processes are conducted in the field where normal interventions such as electrical stimulation cannot be applied.
Cooling	Yes	No	Difficult to apply a standard cooling regime due to field slaughter/dressing and the use of refrigerated trucks.
Processing	Yes	Partly	When linked to commercial export, well defined SOPs exist. Most game meat is exported as deboned, vacuum-packed, frozen muscles/muscle cuts. Packaging material is not standardised. However, for home consumption there are no guidelines.
Cold-chain management	Yes	Partly	When linked to commercial export, well defined SOPs exist. However, for home consumption there are no guidelines and frequently no refrigeration facilities.
Hygiene practices	Yes	Partly	When linked to commercial export, well defined SOPs exist. However, for home consumption there are no guidelines. Water availability is often limited.

SOPs, Standard Operating Procedures.

Game meat is often an 'acquired taste', of which the aroma and flavour have been defined as: 'an aroma and flavour associated with a wild animal species' (Rødbotten *et al.*, 2004; Hoffman *et al.*, 2007d; Van Schalkwyk *et al.*, 2011; Hoffman *et al.*, 2014; North & Hoffman, 2015); 'an aroma and flavour associated with a strong game meat aroma and flavour' (Jones *et al.*, 2015); and 'the intensity of a typical game meat aroma and flavour' (Hoffman *et al.*, 2009b). However, many consumers will still prefer commercially available meat products derived from domestic species (Pollock, 1969; Hoffman, 2007). Nonetheless, consumers judge the quality of game meat under similar criteria (Table 2.1) as those set out for commercial meat products derived from domestic species (Hoffman & Wiklund, 2006). In addition, consumer expectations of game meat quality can be affected by their personality, beliefs, attitudes and past experiences and exposures (Calkins & Hodgen,

2007; Piqueras-Fiszman & Spence, 2015). These expectations influence how consumers perceive game meat quality and consequently their eating experience (Piqueras-Fiszman & Spence, 2015).

South African consumers perceive meat from game species differently from 'traditional' meat types such as those derived from domestic species (Hoffman *et al.*, 2005b). Additionally, game meat in South Africa is only available during the colder seasons due to field harvesting and processing limitations (Apps *et al.*, 1994). Consumers therefore perceive game meat as a seasonal product (Hoffman *et al.*, 2005b). The modern consumer expects meat products to be healthy, produced according to ethical standards and from sustainably reared animals (Kristensen *et al.*, 2014).

Game meat derived from South African species can be marketed as a healthier alternative to the more traditional red meat products (Hoffman *et al.*, 2005a, 2008b). The meat derived from game species can be classified as being low in fat and high in protein (Stevenson *et al.*, 1992; Marks *et al.*, 1997; Hoffman & Wiklund, 2006; Kandeepan *et al.*, 2009; Ramanzin *et al.*, 2010; Daszkiewicz *et al.*, 2012), although this varies with species, age, gender, anatomical location, season and diet. A well-established positive correlation exists between intramuscular lipids (IML) and juiciness and tenderness (Corbin *et al.*, 2015). The low fat content of game meat together with incorrect cooking methods often contribute to negative perceptions of game meat products by consumers who wrongly perceive a dry meat product as being tougher; the so-called 'halo' effect (see section 3.9 on *cooking methods*) (Warriss, 2000; Dhanda *et al.*, 2003; Miller, 2004). Even so, the low fat content of meat is perceived as a positive attribute (Resurreccion, 2003) and health conscious consumers will often sacrifice the sensory quality of meat for a product that is lower in fat (Miller, 2004; Hoffman *et al.*, 2005b). However, the high proportion of polyunsaturated fatty acids (PUFA) (polar lipid fraction) in game meat is more susceptible to oxidation, leading to the development of off-flavours (Wood *et al.*, 1999, 2003). This may negatively influence the shelf-life and sensory quality of game meat.

Game meat and meat products are often perceived as being very dark in colour (Marks *et al.*, 1997; Hoffman *et al.*, 2005b, 2008b; Kandeepan *et al.*, 2009; Ramanzin *et al.*, 2010). Consumers regularly perceive darker coloured meat as being inferior in quality, as they prefer meat that is not extremely pale neither extremely dark in colour (Jeremiah *et al.*, 1972). A darker meat colour can be attributed to higher ante-mortem muscle activities (increased red muscle fibres) (Hoffman, 2001; Hoffman *et al.*, 2008b; Daszkiewicz *et al.*, 2012), as well as to ante-mortem stress, resulting in meat with higher ultimate pH (pHu) values (pH>6.0) that can often be classified as being dark, firm and dry (DFD) (Honikel, 2004; Hoffman *et al.*, 2005b; Daszkiewicz *et al.*, 2012) (see section 3.6 on *harvesting conditions*). The inherent dark colour of game meat is linked to a higher myoglobin content (Young & West, 2001). Furthermore, game meat marketing is also limited by low colour stability and short shelf-life (Onyango *et al.*, 1998; Wiklund *et al.*, 2005, 2006) (see section 3.8 on *packaging and storage conditions*). In contrast, game meat derived from grazing animals can have higher colour stability due to naturally occurring antioxidants (see section 3.5 on *diet*).

The colour of meat at the point of sale is very important for consumer perception of meat quality (Cornforth & Jayasingh, 2004; Troy & Kerry, 2010; Ba *et al.*, 2014). It can, therefore, be said that colour is synonymous with the perception of meat quality at retail level (Renerre & Labas, 1987). Various factors influence ultimate

meat colour (e.g. species, age, gender, anatomical location, diet, and harvesting conditions) and it is vital to understand the extent to which each influences meat colour, due to its significant impact on consumer perception.

The aim of this literature review is thus to discuss the key ante- and post-mortem factors that influence the flavour of game meat, with specific focus on wild and free-living South African game species.

2.2 Meat flavour

Flavour is a very important, but complex attribute of the sensory quality of meat (Mottram, 1998a; Shahidi *et al.*, 2004; Lawrie & Ledward, 2006; Calkins & Hodgen, 2007). Meat flavour can be influenced by compounds that stimulate the olfactory organ (inside the nasal cavity), as well as those influencing the sense of taste (Roberts & Acree, 1995; Mottram, 1998a, 1998b; Pegg & Shahidi, 2004). In addition, the perception of flavour can be influenced by mouthfeel, juiciness, texture and temperature sensations (Mottram, 1998b; Pegg & Shahidi, 2004).

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

Studies on the meat flavour of wild and farmed game/venison species are limited. Furthermore, there is no consistency in the sensory descriptors and definitions used when describing the sensory quality of the meat derived from wild or farmed game/venison species (Table 2.2). The lack of standardisation creates difficulties with comparing results between studies (Table 2.2). As noted in Table 2.2, specific descriptors have different definitions and *vice versa*. This issue is further confounded by the fact that different sensory analytical laboratories use different preparation methods of the meat samples to be evaluated.

Meat flavour is thermally derived, since raw meat has little or no specific aroma and only a blood-like flavour (Mottram, 1998a, 1998b; Shahidi *et al.*, 2004). Primary reactions that occur on heating meat include the thermal degradation of lipids, the interaction between sugars and amino acids (or peptides), thiamine degradation, the degradation of ribonucleotides, the pyrolysis of amino acids and peptides, as well as the caramelisation of carbohydrates. In addition, secondary reactions can occur between the products of these primary reactions (Mottram, 1998b) and contribute to the complexity of the mechanisms by which meat flavour develops (Pegg & Shahidi, 2004). The formation of volatile compounds by the caramelisation of carbohydrates and the thermal degradation of amino acids and peptides, however, require high cooking temperatures (>150°C).

Table 2.2 Sensory descriptors and definitions associated with the meat derived from game and venison (mainly deer species) species from different production systems (wild vs. farmed)

Sensory descriptor	Definition	Production system and species	Reference
Intensity of odour	Intensity of any odour in the product	Farmed reindeer	Wiklund *et al.*, 1996
	Intensity of sum of all odours	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Aroma	None	Wild red deer	Daszkiewicz *et al.*, 2009
	None	Wild blesbok	Hoffman *et al.*, 2010b
Aroma intensity	None	Wild roe deer	Daszkiewicz *et al.*, 2012
	Intensity of aroma, evaluation before eating sample	Farmed fallow and red deer	Bureš *et al.*, 2014
	None	Farmed and wild fallow deer	Daszkiewicz *et al.*, 2015
Overall aroma intensity	Intensity of aroma in first few sniffs	Wild springbok	North & Hoffman, 2015
Gamey odour	Odour of wild animal	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Game meat aroma	Aroma associated with game species	Wild springbok	Hoffman *et al.*, 2007d
Game meat aroma intensity	The intensity of a typical game meat aroma	Wild impala and kudu	Hoffman *et al.*, 2009b
Game aroma intensity	Intensity of typical game meat aroma	Farmed fallow and red deer	Bureš *et al.*, 2014
Gamey aroma	Aroma associated with the meat from wild animal species – combination of liver-like and metallic	Wild springbok	North & Hoffman, 2015
Liver odour	Odour of liver, metallic	Farmed reindeer	Wiklund *et al.*, 1996
	Odour of animal liver	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Liver-like aroma	Aroma associated with pan-fried beef liver	Wild springbok	North & Hoffman, 2015
Metallic odour	Odour of ferrosulphate	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Metallic aroma	Aroma associated with metal/iron/blood	Wild springbok	North & Hoffman, 2015
Beef-like aroma	Aroma associated with cooked beef loin	Wild springbok	North & Hoffman, 2015
Fruity acidic odour	Odour of fruity/fresh and sour/sweet	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Sour aroma	Aroma associated with vacuum-packed, aged meat/off milk	Wild springbok	North & Hoffman, 2015
Sickeningly sweet odour	Flat, stale odour	Farmed reindeer	Wiklund *et al.*, 1996
Sweetness odour	Odour of sugar	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Pungent odour	Strong and intense odour sensation	Farmed reindeer	Wiklund *et al.*, 1996
Off/manure aroma	Aroma associated with farm-yard/contamination/off meat	Wild springbok	North & Hoffman, 2015
Intensity of flavour	Intensity of any flavour in the product	Farmed reindeer	Wiklund *et al.*, 1996
Flavour intensity	Intensity of sum of all flavours	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
	Intensity of meat flavour	Farmed fallow and red deer	Bureš *et al.*, 2014

Table 2.2 continued

Sensory descriptor	Definition	Production system and species	Reference
Meat flavour intensity	None	Wild caribou and farmed reindeer	Rincker *et al.*, 2006
	None	Farmed reindeer	Finstad *et al.*, 2007
Flavour	None	Farmed javan rusa, moluccan rusa, sambar, fallow and red deer	Dahlan & Hanoon, 2008
	None	Farmed fallow and red deer	Hutchison *et al.*, 2010
Gamey flavour	Flavour of wild animal	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
	None	Farmed reindeer	Wiklund & Johansson, 2011
	Flavour associated with the meat from wild animal species – combination of liver-like and metallic	Wild springbok	North & Hoffman, 2015
Overall game meat flavour	Flavour associated with game species	Wild springbok	Hoffman *et al.*, 2007d
Game meat flavour	The intensity of the game meat flavour (combination of taste and swallowing)	Wild impala and kudu	Hoffman *et al.*, 2009b
Game flavour	None	Wild blesbok	Hoffman *et al.*, 2010b
	None	Farmed fallow deer	Hutchison *et al.*, 2012
Game flavour intensity	Intensity of typical game meat flavour	Farmed fallow and red deer	Bureš *et al.*, 2014
Reindeer flavour	None	Farmed reindeer	Wiklund *et al.*, 2000, 2003a
Liver flavour	Flavour of liver, metallic	Farmed reindeer	Wiklund *et al.*, 1996
	None	Farmed reindeer	Wiklund *et al.*, 2000, 2003a; Wiklund & Johansson, 2011
	Flavour of animal liver	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
	None	Farmed fallow deer	Hutchison *et al.*, 2012
Liver-like flavour	Flavour associated with pan-fried beef liver	Wild springbok	North & Hoffman, 2015
Metallic flavour	Flavour of ferrosulphate	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
	Flavour associated with metal/iron/blood	Wild springbok	North & Hoffman, 2015
Beef-like flavour	Flavour associated with cooked beef loin	Wild springbok	North & Hoffman, 2015
Sharp flavour	Strong and intense flavour sensation	Farmed reindeer	Wiklund *et al.*, 1996
Acidic flavour	Primary taste produced by acid (e.g. citric acid, lemon)	Farmed reindeer	Wiklund *et al.*, 1996
	Flavour of fruity/fresh and sour/sweet	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Sour flavour	Flavour associated with off milk	Wild springbok	North & Hoffman, 2015
Sickeningly sweet flavour	Flat, stale flavour	Farmed reindeer	Wiklund *et al.*, 1996
Sweet flavour	None	Farmed reindeer	Wiklund *et al.*, 2000, 2003a; Wiklund & Johansson, 2011
	Flavour of sugar	Wild reindeer and roe deer	Rødbotten *et al.*, 2004

Table 2.2 continued

Sensory descriptor	Definition	Production system and species	Reference
Bitter flavour	None	Farmed reindeer	Wiklund *et al.*, 2000, 2003a; Wiklund & Johansson, 2011
	Flavour of bitter substance, like quinine	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Cloying	Flavour of flat, stale, sweetlike	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Off-flavour	Iron, blood, acidic, metal, sharp and lamb/sheep	Farmed reindeer	Wiklund *et al.*, 2000
	Iron, blood, acidulous, metal, sharp and lamb/sheep	Farmed reindeer	Wiklund *et al.*, 2003a
	None	Farmed reindeer	Wiklund & Johansson, 2011
Off-flavour intensity	Livery or gamey	Wild caribou and farmed reindeer	Rincker *et al.*, 2006
	Livery or gamey	Farmed reindeer	Finstad *et al.*, 2007
Off/manure flavour	Flavour associated with farm-yard/contamination/off meat	Wild springbok	North & Hoffman, 2015
Taste	None	Wild red deer	Daszkiewicz *et al.*, 2009
Taste intensity	None	Wild roe deer	Daszkiewicz *et al.*, 2012
	None	Farmed and wild fallow deer	Daszkiewicz *et al.*, 2015
Fatness	Fatty feeling in the mouth and gum	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Initial juiciness	The amount of fluid exuded on the cut surface when pressed between fingers	Wild springbok	Hoffman *et al.*, 2007d
	The amount of fluid exuded on the cut surface when pressed between forefinger and thumb	Wild impala and kudu	Hoffman *et al.*, 2009b
	None	Wild blesbok	Hoffman *et al.*, 2010b
Juiciness	Perception of juice absorbed from the product	Farmed reindeer	Wiklund *et al.*, 1996
	None	Farmed reindeer	Wiklund *et al.*, 2000, 2003a; Finstad *et al.*, 2007; Wiklund & Johansson, 2011
	Perception of water content in the sample after 3-4 chewings	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
	None	Wild caribou and farmed reindeer	Rincker *et al.*, 2006
	None	Farmed javan rusa, moluccan rusa, sambar, fallow and red deer	Dahlan & Hanoon, 2008
	None	Wild red deer	Daszkiewicz *et al.*, 2009
	None	Farmed fallow and red deer	Hutchison *et al.*, 2010
	None	Wild roe deer	Daszkiewicz *et al.*, 2012
	None	Farmed fallow deer	Hutchison *et al.*, 2012
	Impression of juiciness after first three to five chews	Farmed fallow and red deer	Bureš *et al.*, 2014
	None	Farmed and wild fallow deer	Daszkiewicz *et al.*, 2015

Table 2.2 continued

Sensory descriptor	Definition	Production system and species	Reference
Sustained juiciness	Degree of juiciness perceived after mastication (2-3 chews)	Wild springbok	Hoffman *et al.*, 2007d
	The impression of juiciness after the first 2-3 chews	Wild impala and kudu	Hoffman *et al.*, 2009b
	None	Wild blesbok	Hoffman *et al.*, 2010b
	Amount of moisture perceived during mastication	Wild springbok	North & Hoffman, 2015
Tenderness	None	Wild blesbok	Hoffman *et al.*, 2010b
	Mechanical texture attribute related to cohesiveness and to the length of time or the number of chews required to masticate a solid product into a state ready for swallowing	Farmed reindeer	Wiklund *et al.*, 1996
	None	Farmed reindeer	Wiklund *et al.*, 2000, 2003a; Finstad *et al.*, 2007; Wiklund & Johansson, 2011
	Time and numbers of chewings required to masticate the sample ready for swallowing	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
	None	Wild caribou and farmed reindeer	Rincker *et al.*, 2006
	Impression of tenderness after mastication (2-3 chews)	Wild springbok	Hoffman *et al.*, 2007d
	None	Farmed javan rusa, moluccan rusa, sambar, fallow and red deer	Dahlan & Hanoon, 2008
	None	Wild red deer	Daszkiewicz *et al.*, 2009
	The impression of tenderness after the first 2-3 chews between the molar teeth	Wild impala and kudu	Hoffman *et al.*, 2009b
	None	Farmed fallow and red deer	Hutchison *et al.*, 2010
	None	Wild roe deer	Daszkiewicz *et al.*, 2012
	None	Farmed fallow deer	Hutchison *et al.*, 2012
	Impression of tenderness after first two to three chews	Farmed fallow and red deer	Bureš *et al.*, 2014
	None	Farmed and wild fallow deer	Daszkiewicz *et al.*, 2015
	Impression of tenderness after mastication	Wild springbok	North & Hoffman, 2015
Residue	None	Wild blesbok	Hoffman *et al.*, 2010b
	The amount of residual tissue after most of the sample has been masticated (15 chews)	Wild springbok	Hoffman *et al.*, 2007d
	The amount of residue left after 15 chews	Wild impala and kudu	Hoffman *et al.*, 2009b
	Residual tissue remaining after mastication (difficult to chew through)	Wild springbok	North & Hoffman, 2015
Mealiness	Extremely fine texture. Disintegration of muscle fibre into very small particles that are retained on the tongue	Wild springbok	North & Hoffman, 2015

Table 2.2 continued

Sensory descriptor	Definition	Production system and species	Reference
Coarseness	Degree of granularity of the muscle fibres	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Hardness	Mechanical texture attribute measured by compressing the product between the teeth, force required to produce deformation of the product	Farmed reindeer	Wiklund *et al.*, 1996
	The force required to bite through the sample	Wild reindeer and roe deer	Rødbotten *et al.*, 2004
Chewiness	Force needed to masticate sample for swallowing	Farmed fallow and red deer	Bureš *et al.*, 2014

Venison refers to the meat derived from mainly deer species that are reared under intensive conditions (farmed); blesbok (*Damaliscus pygargus phillipsi*); caribou deer (*Rangifer tarandus*); fallow deer (*Dama dama*); impala (*Aepyceros melampus*); javan rusa deer (*Cervus timorensis russa*); kudu (*Tragelaphus strepsiceros*); moluccan rusa deer (*Cervus timorensis moluccensis*); red deer (*Cervus elaphus*); reindeer (*Rangifer tarandus*); roe deer (*Capreolus capreolus* L.); sambar deer (*Cervus unicolor brookei*); springbok (*Antidorcas marsupialis*).

Such high temperatures are usually not encountered during normal meat cooking methods (Mottram, 1998b; Pegg & Shahidi, 2004), except on meat surfaces during roasting or grilling where temperatures can rise well above the boiling point of water and localised dehydration occurs (Pegg & Shahidi, 2004). The latter cooking methods thus contribute to the development of Maillard reaction products on the surface of the meat. Cooking meat in a pot or oven (cook-in bag) will result in differences in the sensory quality, as these methods include more moisture and lower surface temperatures (Bejerholm & Aaslyng, 2003).

The composition of meat is very complex and consists of macronutrients (water, proteins and lipids) and micronutrients (vitamins, sugars like ribose and nucleotides). Meat is therefore a rich reservoir of flavour precursors that will undergo various reactions upon heating, and consequently produce several desirable aroma and taste characteristics (Pegg & Shahidi, 2004). Primary meat flavour precursors can be separated into water-soluble components and lipids (Mottram, 1998a, 1998b; Pegg & Shahidi, 2004), which include free amino acids, peptides, nucleotides, nucleotide-bound sugars, sugar phosphates, free sugars and other nitrogenous components (Mottram, 1998a, 1998b). Amino acids, peptides and nucleotides also contribute directly to the four primary taste sensations, as well as through their interactions with other muscle components to produce volatile compounds (Shahidi, 1998). The sulphur-containing compounds (e.g. cysteine) are important contributors to meat flavour as their degradation products have very low odour threshold values, and therefore extremely low quantities can contribute significantly to cooked meat aroma (Mottram, 1998b).

Generic meat flavour research associates meat characteristics with water-soluble flavour precursors in lean meat and species-specific characteristics with lipids (Hornstein & Crowe, 1960, 1963; Wasserman & Spinelli, 1972; Mottram, 1998b; Pegg & Shahidi, 2004). However, it is known that lipids have some influence on meat flavour, as the volatile compound profile of cooked meat is generally dominated by lipid-derived compounds (Mottram, 1998b). The latter was proposed by Wasserman and Spinelli (1972) who established that lipid degradation products can interact with products of the Maillard reaction to produce a characteristic meat aroma. The flavour of cooked meat is therefore due to the combined sensation of low molecular weight products

produced by two very important classes of reactions: Maillard reaction; and the thermal degradation of lipids (Mottram, 1998a; Pegg & Shahidi, 2004).

2.2.1 Maillard reaction

The Maillard reaction is a series of complex, non-enzymatic browning reactions between free amino groups of amino acids (or peptides) and reducing sugars in meat (Mottram, 1998a, 1998b; Pegg & Shahidi, 2004). These reactions do not require high cooking temperatures (Mottram, 1998b; Pegg & Shahidi, 2004), which makes the Maillard reaction one of the most important routes to the formation of volatile compounds in meat (Mottram, 1998a, 1998b; Pegg & Shahidi, 2004). The Maillard reaction occurs most frequently at low moisture levels, such as meat surfaces where dehydration often occurs during cooking, though it can also take place in aqueous solutions. Products of the Maillard reaction include high molecular weight brown coloured compounds (melanoidins) and volatile compounds (Pegg & Shahidi, 2004).

The initial step in the Maillard reaction involves the formation of a *N*-substituted glycosylamine through the condensation of the carbonyl group of a reducing sugar with a primary amino group of an amino acid, peptide or protein (Mottram, 1998a, 1998b; Pegg & Shahidi, 2004; Coultate, 2009). The *N*-glycosylamine rearranges to become an Amadori compound, which can be degraded further to generate compounds such as furanones, furfurals, dicarbonyls and hydroxyketones (Mottram, 1998a, 1998b; Pegg & Shahidi, 2004). Although these compounds can contribute directly to meat flavour, they are more important as substrates for generating other volatile compounds (Mottram, 1998b; Pegg & Shahidi, 2004). These substrates can interact with reactive compounds (e.g. amines, amino acids, ammonia, hydrogen sulphide, thiols, acetaldehyde and other aldehydes) to form many important classes of volatile compounds in meat, such as thiophenes, thiazoles, pyrazines, oxazoles and other heterocyclic compounds. Sulphur-containing compounds derived from ribose and cysteine are especially important for the formation of characteristic meat aroma (Pegg & Shahidi, 2004). The Maillard reaction is therefore mainly responsible for the large amount of heterocyclic compounds found in the volatile compound profile of cooked meat, contributing to roast, boiled and savoury flavours (Mottram, 1998a; Pegg & Shahidi, 2004).

2.2.2 Lipid degradation

More than half of the volatile compounds reported in cooked meat are produced through the thermal degradation of lipids. In addition, these lipid derived compounds can be produced by two reactions, thermal oxidation and rancid oxidation. The thermally induced oxidation of acyl chains (fatty acids) of lipids is one of the primary reactions responsible for the formation of volatile compounds during meat cooking, while autoxidation of unsaturated fatty acid chains is responsible for the production of undesirable flavours associated with rancidity, which usually develops during the storage of foods. These reactions (thermal and rancid oxidation) follow similar routes, although slight changes in their mechanisms produce different volatile compound profiles (Mottram, 1998b).

Mottram and Edwards (1983) established the importance of structural phospholipids in the development of meat aroma. In their study, the removal of inter- and intramuscular fats (triglycerides) resulted in slight changes in the aroma of cooked meat, and the development of aliphatic aldehydes and alcohols. However, the removal of triglycerides and structural phospholipids resulted in marked differences in the aroma of cooked meat, as "meat" aroma was consequently replaced with "toasted", "roasted" and "biscuit-like" aroma. In addition, the quantities of aliphatic aldehydes and alcohols were significantly reduced (trace amounts), whereas increased quantities of benzaldehyde and pyrazines were produced (Mottram & Edwards, 1983). Since pyrazines are characteristic products of the Maillard reaction (Farmer & Mottram, 1990; Pegg & Shahidi, 2004), it appears that phospholipids participate in the Maillard reaction, resulting in the reduction (or inhibition) of the levels of heterocyclic compounds produced (Farmer & Mottram, 1990; Mottram, 1998b). The limited participation of triglycerides in the Maillard reaction has been attributed to the fact that triglycerides are less miscible (as compared to phospholipids) with the aqueous Maillard reactants. Nonetheless, many Maillard reaction products are greatly reduced by the addition of lipids (Farmer & Mottram, 1990).

Structural phospholipids have high proportions of PUFA (Fisher *et al.*, 2000; Scollan *et al.*, 2001), which primarily consist of fatty acids with three or more double bonds (such as arachidonic acid, C20:4n6). These highly unsaturated fatty acids are likely to break down during heat processing, forming products that can react with Maillard reaction products. Inter- and intramuscular triglycerides in meat contain very low quantities of PUFA, which is why the removal of these lipids has a minor effect on meat flavour (Mottram, 1998b). Nonetheless, differences in fatty acid compositions and/or polar moieties of the IML of meat will influence the volatile compounds formed by the interaction of lipids in the Maillard reaction (Farmer & Mottram, 1990).

The oxidation of unsaturated fatty acids produce significant quantities of carbonyl compounds (ketones and aldehydes) (Pegg & Shahidi, 2004). Moreover, lipids also act as solvents for fat soluble compounds which will become volatile upon thermal processing (Mottram & Edwards, 1983; Miller, 2004; Pegg & Shahidi, 2004). Boiled, slightly grilled or roasted meat produce primary lipid degradation products of which several have relatively high odour threshold values, resulting in minimal contributions to overall cooked meat flavours. Nonetheless, aldehydes, unsaturated alcohols and ketones, and lactones have low odour threshold values, allowing them to contribute directly to meat aroma (Mottram, 1998b).

2.3 Factors influencing meat flavour

As flavour is a very important attribute contributing to the sensory quality of meat and meat products (Wood *et al.*, 1999; Miller, 2004), it is important to quantify the factors that influence meat flavour quality during meat production and processing (Mottram, 1998a). This is especially of importance for the production of meat from South African game species, as these species are generally wild and free-living (Hoffman *et al.*, 2005b; Hoffman & Wiklund, 2006; Carruthers, 2008). Many factors can therefore influence the flavour of the meat derived from game species, which include ante-mortem factors such as species, gender, age, muscle anatomical

location, diet and harvesting conditions; and post-mortem factors such as meat ageing, packaging and storage conditions and cooking method. These factors will be discussed in more detail in the following sections.

2.3.1 Species

The flavour of muscle foods is highly dependent on the species from which it originates (Sink, 1979; Priolo *et al.*, 2001). In South Africa, wild and free-ranging game species generally have low IML content (Hoffman *et al.*, 2005b; Hoffman & Wiklund, 2006) which primarily consists of structural lipid components (phospholipids and cholesterol) with high proportions of PUFA (Fisher *et al.*, 2000). Table 2.3 depicts the IML content, total fatty acid composition and fatty acid ratios of the meat derived from various extensively reared (free-ranging or pasture-reared) game species. Although the fatty acid composition of fat is important with regard to flavour perception, the total amount of fat present is also important due to the film of fat that can cover the oral surfaces affecting the release of fat soluble aroma and taste components, as well as to provide a fatty mouthfeel and lubrication (Forss, 1973). However, the latter is limited in the meat derived from game species (Table 2.3). Game meat has favourable polyunsaturated to saturated fatty acid (PUFA:SFA) and omega 6 to omega 3 polyunsaturated fatty acid (n6:n3 PUFA) ratios (Table 2.3), as these values are above a recommended value of 0.4 and below 4.0, respectively (Wood *et al.*, 2003). Hoffman and Wiklund (2006) also established that meat derived from South African game species are within the latter recommendations. Wood and Enser (1997) reported PUFA:SFA ratios for beef and lamb meat at 0.11 and 0.15, respectively, which indicates that game meat has higher proportions of PUFA compared to meat derived from domestic species (Field, 2004).

The fatty acid profile of meat has an important role in meat flavour development (Wood *et al.*, 2003, 2008), as saturated fatty acids (SFA), n3 and n6 PUFA produce a variety of different flavour precursors (Wood & Enser, 1997). South African game meat often has a stronger flavour compared to meat products derived from domesticated species (such as beef, pork and lamb) (Field, 2004), which is primarily attributed to higher PUFA percentages in game meat (Swanson & Penfield, 1991). However, the chemical nature of meat volatile compounds from different species is usually comparable qualitatively, but not quantitatively (Wasserman & Spinelli, 1972; Shahidi, 1998; Pegg & Shahidi, 2004). Differences in the fatty acid profiles between species (Table 2.3) will therefore influence the profile and quantity of volatile compounds formed (Wood *et al.*, 2003). Consequently, game meat derived from different species will differ in perceived intensities of various sensory aroma and flavour attributes.

Rødbotten *et al.* (2004) quantified the sensory profiles of commercially available meat derived from 15 wild and domesticated species in Norway. Several flavour attributes were similar between species, but perceived intensities differed. Deer meat (reindeer, *Rangifer tarandus* and roe-deer, *Capreolus capreolus*) had the highest gamey flavour intensities, while all meat derived from wild animals had higher liver-like flavour intensities. Furthermore, gamey and liver-like flavour attributes were found to be most important in describing the flavour differences of the 15 meat species in Norway (Rødbotten *et al.*, 2004). However, no information was available on the age, gender or diet/feeding regime of the meat products derived from the different species

in this study, which could have clarified the extent to which species type influenced the sensory quality of the meat.

Rincker *et al.* (2006) compared sensory attributes of reindeer (*Rangifer tarandus*), caribou (*Rangifer tarandus*) and beef *longissimus dorsi* (LD) muscles. Beef meat had a higher meat flavour intensity, while meat from reindeer and caribou had higher off-flavour intensities, an attribute that the authors associated with liver-like or gamey flavours.

Hoffman *et al.* (2007d) established a moderate positive correlation ($r = 0.470$, $p<0.05$) between gamey flavour intensity and α-linolenic acid (C18:3n3) percentage of springbok meat. Impala meat had higher gamey aroma and overall flavour intensities compared to kudu (*Tragelaphus strepsiceros*) meat, although impala and kudu meat did not differ significantly in α-linolenic acid composition (Hoffman *et al.*, 2009b). The latter can be attributed to the use of qualitative fatty acid data (percentage of total fatty acids) as opposed to quantitative fatty acid data (mg.100 g^{-1} of muscle), as IML content is taken into account with quantitative fatty acid data. Furthermore, since Hoffman *et al.* (2009a) established that impala meat had higher ($p \leq 0.05$) IML contents than kudu meat, the use of quantitative fatty acid data in the study by Hoffman *et al.* (2009b) could have indicated significantly higher α-linolenic acid levels in impala meat and this could have been positively correlated with the more intense gamey aroma of impala meat.

Van Schalkwyk *et al.* (2011) found differences in the sensory profiles of salami produced from four South African game species: springbok (*Antidorcas marsupialis*); gemsbok (*Oryx gazella*); kudu; and zebra (*Equus burchelli*). Springbok salami had the highest ($p<0.05$) gamey aroma and gamey flavour intensities and the sensory quality of springbok differed the most from gemsbok, kudu and zebra salami's.

Furthermore, Bureš *et al.* (2014) established that red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) meat had higher overall aroma/flavour and gamey aroma/flavour intensities compared to Aberdeen Angus and Holstein cattle (*Bos taurus*). Species-specific differences in meat aroma and flavour quality were attributed to differences in fatty acid profiles, especially the PUFA content (Bureš *et al.*, 2014).

The majority of the research quantifying species-specific sensory profiles has established that gamey flavour (sometimes also regarded as a liver-like flavour) is the main sensory attribute differentiating between meat from different game species. However, some of the researchers made use of a limited or too specific list of sensory attributes for quantifying the flavour of game meat by means of descriptive sensory analysis (Hoffman *et al.*, 2007d, Wiklund *et al.*, 2007; Hoffman *et al.*, 2009b; Bureš *et al.*, 2014). Yet the sensory profile should include all perceived sensory attributes and not only selected ones (Murray *et al.*, 2001). Consequently, a limited or too specific list of attributes can limit the amount of identifiable differences in sensory attributes between the species meats. Furthermore, aroma (orthonasal and retronasal), taste and texture attributes are different and should all be taken into account when conducting sensory analysis on meat products (Matsuishi *et al.*, 2004).

Table 2.3 Intramuscular fat content (g.100 g^{-1} of meat), total fatty acid composition (percentage of total fatty acids) and fatty acid ratios of the *longissimus dorsi* of blesbok (*Damaliscus pygargus phillipsi*), red hartebeest (*Alcelaphus buselaphus caama*), springbok (*Antidorcas marsupialis*), impala (*Aepyceros melampus*), kudu (*Tragelaphus strepsiceros*), duiker (*Sylvicapra grimmia*), mountain reedbuck (*Redunca fulvorufula*), Norwegian reindeer (*Rangifer tarandus*) and fallow deer (*Dama dama*)

	Game species								
	Blesbok[1]	**Red hartebeest[2]**	**Springbok[3]**	**Impala[4]**	**Kudu[4]**	**Duiker[5]**	**Mountain reedbuck[6]**	**Norwegian reindeer[7]**	**Fallow deer[8]**
IML content	0.8	0.5	1.2	2.2	1.5	2.1	2.7	0.6	0.6
Fatty acid totals									
SFA	43.6	46.4	41.7	51.1	34.9	22.2	38.0	41.0	31.8
MUFA	17.5	19.0	19.2	14.8	26.3	37.5	18.2	28.6	11.3
PUFA	38.9	34.5	37.9	34.1	38.9	40.3	43.7	23.4	56.9
Fatty acid ratios									
PUFA:SFA	0.9	0.8	0.9	0.7	1.2	1.8	1.2	0.6	1.8
n6:n3 PUFA	3.8	2.7	3.3	3.8	2.2	3.6	2.0	3.7	3.3

IML, intramuscular lipid; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; PUFA:SFA, polyunsaturated to saturated fatty acid ratio; n6:n3 PUFA, omega 6 to omega 3 polyunsaturated fatty acid ratio; [1]Average IML content for *longissimus dorsi* of blesbok from four regions; n6:n3 PUFA ratio was calculated (Hoffman *et al.*, 2008a); [2]Average IML content for *longissimus dorsi* of red hartebeest from four regions (Hoffman *et al.*, 2010a); [3]IML content and fatty acid totals for *longissimus dorsi* of adult springbok; PUFA:SFA and n6:n3 PUFA ratios were calculated (Hoffman *et al.*, 2007c); [4]Average IML content for *longissimus dorsi* of adult male and female impala and kudu (Hoffman *et al.*, 2009a); [5]IML content and fatty acid totals for *longissimus dorsi* of common duiker; PUFA:SFA and n6:n3 PUFA ratios were calculated (Hoffman & Ferreira, 2004); [6]Average IML content, fatty acid totals and ratios for *longissimus dorsi* of male and female mountain reedbuck (Hoffman *et al.*, 2008b); [7]Average IML content, fatty acid totals and ratios for *longissimus lumborum* of male and female Norwegian reindeer (Triumf *et al.*, 2012); [8]IML content, fatty acid totals and n6:n3 PUFA ratio for *longissimus thoracis et lumborum* of pasture-reared male fallow deer; PUFA:SFA ratio was calculated (Volpelli *et al.*, 2003).

Research on species differences for meat tenderness is inconsistent and can be attributed to various factors, such as physical activity levels (Geldenhuys *et al.*, 2014); muscle fibre type composition; sarcomere length; concentration of connective tissue and degree of cross-linking (see section 3.4 on *muscle anatomical location*); age (see section 3.2 on *age*); gender (see section 3.3 on *gender*); ante-mortem stress (see section 3.6 on *harvesting conditions*); post-mortem ageing (see section 3.7 on *ageing of meat*); cooking method (see section 3.9 on *cooking method*s) (Warriss, 2000). Moreover, meat tenderness is also influenced by the IML content. A high amount of IML can have a diluting effect and therefore result in more tender meat (Webb & O'Neill, 2008); however, due to the low IML content of game meat in general (Table 2.3), this phenomenon will not be evident in game meat.

It is virtually impossible to compare results from different sensory studies due to differences in ante-mortem factors, muscle cuts used, ageing and storage of samples, sample preparation sensory analysis and statistical methods used (Rødbotten *et al.*, 2004; Rincker *et al.*, 2006; Hoffman *et al.*, 2007d, 2009b). Although numerous researchers have investigated the sensory quality of various deer species (Wiklund *et al.*, 2003a, 2003b; Rincker *et al.*, 2006; Hutchison *et al.*, 2010), similar studies on meat derived from South African game species is limited. As meat flavour has been reported to be species-specific (Priolo *et al.*, 2001; Ramanzin *et al.*, 2010), more research comparing the flavour between game species is required. In addition, more in-depth research is also required for identifying volatile compounds associated with species-specific differences in South African game meat flavour.

2.3.2 Age

A key compositional change in muscle tissue with animal age is the increase of intramuscular lipid (IML) content of muscle tissue, as IML is the last tissue to mature (Warriss, 2000; Keeton & Eddy, 2004). The IML content is generally inversely related to the moisture content of muscle tissue (Keeton & Eddy, 2004; Legako *et al.*, 2015), however, game meat is low in fat (Table 2.3; Hoffman & Wiklund, 2006) and this inverse correlation is therefore not as prevalent in the muscle tissue of game species (Neethling *et al.*, 2014b).

Age-related changes in IML content of muscle tissue result in differences in fatty acid profiles, which influence meat flavour (Farmer & Mottram, 1990; Wood *et al.*, 1999, 2003; Calkins & Hodgen, 2007; Stelzleni & Johnson, 2010). Meat flavour generally increases with animal age and meat flavour differences can be attributed to age-related changes in the meat flavour precursors (Young & Braggins, 1998; Fisher *et al.*, 2000; Lawrie & Ledward, 2006; Ramanzin *et al.*, 2010). Muscles of younger game animals often contain higher concentrations of PUFA and consequently higher PUFA:SFA ratios (Rule & McCormick, 1998; Daszkiewicz *et al.*, 2012), while meat from older animals generally contain higher IML percentages (Sampels *et al.*, 2005), characterised by higher quantities of SFA (Lawrie & Ledward, 2006). Sink (1979), however, suggested that animal age has a greater influence on the water-soluble "meat" characteristics compared to the lipid-soluble "species-specific" characteristics of meat flavour.

Differences in meat flavour with increasing animal age has been reported for meat derived from beef (Schönfeldt & Strydom, 2011), sheep and goats (Schönfeldt *et al.*, 1993). Sookhareea *et al.* (1995) found

slight changes in the IML content and meat flavour intensity of male Javan rusa (*Cervus timoriensis*) deer with increasing animal age. Volpelli *et al.* (2003) found significantly higher total IML and MUFA percentages and significantly lower n3 and n6 PUFA percentages in fallow deer meat of older animals (18 vs. 30 months). Hoffman *et al.* (2009b) also found lower ($p \leq 0.05$) total PUFA percentages and PUFA:SFA ratios in adult kudu and impala meat when compared to sub-adults. However, Girolami *et al.* (2003) found no significant influence of age on the IML content of ostrich meat, although the total SFA percentage, total MUFA percentage and n6:n3 PUFA ratio increased and the total PUFA percentage decreased with increasing animal age.

In contrast to the above-mentioned differences, Kandeepan *et al.* (2009) found no significant differences in the flavour of buffalo meat due to age. Hoffman *et al.* (2007c, 2007d) also found no differences in total PUFA percentages, PUFA:SFA ratios and gamey flavour intensity of sub-adult and adult springbok LD muscles. Similarly, Renecker *et al.* (2005) found no differences in the gamey flavour intensity of loin steaks from free-ranging reindeer of different ages.

In addition, meat generally becomes less tender with increasing animal age (Warriss, 2000; Lawrie & Ledward, 2006). The latter can be attributed to more insoluble or heat-stable collagen (Warriss, 2000; Miller, 2004; Lepetit, 2007) and an increased number of cross-links between collagen molecules and fibrils (Lawrie & Ledward, 2006; Lepetit, 2007). Volpelli *et al.* (2003) established that older fallow deer *longissimus thoracis et lumborum* (LTL) muscles had higher Warner-Bratzler peak force values (kg) and lower collagen solubility. Ostrich meat from older animals was also found to be tougher (Hoffman & Fisher, 2001; Girolami *et al.*, 2003). Meat from older buffalo had significantly lower collagen solubility and larger muscle fibre diameter, contributing to tougher meat compared to younger animals (Kandeepan *et al.*, 2009). However, Sookhareea *et al.* (1995), Hoffman *et al.* (2007a) and Hoffman *et al.* (2009a) found no significant effect of age on the instrumental tenderness (Warner-Bratzler shear force values) of meat from male Javan rusa (*Cervus timoriensis*) deer, springbok, and kudu and impala, respectively. Renecker *et al.* (2005) also found no significant age effect on the sensory and instrumental tenderness of reindeer loin steaks.

It is difficult to compare research investigating the influence of animal age on the sensory quality of game meat, as the classification of age and maturity can differ between game species and it is also difficult to determine the age of these ungulates (Hoffman *et al.*, 2008b). These effects on tenderness are confounded further with additional factors such as exercise that is typically higher in wild species compared to farmed livestock. It is well-known that an increase in exercise results in tougher meat due to the effect thereof on collagen. As discussed, the effect of IML on tenderness and the interaction of the various intrinsic and extrinsic factors on the amount of IML also need to be taken into consideration (Nishimura, 2015). Furthermore, the research on the effect of age on the sensory quality of the meat derived from various game species is inconsistent. However, it is suggested that the effect of age on the sensory quality of game meat is species-specific.

2.3.3 Gender

Meat from female animals generally contain significantly higher amounts of IML compared to males (Hoffman *et al.*, 2005a, Renecker *et al.*, 2005; Sampels *et al.*, 2005; Lawrie & Ledward, 2006; Hoffman *et al.*, 2007b, 2007c; Daszkiewicz *et al.*, 2009; Hoffman *et al.*, 2009c; Kandeepan *et al.*, 2009; Daszkiewicz *et al.*, 2012) and as a result also contain higher proportions of SFA (Fisher *et al.*, 2000; Sampels *et al.*, 2005; Daszkiewicz *et al.*, 2012), while male animals often have higher proportions of PUFA (Hoffman *et al.*, 2005a; Wood *et al.*, 2008; Daszkiewicz *et al.*, 2012; Neethling *et al.*, 2014a).

Seasonal behavioural differences between genders also influence biochemical changes in the meat (Hoffman *et al.*, 2009c). The mating season influences the condition of male game animals, since the energetic drain of the rut usually result in rapid weight loss in males (Stevenson *et al.*, 1992; Nagy & Knight, 1994; Hewison *et al.*, 1996; Renecker *et al.*, 2005; Daszkiewicz *et al.*, 2012), in addition to males spending less time feeding (Hoffman, 2000; Mysterud *et al.*, 2004). The latter results in significant reductions in the IML content of male skeletal muscles (Renecker *et al.*, 2005). Gestation and lactation can also influence the chemical composition of the meat derived from female game animals (Hewison *et al.*, 1996; Sampels *et al.*, 2005). Mating season is therefore a vital consideration for meat production from game species.

As mentioned previously, the fatty acid composition of meat influences the volatile compounds produced upon cooking, which influences the aroma and flavour of meat (Farmer & Mottram, 1990; Wood *et al.*, 2003). Differences in IML content between genders can therefore influence the aroma and flavour of the meat derived from different genders.

Daszkiewicz *et al.* (2009) found significantly higher taste intensities, but lower taste desirability for female red deer. Neethling *et al.* (2014b) found no seasonal differences in the IML content of male and female blesbok meat. However, female blesbok meat had significantly higher total MUFA percentages, while male blesbok meat had significantly higher PUFA:SFA ratios (Neethling *et al.*, 2014a). However, Hoffman *et al.* (2010b) found no significant gender differences for overall aroma and gamey flavour intensities of blesbok meat. Kandeepan *et al.* (2009) also found no significant differences in the flavour of the meat derived from male and female buffalo. Mostert and Hoffman (2007) and Hoffman *et al.* (2008b) found no significant gender differences in the IML content of kudu and mountain reedbuck meat, respectively. In addition, PUFA:SFA and n6:n3 PUFA ratios of the meat from the latter two species also did not differ between genders (Mostert & Hoffman, 2007; Hoffman *et al.*, 2008b).

Linoleic acid (C18:2n6) and α-linolenic acid percentages differed between genders for mountain reedbuck meat (Hoffman *et al.*, 2008b). Hoffman *et al.* (2007c) found significantly higher total MUFA percentages in male compared to female springbok meat, although no significant gender differences were found for total PUFA percentages. Moreover, the PUFA:SFA and n6:n3 PUFA ratios did not differ between male and female springbok meat. Hoffman *et al.* (2007d) also found no significant gender differences in gamey aroma and gamey flavour intensities of springbok meat. In pigs, so-called boar taint (off-flavour) is caused by high levels of androstenone and/or skatole (testicular steroids) (Mörlein *et al.*, 2015). However, this does not seem to be

relevant to the meat derived from male game species although anecdotal information seems to suggest that males when in rut do have a "male/urine like" flavour and odour, this aspect warrants further research.

Furthermore, gender differences in meat tenderness have also been reported; female buffalo meat had significantly higher shear force values compared to males (Kandeepan *et al.*, 2009). However, meat from female springbok (Hoffman *et al.*, 2007a), black wildebeest (Hoffman *et al.*, 2009c) and roe deer (*Capreolus capreolus*) (Daszkiewicz *et al.*, 2012) was found to be significantly more tender than that from males, whereas gender had no significant influence on the shear force values of meat from the greater kudu (Mostert & Hoffman, 2007) and mountain reedbuck (*Redunca fulvorufula*) (Hoffman *et al.*, 2008b). It should be noted though that most of these studies did not describe the age of the animals apart from mentioning that they were mature and as discussed, age influences shear force values.

It is evident from the above-mentioned studies that gender can influence the sensory attributes of game meat, although these differences vary across game species. Therefore the influence of gender on the sensory quality of game meat should be established per species, so as to establish whether the commercial game meat market should take gender into account with the marketing of species-specific game meat products.

2.3.4 Muscle anatomical location

The physiological functions of skeletal muscles are unique as each muscle has a distinct anatomical location and function. As a result, the physicochemical composition of muscles differs, which influences the sensory quality of meat (Daszkiewicz *et al.*, 2012; Ba *et al.*, 2014). The muscle fibre type composition can differ due to the influence of ante-mortem production system (intensive vs. extensive) and/or physical activity level (Vestergaard *et al.*, 2000), which will also contribute to differences in the sensory quality of the meat. It is therefore important to quantify differences in the composition and flavour of meat products derived from different anatomical locations or muscles.

Research regarding the flavour differences among skeletal muscles has primarily focused on flavour intensity and the presence of off-flavours (Legako *et al.*, 2015). The latter has been summarised by Calkins and Hodgen (2007) for various beef muscles. In addition, a beef flavour lexicon (beef attributes) has also been used to determine differences in the flavour of various beef cuts (Adhikari & Chambers IV, 2010; Miller, 2010). Carmack *et al.* (1995) found differences in the flavour intensity of beef meat derived from 12 anatomical locations. Additionally, important differences in the tenderness of various beef muscles have also been established (Dransfield & Jones, 1981; Carmack *et al.*, 1995; Sullivan & Calkins, 2011; Legako *et al.*, 2015).

Ba *et al.* (2014) found a significant muscle type effect on the moisture and IML content, cooking loss percentage, total collagen content and WBSF value of beef meat. The effect of ageing time can also impact various skeletal muscles differently, as Ba *et al.* (2014) found that the ageing of beef *Semitendinosus* (ST) muscles past seven days negatively influenced the sensory quality of the meat, while the flavour of beef LD muscles was unaffected. The authors attributed the latter to the decreased levels of important volatile

compounds (octanal and nonanal) associated with pleasant flavours and produced by the oxidation of oleic acid (C18:1n9).

Legako *et al.* (2015) established differences in the quantity of the volatile compounds produced from four beef muscles (*longissimus lumborum, psoas major, gluteus medius and semimembranosus*). The content of five compounds (2,3-butanedione, heptane, 3-hydroxy-2-butanone, octane and methyl pyrazine) was found to be significantly different between the four beef muscles, irrespective of their quality grade and it was suggested to play a valuable role in explaining consumer liking. Of the above-mentioned volatile compounds, 2,3-butanedione (diacetyl), 3-hydroxy-2-butanone (acetoin) and methyl pyrazine have been found to be aroma-active, contributing to butter, fruit-like, yoghurt, rubber and sweet characteristics of meat (Berdagué *et al.*, 2007; Resconi *et al.*, 2012; Wu *et al.*, 2014b).

It can therefore be expected that the anatomical location of the muscles derived from game species will also influence the chemical composition, sensory quality and the volatile compounds of the meat (Dhanda *et al.*, 2003; Ba *et al.*, 2014; Legako *et al.*, 2015). However, the extent of the latter differences will most probably depend on the species, as well as the production system (diet).

2.3.5 Diet

South Africa has a rich variety of game species distributed throughout the various vegetation types/biomes (Van Der Merwe *et al.*, 2014). These wild and free-living game species can be generalists or selective in their feeding habits, in addition to being classified as grazers, browsers or mixed feeders (Liversidge & Van Eck, 1994). Browsing refers to the consumption of leaves, twigs, bark, flowers, shrubs, pods and fruits (Bothma, 2002), while grazing refers to the consumption of only grass species. Furthermore, the dietary regime of South African game species vary in accordance with the vegetation available within their habitat and due to seasonal rainfall patterns.

Meat derived from ruminant animals often contain higher levels of SFA, due to the bio-hydrogenation (in the rumen) of unsaturated fatty acids in the diet, to more saturated forms (Wood *et al.*, 1999; Priolo *et al.*, 2001; Lawrie & Ledward, 2006). Nonetheless, diet can influence fatty acid profiles of ruminant meat, as some unsaturated fatty acids can go through the rumen unchanged (Wood & Enser, 1997; Wood *et al.*, 1999, 2003). Dietary differences therefore result in changes in the fatty acid composition of meat (Dhanda *et al.*, 2003; Nuernberg *et al.*, 2005; Ramanzin *et al.*, 2010; Stelzleni & Johnson, 2010), consequently influencing lipid stability during storage (Wood *et al.*, 1999, 2003) and ultimate sensory quality (Melton, 1990; Wood *et al.*, 1999; Fisher *et al.*, 2000; Priolo *et al.*, 2001; Calkins & Hodgen, 2007).

The majority of studies investigating the influence of diet on meat flavour focus on grass-fed compared to concentrate-fed (grain-based) diets (Larick & Turner, 1990; Wood *et al.*, 1999; Priolo *et al.*, 2001; Wiklund *et al.*, 2003a, 2003b; Nuernberg *et al.*, 2005). These dietary differences have a significant influence on meat flavour, as grass is naturally high in α-linolenic acid (Wood *et al.*, 1999; Priolo *et al.*, 2001; Wiklund *et al.*, 2003b; Wood *et al.*, 2003), while grain-based and diets containing other seeds and plants are high in linoleic acid (Wood *et al.*, 1999; Wiklund *et al.*, 2003b; Wood *et al.*, 2003; Nuernberg *et al.*, 2005). Consequently,

meat derived from grass and concentrate-fed animals have higher n3 and n6 PUFA percentages, respectively (Wood *et al.,* 1999; Fisher *et al.,* 2000; Wood *et al.,* 2003; Calkins & Hodgen, 2007). The meat from game species feeding on different, naturally available vegetation types (browsing, grazing or mixed feeding) can also differ in flavour (Ramanzin *et al.,* 2010). Hoffman *et al.* (2005a) noted that the fatty acid profile of meat derived from predominantly browsing impala (Mopani veld where *Colophospermum mopani* is the dominant tree species) differed from animals feeding mainly on grass (Arid Sweet Bushveld). Nonetheless, research quantifying the effect of dietary regime on the sensory quality of game meat is very limited.

Red meat consumers often consider meat derived from pasture reared animals to differ in flavour from concentrate-fed animals (Priolo *et al.,* 2001). Meat from grass-fed animals has higher flavour intensities (compared to concentrates) due to higher n3 PUFA percentages (Wood *et al.,* 1999; Fisher *et al.,* 2000; Campo *et al.,* 2003). Furthermore, meat with high percentages of long chain n3 PUFA can development grassy (Wiklund *et al.,* 2003b; Scollan *et al.,* 2006) or fishy flavour attributes, which are often not perceived as positive flavour attributes (Nuernberg *et al.,* 2005; Scollan *et al.,* 2006) upon heating. A grassy or 'pastoral' aroma and flavour is also determined by products of α-linolenic acid oxidation and its derivatives (hexanal) (Priolo *et al.,* 2001), as well as compounds derived from oleic acid, while a 'soapy' aroma (octanal) is derived from linoleic acid (Lorenz *et al.,* 2002 as cited in Scollan *et al.,* 2006). A grassy or green aroma has been linked to 1-penten-3-ol, as well as selected aldehydes such as hexanal (green-grassy), octanal (green-fresh) and nonanal (green) in dry-cured ham (Barbieri *et al.,* 1992; Flores *et al.,* 1997).

Larick and Turner (1990) established that a sweet taste and gamey flavour were indicators of forage flavours found in beef meat. Wiklund *et al.* (2003a) found higher sweet taste intensities for meat derived from grass-fed reindeer compared to concentrate-fed animals.

The development of rancid or off-flavours are generally linked to the oxidation of PUFA (Wood *et al.,* 2003; Miller, 2004; Calkins & Hodgen, 2007). Different fatty acids can produce a variety of different meat flavour precursors (Wood & Enser, 1997), as PUFA (especially from polar lipid fractions) are more susceptible to lipid oxidation than MUFA and SFA (Wood *et al.,* 1999; Fisher *et al.,* 2000; Wood *et al.,* 2003; Yancey *et al.,* 2006; Legako *et al.,* 2015). Furthermore, C18:1, C18:2 and C18:3 PUFA will produce different volatile compounds upon heating (Campo *et al.,* 2003). Wood *et al.* (2003) reported that meat with an α-linolenic acid content above 3.0% (of total fatty acids) can produce volatile compounds that adversely impact meat flavour upon cooking. Wiklund *et al.* (2003a) found that meat derived from grass-fed reindeer had higher off-flavour intensities compared to concentrate diets. Priolo *et al.* (2002) and Wiklund *et al.* (2003a) found higher liver-like flavour intensities in meat derived from grass-fed lambs and reindeer, respectively, as compared to concentrate fed animals. Fisher *et al.* (2000) attributed a stronger liver flavour in lamb meat to a higher myoglobin content and the susceptibility of n3 and n6 PUFA to peroxidation during cooking. However, Yancey *et al.* (2006) suggested that a liver-like flavour is not linked to lipid oxidation.

Nonetheless, the meat derived from grass-fed animals often have a higher oxidative stability compared to concentrate-fed animals (Nuernberg *et al.,* 2005), due to higher concentrations of antioxidant vitamin E (α-tocopherol) naturally present in grass-based diets (Wood & Enser, 1997; Mercier *et al.,* 2004; Nuernberg *et*

al., 2005). Vitamin E acts as an antioxidant in cellular membranes where it protects phospholipids from free radicals and thus decreases the rate of pigment and lipid oxidation (Leygonie *et al.*, 2012).

The fatty acid composition of meat from wild ruminants can be altered to more nutritionally favourable levels by manipulating the composition of the diet (Wood *et al.*, 1999; Sampels *et al.*, 2006), however, meat from South African game species are wild and these species are therefore dependent on naturally occurring vegetation in their habitats (Hoffman *et al.*, 2005b; Hoffman & Wiklund, 2006; Carruthers, 2008). South Africa has a range of biomes which account for great variations in vegetation types between regions (Pollock, 1969; Rutherford *et al.*, 2006; Hanks, 2009). As the consumption of different vegetation types can result in differences in fatty acid profiles of the meat, it is suggested that the flavour of game meat derived from South African species will differ between regions, as was found by Hoffman *et al.* (2005a) for impala. In addition, the nutritional value of naturally occurring vegetation can also vary between seasons and consequently influence game meat flavour (Ramanzin *et al.*, 2010; Neethling *et al.*, 2014a). It is therefore important to quantify the effect of dietary differences on the sensory quality of the meat derived from South African game species.

2.3.6 Harvesting conditions

The majority of South African game species utilised for game meat production is classified as wild and free-living (Hoffman *et al.*, 2005b; Hoffman & Wiklund, 2006; Carruthers, 2008). South African game species are therefore often harvested at night so as to minimise the effect of ante-mortem stress on meat quality (Lewis *et al.*, 1997; Kritzinger *et al.*, 2003). However, some habitats (mountains and dense vegetation) and species types (such as kudu, *Tragelaphus strepsiceros*) are more suited for day harvesting (Kritzinger *et al.*, 2003; Hoffman & Wiklund, 2006; Hoffman & Laubscher, 2011), even though the latter is linked to increased levels of ante-mortem stress, as animals are able to see better than at night (Kritzinger *et al.*, 2003; Hoffman & Laubscher, 2009, 2010).

Nevertheless, wild species are generally more susceptible to ante-mortem stress (Hoffman & Wiklund, 2006; Daszkiewicz *et al.*, 2012), which can result in high pHu values causing dark, firm and dry (DFD) meat (Hoffman & Wiklund, 2006; Hoffman *et al.*, 2007a; Wiklund *et al.*, 2007). Furthermore, the susceptibility of game species to ante-mortem stress differs between species (Hoffman & Wiklund, 2006; Daszkiewicz *et al.*, 2012) and due to the reproductive cycle (rut/mating season) (Wiklund *et al.*, 1996; Renecker *et al.*, 2005; Wiklund *et al.*, 2010; Daszkiewicz *et al.*, 2012). In addition, diet or feeding regime can also influence the pHu of meat (Priolo *et al.*, 2001). Lower glycogen stores in the muscles of grass-fed animals have been correlated with higher pHu values in meat (Priolo *et al.*, 2002; Wiklund *et al.*, 2003a), although some contradictory results on the latter have been reported (Wiklund *et al.*, 2003b). Wiklund *et al.* (1996) noted that the nutritional status and physical condition of reindeer had a significant influence on their ability to tolerate stress factors.

Several studies have reported on the influence of pHu on the sensory quality (Ba *et al.*, 2014), more specifically meat flavour (Young *et al.*, 1993; Calkins & Hodgen, 2007), tenderness (Hoffman *et al.*, 2007a; Ramanzin *et al.*, 2010; Wu *et al.*, 2014a) and juiciness (Hoffman, 2000; Dhanda *et al.*, 2003). Braggins (1996)

established that desirable aroma and flavours associated with cooked mutton decreased, while undesirable aroma and flavours increased with an increase in meat pHu values. Furthermore, this author also found decreased concentrations of several volatile compounds (primarily aldehydes) due to increased pHu values of the meat. Van Ba *et al.* (2013) also established that the formation of volatile compounds associated with desirable attributes of meat was ideal at a pHu of 5.5, as compared to a pH of 6.2. Wiklund *et al.* (2007) established that reindeer meat is tender regardless of the pHu value.

Wild and free-living game species are thus more susceptible to ante-mortem stress and as a result the meat will often have higher pHu values. In addition, the muscles of wild game species generally have much lower glycogen stores than farmed species. The meat from the former will therefore be more prone to higher pHu values. The variability in pHu values of meat derived from these game species will negatively influence the sensory attributes and consequently the consistency of commercially available game meat products. The harvesting method used for game species should therefore be considered carefully and the species and habitat involved should also be taken into account.

2.3.7 Ageing of meat

The ageing of meat (also known as conditioning) is the process of keeping unprocessed meat above the freezing point (time may vary according to species and muscle cut used), so as to increase the flavour and tenderness (Lawrie & Ledward, 2006). Ageing is therefore generally applied as a means to improve the sensory quality of meat (Ba *et al.*, 2014), principally the tenderness (Spanier *et al.*, 1997; Ngapo *et al.*, 2013; Ba *et al.*, 2014; North & Hoffman, 2015). However, the steady breakdown of the myofibrillar protein structure during ageing (Wood *et al.*, 1999; Ngapo *et al.*, 2013; Ba *et al.*, 2014) generates amino acids and peptides which can cause changes in meat flavour and taste (Wood *et al.*, 1999; Ngapo *et al.*, 2013). It is therefore important to consider the effect of ageing on the formation of volatile compounds, in addition to the non-volatile compounds contributing to meat taste (Shahidi, 1998; Ba *et al.*, 2014).

Ba *et al.* (2014) found increased values for the thiobarbituric acid reactive substances (TBARS) with an increased meat ageing time. However, it was established that ageing beef for 28 days did not result in the excessive oxidation of lipids. Nonetheless, the ageing of beef produced 58 volatile compounds through lipid oxidation/degradation of fatty acids and the Maillard reaction. Lipid oxidation/degradation produced straight chain aldehydes, ketones, alcohols, hydrocarbons and furans, while the Maillard reaction produced sulphur and nitrogen compounds such as pyrazines. Ageing time significantly influenced the quantities of 26 volatile compounds, primarily aldehydes. However, some Maillard compounds (methanethiol, dimythyldisulfide and 2-methylpyrazine) also increased significantly with ageing time, which are attributable to increased concentrations of free amino acids during ageing. In addition, Ba *et al.* (2014) found differences in the influence of ageing time on volatile compounds in beef meat derived from LD and ST muscles, as beef ST muscles contained higher quantities of benzaldehyde (associated with unpleasant flavours) after 28 days of ageing. The influence of ageing time can therefore be different between anatomical locations (see section 3.4 on *muscle anatomical location*).

Smith *et al.* (2014) established that extreme dry-ageing of beef carcasses resulted in extreme drying of the exterior muscles (*M. spinalis thoracis* and *M. gluteobiceps*), resulting in the development of undesirable flavours such as musty and putrid flavours. Campo *et al.* (1999) found that the overall aroma, liver-like aroma and acid-associated flavour intensities increased when beef strip loin was aged past 21 days. Other researchers have established that beef meat aged over 28 days can also result in undesirable sensory changes, such as the formation of bitter or sour tastes. Furthermore, post-mortem ageing can result in a decline in positive meat flavour attributes (Spanier *et al.*, 1997). Marks *et al.* (1997) established that ostrich meat aged for seven days had higher perceived intensities of flavour attributes compared to beef cuts. In addition, reindeer *longissimus* muscles has been found to have higher proteolytic enzyme activity, as well as lower inhibitor levels compared to beef muscles (Barnier *et al.*, 1999). The latter suggests that the meat derived from game species might not require as long ageing periods compared to beef meat (North *et al.*, 2015), which warrants species-specific research on the effect of different ageing times on the sensory quality of various game meats.

The post-mortem ageing of meat thus influences the sensory quality, by changing the overall flavour, levels of volatile compounds, as well as the protein composition (Spanier *et al.*, 1997). However, research investigating the effect of ageing and ageing time on the sensory quality of South African game meat or any other exotic meat is limited. This limitation is most probably attributable to the fact that very little game meat is aged; most of the game meat exported is in a deboned, frozen form (Hoffman & Wiklund, 2006). Nonetheless, it is evident from literature that post-mortem ageing will have an effect on the sensory quality of game meat.

2.3.8 Packaging and storage conditions

The game meat industry of South Africa is a developed industry (Ramanzin *et al.*, 2010). In southern Africa, game species are primarily harvested for commercial meat production during winter from May to August, as this period is classified as the hunting season (Hoffman *et al.*, 2009c). Consequently, a large amount of meat is available in a short period of time. South African game meat can therefore not be sold entirely as fresh meat. As a result game meat is often frozen to prolong the shelf-life and to allow for its distribution to different regions and countries (exports) (Leygonie *et al.*, 2012).

Game meat products are therefore primarily exported from South Africa as frozen products (Leygonie *et al.*, 2012). Typically whole muscles are vacuum-packed and frozen prior to export. Freezing of meat products for prolonged shelf-life is an age-old practice, however, Leygonie *et al.* (2012) indicated that freezing and thawing has a significant impact on the quality and flavour of meat. The final temperature of frozen storage determines the quantity of unfrozen water available for chemical reactions (Leygonie *et al.*, 2012), such as primary lipid oxidation (peroxidation) in meat, which upon thawing can lead to radical secondary lipid oxidation reactions (Hansen *et al.*, 2004). These chemical reactions result in adverse changes in meat colour, aroma, flavour and healthiness (Monahan, 2000; Hansen *et al.*, 2004; Faustman *et al.*, 2010; Hoffman *et al.*, 2014).

Furthermore, ice crystal formation during freezing damages the ultrastructure and concentrates the solutes of meat, consequently influencing the physical quality characteristics of meat (Leygonie *et al.,* 2012). The latter, together with the denaturation and/or modification of proteins, result in decreased water-holding capacity of meat (Savage *et al.,* 1990), which leads to higher volumes of exudates in meat packaging and negatively influences consumer acceptability (Leygonie *et al.,* 2012). Freezing damage to cell membranes by ice crystals also cause the release of mitochondrial and lysosomal enzymes, haem iron and other prooxidants (Thanonkaew *et al.,* 2006), which contributes to increased secondary lipid oxidation, as well as an increased rate and degree of protein oxidation (Monahan, 2000). Protein oxidation will ultimately influence the sensory quality (Wood *et al.,* 1999) and consumer acceptance (Miller, 2004) of meat products.

Prolonged frozen storage is therefore not necessarily a means of ensuring the shelf-life and sensory quality. Nonetheless, the storage of muscle foods at freezer or refrigeration temperatures, compared to ambient storage temperatures, will retard the oxidative deterioration process, although lower storage temperatures do not always reduce the susceptibility to lipid oxidation (Monahan, 2000). During fresh meat display at retail, red oxymyoglobin is oxidised to brown metmyoglobin, which results in changes in meat colour. The latter usually occurs parallel to the development of rancidity in meat at retail (Wood *et al.,* 2003). As meat derived from game species are generally low in IML content (Table 2.3) and contain high percentages of PUFA (polar lipids), it is more susceptible to rapid lipid oxidation (Wood *et al.,* 1999, 2003), resulting in colour deterioration (Wood *et al.,* 2003; Cornforth & Jayasingh, 2004) and rancidity, consequently influencing the shelf-life of the end-product (Wood *et al.,* 2003). This susceptibility to oxidation influences flavour development during cooking (Wood *et al.,* 1999, 2003) (see section 3.9 on *cooking methods*). Antioxidants in meat can delay colour and lipid oxidation and consequently extend the shelf-life of fresh meat (Wood *et al.,* 2003) (see section 3.5 on *diet*).

Packaging of muscle foods play an important role in determining the rate and extent of lipid oxidation (Monahan, 2000). Modified atmosphere packaging (MAP) with the inclusion of some oxygen (O_2) and carbon dioxide (CO_2) can prolong the shelf-life of fresh meat, as it helps to maintain a bloomed, red appearance and decreases microbial activity, respectively (McMillin, 2008). Although MAP reduces the negative influence of freezing and thawing on meat colour stability (Mancini & Hunt, 2005; Joseph *et al.,* 2010), the inclusion of high concentrations of oxygen in MAP can result in increased oxidation of lipid and protein fractions in meat (Mancini & Hunt, 2005; Cruzen *et al.,* 2015). Cruzen *et al.* (2015) found that high-oxygen MAP (80% O_2 / 20% CO_2) of beef round (*Semimembranosus*, *Semitendinosus* and *Adductor*) cuts were more discoloured, with greater lipid oxidation and decreased sensory quality compared to vacuum packaged steaks (*Semimembranosus*). While, Brenesselová *et al.* (2015) established that vacuum-packaged storage conditions positively influenced the microbiological, biochemical and sensory characteristics of ostrich meat (as compared with non-vacuum packed). Vacuum-packaging and oxygen-depleted MAP can minimise bacterial growth and lipid oxidation as long as there is no requirement for myoglobin to be in the red, oxygenated form (Monahan, 2000). Within the South African context, most of the game meat exported is in the form of individually vacuum-packed frozen muscles which may be defrosted and re-packaged as steaks under MAP

conditions in the importing country. Very little is known about this practice. Similarly, little fresh game meat is sold as such in South Africa; that which is sold is typically vacuum-packaged.

While meat colour is the first and most important intrinsic quality cue influencing consumer acceptability of meat at the point of sale (Cornforth & Jayasingh, 2004; Troy & Kerry, 2010), it is suggested that high-oxygen MAP is not a suitable packaging type for South African game meat. Though an enhanced meat colour can improve the demand for game meat products, higher sensory quality linked to oxygen-free packaging can ensure the ongoing purchasing intent of game meat products. The meat derived from game species should therefore be sold fresh and vacuum-packaged or in oxygen-depleted MAP if possible, so as to minimise adverse effects of long-term storage at refrigerated or frozen temperatures.

2.3.9 Cooking methods

The sensory attributes of meat is influenced by the cooking method and final internal (core) temperature (Spanier *et al.*, 1997; Calkins & Hodgen, 2007; Ngapo *et al.*, 2013). Upon heating (cooking) meat flavour is developed through the production of volatile, aroma and lipid oxidation products and the reaction of these with Maillard reaction products, so as to produce additional volatile compounds (Farmer & Mottram, 1992; Wood *et al.*, 2003). Meat flavour development during cooking is extremely complex. Furthermore, the fatty acid composition of meat is especially important for meat flavour development during cooking (Wood *et al.*, 2003), as lipid oxidation is accelerated in cooked meat (Igene *et al.*, 1979; Tichivangana & Morrissey, 1985). Non-haem, especially ferrous iron (Fe^{2+}), is a major pro-oxidant of lipid autoxidation in cooked meat. Cooking causes denaturation of lipoproteins and the destabilisation of muscle structures and therefore releases non-haem iron from haem pigments (Igene *et al.*, 1979; Tichivangana & Morrissey, 1985). Cooking also causes the denaturation (unfolding) of the globin protein in myoglobin, leaving the haem molecule exposed and even more prone to oxidation (Cornforth & Jayasingh, 2004).

The high PUFA content of South African game meat (Table 2.3) is a vital consideration upon cooking, as the thermal oxidation of long-chain PUFA can contribute to the formation of undesirable flavours (Wood *et al.*, 1999; Calkins & Hodgen, 2007). Meat derived from game species generally contain higher levels of myoglobin (darker colour) and thus also higher iron content compared to meat derived from domestic species (Williams *et al.*, 1983; Hoffman *et al.*, 2005a; Lawrie & Ledward, 2006; Nair *et al.*, 2014). Tichivangana and Morrissey (1985) established that a higher degree of unsaturation of a meat product increases its susceptibility to lipid oxidation by pro-oxidants such as ferrous iron (Fe^{2+}). The high iron content together with the higher levels of PUFA increases the susceptibility of game meat to lipid oxidation during cooking. South African game meat is therefore more prone to the formation of off-flavours and aroma during cooking, although the susceptibility to oxidation is species-specific (Onyango *et al.*, 1998; Ramanthan *et al.*, 2009).

Furthermore, a limiting factor with consumer acceptability of cooked game meat is that the meat is generally very lean and therefore often overcooked (Dhanda *et al.*, 2003). Dhanda *et al.* (2003) suggested the use of marinades to compensate for the loss of moisture during cooking, while not losing the characteristic flavour of the meat. However, the correct cooking methods for the preparation of lean game meat will not necessitate

the use of marinades; no literature could be sourced that describes the effect of cooking temperature on the sensory attributes of game meat.

2.4 Concluding remarks

South African game species are still wild and free-living (Hoffman & Wiklund, 2006). Presently, little selection as pertaining to age and gender is practiced when harvesting game; typically the animals found are hunted. Very little knowledge exists on the ideal age structure and gender ratio on the production efficiency of the various game species.

However, in-depth meat flavour studies quantifying the sensory attributes, using descriptive sensory analysis with a trained panel and volatile compounds for game meat derived from these wild species, is lacking. In addition, no research is available on the use of GC-O, a valuable flavour analysis technique used to characterise odour-active volatile compounds contributing to the characteristic flavour of foodstuffs. Moreover, the odour threshold values of each component should also be established, so as to establish the contribution of each compound towards the flavour of the meat. Also, more studies comparing the sensory quality of meat from different game species is required, as the comparison of results from individual studies is virtually impossible due to differences in sample preparation and methods of analyses (Rødbotten *et al.,* 2004). It is also suggested that method development be conducted so as to standardise a method for determining the volatile compounds present in raw game meat. The latter should also be developed to allow for relevant correlations with descriptive sensory analysis results for game meat.

It is evident that there exists a variety of factors influencing the sensory quality of game meat. The influence of each factor on the flavour of game meat is suggested to be species-specific, as results from various studies were found to be contradictory. The latter therefore warrants further research as meat derived from South African game species is often marketed under a generic name ("game meat").

Furthermore, age and gender is not taken into account when harvesting game species for commercial use as there are no set standards for the classification of age and since most animals are harvested at night, which results in difficulties with identifying genders. Nonetheless, age and gender both influence the sensory quality of game meat. In addition, muscle anatomical location will also influence the flavour of game meat, especially when the meat is derived from wild and free-living species with varying activity levels. However, researchers often only analyse the LTL muscle due to its commercial importance (Kauffman *et al.,* 1990) and since it is generally larger in size relative to other skeletal muscles.

Moreover, it is difficult to establish the impact of dietary regime on the flavour of South African game meat products, as these animals occur throughout the country and consume a variety of different vegetation types (browse, graze and mixed diets). A limited number of researchers have investigated the influence of dietary regime (and season) on the quality and chemical composition of South African game species (Hoffman *et al.,* 2005a, 2007a, 2007b, 2007c, 2007d; Neethling *et al.,* 2014a, 2014b).

Nonetheless, the meat derived from South African game species is generally high in protein and can be marketed as being low in fat (<3.0 g.100 g^{-1}) according to South African regulations (Anon., 2010).

Furthermore, game meat often has favourable fatty acid profiles and is generally considered healthy and tender (Warner-Bratzler shear force values <42.87 N) (Hoffman, 2000; Destefanis *et al.*, 2008; Hoffman & Laubscher, 2009; Hoffman *et al.*, 2010b; North & Hoffman, 2015). The game meat industries should thus focus on these attributes in their marketing strategies, as no meat industry can survive without consumer satisfaction (Troy & Kerry, 2010).

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Chapter 3

Influence of farm location and gender on the fatty acid content and volatile compound profile of springbok (*Antidorcas marsupialis*) meat

Abstract

In South Africa, springbok are harvested on various farms, situated in different regions consisting of a variety of vegetation types. However, dietary regime and gender influence the fatty acid content and volatile compound profile of ruminant meat. The aim of this study was to quantify the influence of farm location and gender on the fatty acid content (mg.g^{-1} of meat) and volatile compound profile of springbok meat. Twelve mature springbok (six males and females) were randomly harvested from each of three farms situated in different regions of South Africa. The volatile compound profile of the *longissimus thoracis et lumborum* was dominated by lipid-derived compounds. Higher C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) content was linked to higher percentages of selected aldehydes, alcohols, ketones and 2-pentylfuran. Gender influenced the volatile compound profile of springbok meat from one farm only, as the meat from female animals contained higher percentages of lipid-derived compounds. Furthermore, the total polyunsaturated fatty acid (PUFA) content was highest for the meat from male springbok, resulting in lower ($p<0.05$) polyunsaturated to saturated fatty acid (PUFA:SFA) ratios. These results indicate that farm location (diet) and gender influences the fatty acid content and volatile compound profile of springbok meat.

Keywords: Game meat; Volatile compounds; Fatty acids; Grazing; Browsing

3.1 Introduction

Flavour development in foodstuffs is very complex (Pegg & Shahidi, 2004; Calkins & Hodgen, 2007). A specific flavour sensation can be produced by one or a combination of volatile compounds (Mottram, 1998a, 1998b; Chambers IV & Koppel, 2013). As a result, hundreds of volatile compounds exist and can contribute to the characteristic aroma and flavour of meat (Calkins & Hodgen, 2007).

Meat is a very important source of macro- and micronutrients, yet the consumption thereof is generally not linked to the nutritional properties, but rather to a characteristic texture, aroma and/or flavour (Farmer, 1994). Nonetheless, the flavour of meat is linked to its nutritional properties, which is influenced by the dietary regime of the animal (Farmer, 1994; Vasta & Priolo, 2006; Calkins & Hodgen, 2007).

Numerous studies investigating the influence of dietary regimes on the composition and sensory quality of meat, focus on grass vs. grain (or concentrate) diets in domesticated species (Wood *et al.*, 1999; Wiklund *et al.*, 2001, 2003a, 2003b; Vasta & Priolo, 2006). Grasses are high in C18:3n3 (α-linolenic acid), while grain-based or concentrate diets are high in C18:2n6c (linoleic acid). Consequently the meat derived from these two diets will contain high levels of omega-3 polyunsaturated fatty acids (n3 PUFAs) and omega-6 polyunsaturated fatty acids (n6 PUFAs), respectively (Wiklund *et al.*, 2001).

Hoffman *et al.* (2005a) found differences in the fatty acid profile (percentage of total fatty acids) of impala (*Aepyceros melampus*) meat derived from two regions (farms), however, aroma and flavour differences were

not investigated. Hoffman *et al.* (2007a) found no differences in the fatty acid profile (percentage of total fatty acids) of springbok meat, while these authors did find differences in the sensory quality (gamey aroma, initial and sustained juiciness and residual tissue) of springbok meat derived from different regions (farms) (Hoffman *et al.*, 2007b). Instrumental methods for the analysis of meat aroma and flavour would have been useful to clarify which volatile compounds contributed to the latter sensory differences in springbok meat. However, no research is available on the volatile compounds of the meat derived from South African game species.

Brown *et al.* (2014) established that correlations between sensory flavour descriptors, consumer preferences, the fatty acid content and the volatile compound profile of meat is driven by the fatty acids present in the polar lipid fraction (phospholipids) of the intramuscular lipids (IML). Furthermore, the structural phospholipids contain high quantities of PUFA (Fisher *et al.*, 2000). In addition, Mottram and Edwards (1983) established the importance of phospholipids, as opposed to triglycerides, in meat flavour development. The meat derived from South African game species have low levels of IML and high proportions of PUFAs (Fisher *et al.*, 2000; Hoffman & Wiklund, 2006); variations in the PUFA composition of the meat derived from game species could therefore influence the profile of volatile compounds contributing to the characteristic aroma and flavour of game meat.

South African game species are still wild and free-living and therefore dependent on natural vegetation types as food sources in their habitats (Hoffman *et al.*, 2005b; Hoffman & Wiklund, 2006). The springbok is the most well-known and extensively harvested game species in South Africa and Namibia (Hoffman *et al.*, 2004; Hoffman & McMillin, 2009). Furthermore, springbok are found widely distributed throughout southern Africa (Cain III *et al.*, 2004) and utilise both grasses and bushes. Consequently, springbok are classified as a mixed feeding species (Van Zyl, 1965), although the proportion of grazing and browsing in the diet of springbok could vary between regions (farms). Van Zyl (1965) suggested that grazing is of greater importance to springbok during the wet season, while shrubs and leaves from bushes (browsing) are preferred during the dry season. In addition, the vegetation types and rainfall patterns differ between regions (Kruger, 2007; Hanks, 2009). The dietary regime of springbok is therefore different between regions (farms), as well as due to seasonal differences in the nutritional value and quality of naturally occurring vegetation (Bigalke, 1972).

The aim of the present study was to investigate the influence of farm location and gender on the fatty acid content and volatile compound profile of springbok meat derived from three farms (diets), located in regions with different naturally occurring vegetation types (grazing and browsing).

3.2 Materials and methods

3.2.1 Experimental layout and harvesting

In this study mature springbok were harvested from three farms in South Africa: farm A, Kimberley District in the Northern Cape Province; farm B, Coastline of the Western Cape Province near Witsand; and farm C, Wellington District of the Western Cape Province.

Farm A was situated in the Savanna Biome and contained Kimberley Thornveld, which formed part of the Eastern Kalahari Bushveld Bioregion (Mucina & Rutherford, 2006). This farm generally receives seasonal

rainfall which primarily (>66%) occurs between October and April and peaks from January to March (Kruger, 2007).

Farm B was situated in the Fynbos biome and contained Eastern Rûens Shale Renosterveld, which formed part of the East Coast Renosterveld Bioregion (Mucina & Rutherford, 2006). In addition, some sections of this farm consisted of cultivated land (Lucerne [alpha alpha] and rye grass). Springbok from farm B could roam freely between the latter vegetation types. The region in which farm B was situated received rain more or less throughout the year, with the majority (>66%) of the precipitation occurring between April and September in addition to receiving some rainfall patterns in summer (December to February) and autumn (March to May) (Acocks & Momberg, 1988; Rebelo, 1996; Rutherford *et al.*, 2006; Kruger, 2007).

Farm C was situated in the Fynbos Biome and contained Hawequas Sandstone Fynbos, Swartland Alluvium Fynbos and Swartland Shale Renosterveld (Mucina & Rutherford, 2006). In addition, sections of farm C consisted of old cultivated land (abandoned 10-25 years ago) dominated by grass species, in particular *Cynodon dactylon* (kweek, Bermuda grass). Farm C received the majority of its rainfall in the winter months (April to September). The springbok on farm C was also able to roam freely between the above-mentioned vegetation types.

All springbok were harvested during July of 2013. July is characterised as the dry season for farm A, while for farms B and C July is generally the middle of the wet season. Twelve mature springbok were randomly selected and harvested per farm, of which six were male and six were female. Harvesting occurred at night (ethical clearance number: SU-ACUM14-001SOP) in accordance with the *Guidelines for the Harvesting of Game for Meat Export* (Van Schalkwyk & Hoffman, 2010). Exanguination occurred in the field and the bled, undressed carcasses were weighed (farm A, 24.77 kg ± 1.105; farm B, 26.46 kg ± 0.798; farm C, 28.87 kg ± 1.040, female, 24.46 kg ± 0.476; male, 28.94 kg ± 0.886) within two hours post-mortem, where after the head, legs and skin were removed and evisceration occurred. The springbok carcasses were refrigerated following dressing. After 24 h of refrigeration (4 ± 1°C) the dressed carcasses were weighed to obtain the cold carcass weight (farm A, 14.07 kg ± 0.509; farm B, 15.07 kg ± 0.555; farm C, 15.73 kg ± 0.782; female, 13.36 kg ± 0.212; male, 16.56 kg ± 0.466) and the dressing percentages were calculated (farm A, 57.2% ± 1.468; farm B, 56.9% ± 0.947; farm C, 54.2% ± 0.870; female, 54.8% ± 1.133; male, 57.4% ± 0.625).

3.2.2 Sampling and sample preparation

The *longissimus thoracis et lumborum* (LTL) muscle was sampled from the right side of the cooled springbok carcasses and all visible connective tissue was removed. The *longissimus lumborum* section was sub-sampled from the LTL muscle, homogenised, vacuum-packed and frozen at -20°C for analysis of the fatty acid content ($mg.g^{-1}$ of meat).

3.2.3 Analysis of fatty acids

The homogenised meat samples were thawed for 24 h at 4°C (± 1°C) prior to fatty acid analysis. Two grams of each sample was extracted according to the method by Folch *et al.* (1957) and as described in detail by

Neethling *et al.* (2014), with the exception of 100 µl hexane which was added to the dried sample before transferring 1 µl to a vial for injection.

Fatty acid methyl esters (FAMES) were analysed on an Agilent 6890 N (Agilent Technologies, Palo Alto, CA, USA) gas chromatograph (GC) flame ionisation detector. Separation was performed on an Agilent J&W DB-225MS (30 m, 0.25 mm internal diameter, 0.25 µm film thickness) capillary column (part number 122-2932). The oven temperature was initially held at 50°C for 1 min, then increased to 175°C at 25°C.min^{-1}. Once the latter temperature was reached, a further temperature increase up to 210°C followed at 2°C.min^{-1} and was held for 6 min, followed by a final temperature increase to 220°C at 1°C.min^{-1}, held for 7 min. Hydrogen was used as carrier gas at a flow rate of 0.7 ml.min^{-1}. The injection temperature was maintained at 240°C with a split of 5:1. The FAMES in the total lipids of each sample (mg.g^{-1} of sample) were identified by comparing their retention times with those of a standard FAME mixture (Supelco™ 37 Component FAME Mix, 10 mg.ml^{-1} in CH_2Cl_2, Catalogue Number 47885-U, Supelco™, North Harrison Road, Bellefonte, PA 16823-0048, USA).

3.2.4 Analysis of volatile compounds using SPME-GC-MS

A portion of the freshly homogenised springbok LTL sections was weighed (6.0 g ± 0.1) in 20 mL solid-phase microextraction (SPME) headspace vials and sealed with a polytetrafluoroethylene (PTFE, Teflon®)/silicone septa and steel cap. All samples were frozen for less than a month at -20°C prior to analysis. Upon thawing, 50 µL of 3-octanol was added as internal standard. The vials were equilibrated at 70°C for 30 min using a CombiPAL SPME autosampler (CTC, Switzerland). A fibre (conditioned by heating in a gas chromatograph injection port at 270°C for 60 min) coated with a 50/30 µm thickness of divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) was inserted into the headspace above the sample and held for 10 min (with agitation). The fibre was consequently withdrawn into the needle by the autosampler and inserted into the injection port of an Agilent 6890 N (Agilent Technologies, Palo Alto, CA, USA) gas chromatograph (GC) coupled with a mass spectrometer (MS) detector 5975B (Agilent Technologies). The SPME fibre was desorbed and held in the injection port at 250°C for 10 min. The fibre was inserted in a fibre conditioning station for 15 min between samples for cleaning so as to prevent cross-contamination. The injection port was operated in pulsed splitless mode (300 kPa). Volatile compounds were separated using a DB-FFAP capillary column (60 m, 0.25 mm internal diameter, 0.5 µm film thickness). The oven temperature was initially held at 70°C for 1 min, increased to 142°C at 3°C.min^{-1}, followed by a further increase to 240°C at 5°C.min^{-1} and held at 240°C for 3 min. The total run time per sample was 48 min.

Helium was used as the carrier gas with a constant flow rate of 1.9 ml.min^{-1}. The transfer line was maintained at 280°C. Mass spectra was obtained using a mass selective detector working in electronic impact at 70 eV, operated in full scan mode (35-450 *m/z*) with the ion source and quadrupole temperatures maintained at 240°C and 150°C, respectively.

Compounds were tentatively identified by comparing their mass spectra with those contained in the NIST05 (National Institute of Standards and Technology, Gaithersburg) library, and the Wiley (275) library. The

results reported are expressed as the percentage area of the peak for the total ion count (TIC) and is therefore semi-quantitative.

3.2.5 Statistical analysis

The experimental design was a completely randomised factorial design with six springbok harvested at random from each of the three farms and two genders. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed, using General Linear Models (GLM) Procedure of SAS software (Version 9.2; SAS Institute Inc, Cary, USA). The model for the statistical design is indicated by the following equation:

Model: $y_{ijk} = \mu + f_i + g_j + fg_{ij} + \varepsilon_{ijk}$

where terms within the model are defined as: the response obtained for the k^{th} observation from the i^{th} farm and the j^{th} gender (y_{ijk}), the overall mean (μ), the farm main effect (f_i), the gender main effect (g_j), the farm by gender interaction effect (fg_{ij}) and the random error (ε_{ijk}) associated with response on the k^{th} observation in the i^{th} farm and the j^{th} gender.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In cases where there was significant deviation from normality outliers were removed when the standardised residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to compare means (Ott, 1998). A probability level of 5% was considered significant for all significance tests, while 10% was considered significant where biologically relevant. Where applicable, correlation coefficients were calculated for the fatty acid and volatile compound data by means of the Pearson's correlation coefficient (r) (Snedecor & Cochran, 1980).

3.3 Results

3.3.1 Fatty acid content

Table 3.1 indicates the level of statistical significance (p-values) for the influence of the main effects of farm (F) and gender (G), and their interaction (FxG) on the fatty acid content (mg.g^{-1} of meat) of springbok meat. The average means ± standard error (Means ± SE), minimum and maximum values for the fatty acid content of springbok meat in this study are indicated in Table 3.1, so as to provide insight into the importance of each of the fatty acids. The IML content (g.100 g^{-1} of meat) of springbok meat in this study was more or less 3.0 g.100 g^{-1}, being higher ($p<0.01$) for the meat derived from farm C (farm C, 3.37 g ± 0.200), intermediate for farm B (farm B, 3.06 g ± 0.221) and lowest ($p<0.01$) for farm A (farm A, 2.81 g ± 0.138). The IML content also differed between genders, being higher ($p<0.01$) in the meat derived from female animals (3.52 g ± 0.154) as compared to males (2.64 g ± 0.076). Due to the low IML content of springbok meat in this study, the fatty acids present at very low levels (<10 mg.g^{-1} of meat) will not be discussed further. However, the essential

fatty acids (C18:2n6c, linoleic acid and C18:3n3, α-linolenic acid) and fatty acid totals will be discussed irrespective of their presence at low levels in springbok meat.

A significant interaction existed between the main effects (farm and gender) for the C18:1n9c (oleic acid), C18:3n3 (α-linolenic acid), total saturated fatty acids (SFA), total monounsaturated fatty acids (MUFA) and the polyunsaturated to saturated fatty acid ratio (PUFA:SFA ratio) content of springbok meat (Tables 3.1 and 3.2). Table 3.3 depicts the significant effect of farm (diet) on the content of C18:2n6c (linoleic acid), total n3 PUFA and the omega-6 to omega-3 polyunsaturated fatty acid ratio (n6:n3 PUFA ratio) in springbok meat. Springbok meat derived from farm B had the highest ($p<0.10$) C18:2n6c (linoleic acid) content (Table 3.3). The total n3 PUFA content was highest ($p<0.05$) in springbok meat derived from farms B and C, while the n6:n3 PUFA ratio was highest ($p<0.01$) in springbok meat derived from farm A (Table 3.3).

Table 3.4 depicts the influence of gender on the content of C18:2n6c (linoleic acid) and the total PUFA in springbok meat. The C18:2n6c (linoleic acid) and total PUFA content was highest ($p<0.01$) in springbok meat derived from male animals (Table 3.4).

3.3.2 Volatile compounds

Table 3.5 depicts the profile of volatile compounds present in springbok meat, as arranged by chemical classes: aldehydes; alcohols; ketones; benzene compounds (aromatics); furans; carboxylic acids; esters; ethers; sulphur-containing compounds; and sulphur- and nitrogen containing compounds. Table 3.5 also indicates the retention times, aroma descriptions derived from literature (relevant to whole meat portions from a variety of species) and level of statistical significance (p-values) for the influence of the main effects of farm (F) and gender (G), and their interaction (FxG) on the quantity (semi-quantitative data) of the volatile compounds (percentage area of the peak) present in springbok meat.

Octanal (aldehyde), 1-penten-3-ol (alcohol), 6-methyl-5-hepten-2-one (ketone) and pentanoic acid (carboxylic acid) were detected in the meat of a few springbok, however, these were only in selected samples from various farms. It was therefore decided not to include these compounds as they were deemed not to be representative of the farm location (dietary regime) (Table 3.5).

A significant interaction existed between the main effects (farm and gender) for the percentages of some aldehydes (heptanal and nonanal), alcohols (1-hexanol, 1-heptanol, 2-octen-1-ol, 1-octanol and 1-nonen-4-ol), benzene compounds (4-ethylbenzaldehyde) and sulphur-containing compounds (dimethyl sulphone) in springbok meat (Table 3.6). Table 3.7 depicts the significant effect of farm (diet) on the percentages of some aldehydes (hexanal), alcohols (2,3-butanediol, 1-pentanol, 1-octen-3-ol and 2-ethylhexanol), ketones (2,3-butanedione, 3-hydroxy-2-butanone, 2,3-octanedione and 3-octanone), furans (2-pentylfuran), carboxylic acids (acetic acid, butanoic acid, hexanoic acid and heptanoic acid), esters (2-propenoic acid, butyl ester and propanoic acid, butyl ester), ethers (propane, 2-(ethenyloxy)-) and sulphur- and nitrogen containing compounds (4-methylthiazole) in springbok meat. The 2,3-butanediol and 2,3-butanedione (diacetyl) percentages were significantly higher in springbok meat derived from farm A (Table 3.7). The 3-hydroxy-2-butanone (acetoin) percentage was highest ($p<0.01$) in springbok meat derived from farms A and C, while the

2-ethylhexanol, acetic acid, 2-propenoic acid, butyl ester and propanoic acid, butyl ester percentages were significantly higher in springbok meat derived from farm C (Table 3.7). Springbok meat derived from farm B had the highest ($p<0.01$) percentage of hexanal, 1-pentanol, 1-octen-3-ol, 2,3-octanedione, 3-octanone, 2-pentylfuran, butanoic acid, hexanoic acid, heptanoic acid, propane, 2-(ethenyloxy)- and 4-methylthiazole (Table 3.7). The 3-hydroxy-2-butanone (acetoin) percentage differed ($p<0.01$) between genders, being higher in the meat derived from female springbok as compared to males.

3.4 Discussion

The key precursors of meat flavour are lipid and water-soluble compounds (Mottram, 1998a). Furthermore, the majority of volatile compounds formed in cooked meat are derived from the thermal degradation of lipids and the Maillard reaction (Mottram, 1998a; Roldán *et al.*, 2015). The lean portion of meat contributes to a general meat-like flavour (non-species-specific), while the IML (phospholipids and to a lesser extent triglycerides) contribute to species-specific flavours of cooked meat (Hornstein & Crowe, 1960, 1963; Mottram, 1998b).

The method and time of cooking can influence the volatile compound profile of meat (Lorenzo & Domínguez, 2014). Mild cooking methods and temperatures have been associated with the formation of mainly lipid degradation/oxidation products, while more intense methods (higher temperatures and longer times) have been associated with a decrease in lipid degradation/oxidation products and an increase in the formation of Maillard reaction and Strecker degradation products in meat (Mottram, 1985; Roldán *et al.*, 2015). The extraction temperature used in this study (70°C) was not well suited for the formation of compounds derived from heat-induced pathways such as the Maillard reaction and Strecker degradation (Calkins & Hodgen, 2007). Nonetheless, this extraction temperature was specifically chosen as it is close to the recommended internal temperature for cooked lamb and beef meat (71°C) when conducting descriptive sensory analysis of cooked meat (AMSA, 1995). Moreover, it was postulated that the use of a similar temperature would enable possible correlations between the volatile compound profile and the descriptive sensory analysis profile of springbok meat at a later stage.

A total of 32 volatile compounds were tentatively identified in springbok meat derived from the three farms (Table 3.5). The volatile compound profile of springbok meat was dominated by lipid-derived compounds, as aldehydes, alcohols, ketones, lactones, benzene compounds, furans and carboxylic acids are formed by the thermal oxidation of fatty acids from the phospholipids and triglycerides (Forss, 1973; Mottram, 1998a; Song *et al.*, 2011). Additionally, esters are derived from the esterification of various alcohols and carboxylic acids in meat (Um *et al.*, 1992). Selected volatile compounds in springbok meat were possibly Maillard reaction products, such as the heterocyclic sulphur-containing compounds, as well as the sulphur- and nitrogen-containing compounds (Forss, 1973; Mottram, 1998a).

Table 3.1 Level of statistical significance (p-values) for the main effects of farm (F) and gender (G) and their interaction (FxG) on the fatty acid content (mg.g^{-1} of meat) of springbok meat

Fatty acid	Common name	FxG	Farm	Gender	Average*	Min	Max
C14:0	Myristic acid	0.020	0.011	<0.0001	0.66 ± 0.129	0.09	2.01
C15:0	Pentadecylic acid	0.595	0.597	0.008	0.17 ± 0.065	0.09	0.31
C16:0	Palmitic acid	0.075	0.026	<0.0001	7.19 ± 0.805	3.02	15.45
C18:0	Stearic acid	0.182	0.010	0.003	6.85 ± 0.751	3.26	15.01
C20:0	Arachidic acid	0.233	0.254	0.018	0.10 ± 0.007	0.06	0.18
C21:0	Heneicosylic acid	0.336	0.076	<0.0001	0.07 ± 0.004	0.04	0.13
C22:0	Behenic acid	nd	nd	nd	nd	nd	nd
C23:0	Tricosylic acid	0.123	0.147	0.019	0.03 ± 0.002	0.01	0.04
C24:0	Lignoceric acid	0.845	0.092	0.000	0.15 ± 0.013	0.08	0.26
C14:1n9c	Myristoleic acid	0.482	0.189	0.009	0.04 ± 0.004	0.01	0.08
C15:1n9t	*cis*-10-Pentadecenoic acid	0.508	0.310	0.110	0.14 ± 0.016	0.05	0.29
C16:1n7	Palmitoleic acid	nd	nd	nd	nd	nd	nd
C18:1n9c	Oleic acid	0.017	0.005	<0.0001	6.21 ± 0.851	1.58	13.40
C18:1n9t	Elaidic acid	nd	nd	nd	nd	nd	nd
C20:1n9	Gondoic acid	0.832	0.003	0.672	0.01 ± 0.002	0.00	0.04
C22:1n9	Erucic acid	0.144	0.021	0.000	0.04 ± 0.002	0.02	0.05
C24:1n9	Nervonic acid	0.575	0.160	0.411	0.05 ± 0.007	0.01	0.11
C18:2n6c	Linoleic acid	0.291	0.064	0.000	4.87 ± 0.434	2.11	8.06
C18:2n6t	Linolelaidic acid	nd	nd	nd	nd	nd	nd
C18:3n6	Gamma-linolenic acid	0.683	0.876	0.607	0.02 ± 0.005	0.00	0.05
C18:3n3	Alpha-linolenic acid	0.002	<0.0001	0.931	1.49 ± 0.128	0.48	2.25
C20:2n6	Eicosadienoic acid	0.592	0.378	0.006	0.04 ± 0.003	0.02	0.07
C20:3n6	Dihomo-gamma-linolenic acid	0.394	0.008	0.371	0.20 ± 0.015	0.10	0.39
C20:3n3	Eicosatrienoic acid	0.267	0.517	0.602	0.09 ± 0.015	0.02	0.21
C20:4n6	Arachidonic acid	0.675	0.059	0.222	1.41 ± 0.140	0.46	2.33
C20:5n3	Eicosapentaenoic acid, EPA	0.019	0.988	0.956	0.52 ± 0.056	0.18	0.93
C22:2n6	Docosadienoic acid	0.243	0.006	<0.0001	0.17 ± 0.014	0.11	0.29
C22:6n3	Docosahexaenoic acid, DHA	0.035	0.667	0.139	0.17 ± 0.020	0.07	0.30
SFA		0.031	0.037	<0.0001	13.72 ± 1.225	7.82	21.15
MUFA		0.025	0.073	<0.0001	6.81 ± 0.880	1.88	13.76
PUFA		0.161	0.138	0.001	9.33 ± 0.710	4.12	15.18
PUFA:SFA ratio		0.031	0.057	<0.0001	0.71 ± 0.110	0.13	1.55
n6 PUFA		0.796	0.399	0.112	6.27 ± 0.724	0.96	12.13
n3 PUFA		0.372	0.044	0.395	2.24 ± 0.204	0.86	3.35
n6:n3 PUFA ratio		0.523	<0.0001	0.565	2.86 ± 0.191	0.93	4.89

*Average values (Means ± SE) were calculated irrespective of significant effects of farm (F) and/or gender (G) or their interaction (FxG); SE, standard error; Min, Minimum; Max, Maximum; nd, not detected in springbok meat; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

Table 3.2 Influence of the interaction (FxG) between the main effects of farm (F) and gender (G) on the content (mg.g^{-1} of meat) of selected fatty acids in springbok meat (Means ± SE)

	Farm A		Farm B		Farm C	
Fatty acid	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
C14:0**	0.73^{b} ± 0.117	0.47^{bc} ± 0.121	0.76^{b} ± 0.130	0.24^{c} ± 0.067	1.44^{a} ± 0.216	0.44^{bc} ± 0.061
C16:0***	7.67^{b} ± 0.834	5.57^{bc} ± 0.683	7.67^{b} ± 0.483	4.88^{c} ± 1.037	11.50^{a} ± 1.279	5.65^{bc} ± 0.326
C18:1n9c**	6.86^{bc} ± 0.730	5.30^{c} ± 0.956	7.53^{b} ± 0.562	2.33^{d} ± 0.284	10.60^{a} ± 1.113	5.00^{c} ± 0.439
C18:3n3*	0.81^{b} ± 0.094	1.21^{b} ± 0.136	1.97^{a} ± 0.106	1.20^{b} ± 0.365	1.72^{a} ± 0.100	1.97^{a} ± 0.094
C20:5n3**	0.41^{b} ± 0.050	0.63^{a} ± 0.110	0.52^{ab} ± 0.075	0.52^{ab} ± 0.105	0.64^{a} ± 0.041	0.41^{b} ± 0.024
C22:6n3**	0.15^{b} ± 0.021	0.16^{ab} ± 0.044	0.17^{ab} ± 0.021	0.18^{ab} ± 0.031	0.23^{a} ± 0.032	0.12^{b} ± 0.004
SFA**	13.46^{b} ± 1.482	11.42^{bc} ± 1.286	17.01^{a} ± 1.269	8.83^{c} ± 0.228	18.96^{a} ± 1.001	12.91^{b} ± 0.553
MUFA**	7.35^{bc} ± 0.711	5.61^{c} ± 0.939	8.61^{b} ± 0.813	2.96^{d} ± 0.504	10.87^{a} ± 1.125	5.29^{c} ± 0.373
PUFA:SFA ratio**	0.56^{cd} ± 0.083	1.00^{b} ± 0.155	0.51^{cd} ± 0.106	1.39^{a} ± 0.086	0.40^{d} ± 0.046	0.72^{bc} ± 0.054

$^{a-d}$Means within a variable with superscripts that do not have a common letter indicate significant differences *(p<0.01), **(p<0.05), ***(p<0.10) between farms and/or genders; SE, standard error; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0).

Table 3.3 Influence of farm (diet) on the content (mg.g^{-1} of meat) of selected fatty acids in springbok meat (Means ± SE)

Fatty acid	Farm A	Farm B	Farm C
C18:0**	5.01^{b} ± 0.336	7.43^{a} ± 1.014	8.10^{a} ± 0.904
C21:0***	0.07^{ab} ± 0.003	0.07^{a} ± 0.005	0.06^{b} ± 0.004
C24:0***	0.17^{a} ± 0.014	0.15^{ab} ± 0.014	0.13^{b} ± 0.011
C20:1n9*	0.02^{a} ± 0.005	0.00^{b} ± 0.000	0.00^{b} ± 0.000
C22:1n9**	0.03^{b} ± 0.002	0.04^{a} ± 0.003	0.03^{b} ± 0.002
C18:2n6c***	4.84^{ab} ± 0.493	5.51^{a} ± 0.596	4.25^{b} ± 0.213
C20:3n6*	0.24^{a} ± 0.023	0.17^{b} ± 0.010	0.18^{b} ± 0.011
C20:4n6***	1.70^{a} ± 0.137	1.26^{b} ± 0.188	1.26^{b} ± 0.096
C22:2n6*	0.15^{b} ± 0.012	0.20^{a} ± 0.017	0.16^{b} ± 0.013
n3 PUFA**	1.76^{b} ± 0.191	2.45^{a} ± 0.262	2.51^{a} ± 0.160
n6:n3 PUFA ratio*	3.95^{a} ± 0.188	2.53^{b} ± 0.243	2.10^{b} ± 0.140

$^{a-b}$Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between farms; SE, standard error; n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

Table 3.4 Influence of gender on the content (mg.g^{-1} of meat) of selected fatty acids in springbok meat (Means ± SE)

Fatty acid	Female	Male
C15:0*	0.20^{a} ± 0.046	0.15^{b} ± 0.037
C18:0*	8.09^{a} ± 0.803	5.53^{b} ± 0.410
C20:0**	0.11^{a} ± 0.007	0.09^{b} ± 0.004
C21:0*	0.06^{b} ± 0.002	0.08^{a} ± 0.003
C23:0**	0.02^{b} ± 0.001	0.03^{a} ± 0.002
C24:0*	0.13^{b} ± 0.006	0.18^{a} ± 0.012
C14:1n9c*	0.05^{a} ± 0.004	0.04^{b} ± 0.003
C22:1n9*	0.03^{b} ± 0.002	0.04^{a} ± 0.002
C18:2n6c*	4.08^{b} ± 0.286	5.17^{a} ± 0.369
C20:2n6*	0.03^{b} ± 0.002	0.04^{a} ± 0.003
C22:2n6*	0.14^{b} ± 0.006	0.21^{a} ± 0.014
PUFA*	8.08^{b} ± 0.483	10.68^{a} ± 0.601

$^{a\text{-}b}$Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$) between genders; SE, standard error; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3.

Table 3.5 Level of statistical significance (p-values) for the main effects of farm (F) and gender (G) and their interaction (FxG) on the percentages of volatile compounds in springbok meat

Volatile compounds*	RT	Aroma description	FxG	Farm	Gender
Aldehydes					
hexanal	6.74	green[1,4,5,6,13,14,17,18,19,20,23,24,27,28], sweet[4], fat[4,5,7,11,17,19,21,28], grass[4,6,7,8,9,11,12,13,14,17,19,21,23,27,28], tallow[11,17], garlic[12], rancid[14], green apple[16,25], liver-like[17], fruit[24,25], vegetable[25]	0.264	<0.0001	0.198
heptanal	9.49	oil[1,14,17,23], putty[1], fruit[4,14,16,23,24,25], fat[4,11,14,17,19,23,28], sweet[4], green[4,12,13,23], grass[4], potatoes[8], citrus[11,18,23], rancid[11,17], floral[12], cured ham-like[14,19,28], toasted[14], unpleasant[17], grease[19,28], nut[24]	<0.0001	<0.0001	<0.0001
octanal	12.83	fat[1,11,17,23], soapy[5,11,17,23], green[6,11,13,14,17,19,20,23,25,28], fresh[6,14,19,28], lemon[11,13,17,23,27], citrus[12,13,16,18], fruit[12,16,25], harsh[17], orange peel[17,20], honey[17], meat-like[19,28], chemical[25], floral[27]	nd	nd	nd
nonanal	16.94	tallow[1,5,21], floral[2,17,23], fruit[2], herbaceous[2], lemon[2,15], fragrant[4], sweet[4], fat[4,11,14,16,17,19,23,28], green[4,5,6,10,11,13,17,20,23,24,25], pungent[4], gravy[10], citrus[11,13,17], sea[13], citronella grass[13], rancid[14,16,19,25,28], grass[15,17,24], tea[15], vegetable[15], sour[15], beef-like[15,24], wax[17], stale[20], orange[20,27], soap[21], plastic[25], toast[27]	0.010	<0.0001	0.007
unidentified aldehyde	32.11		0.415	<0.0001	0.349
unidentified aldehyde	34.81		0.044	<0.0001	0.020
unidentified aldehyde	36.07		<0.0001	<0.0001	0.000
unidentified aldehyde	37.20		0.001	<0.0001	0.003
unidentified aldehyde	39.40		0.009	0.001	0.029
Alcohols					
2,3-butanediol	23.88		0.774	0.014	0.463
1-penten-3-ol	8.27	sharp[1], irritating[1], penetrating[3], grass[3], ethereal[3], butter[23], green[23], pungent[23], diesel oil[27], cologne[27], toast[27], meat broth[27]	nd	nd	nd
1-pentanol	11.28	mild[17], fusel oil[17], fruit[17], balsamic[17,23], alcoholic[23], sharp[23]	0.315	0.001	0.149
1-hexanol	15.00	floral[23], fat[23], green[23]	<0.0001	<0.0001	<0.0001
1-heptanol	18.98	fragrant[17,23], wood[17,23], oil[17,23], green[17], fat[17], wine[17], sap[17], herbaceous[17]	<0.0001	<0.0001	<0.0001
1-octen-3-ol	18.74	mushroom[1,3,8,12,14,16,17,19,21,22,23,24,26,28], liver-like[17], earth[19,28], dust[19], moss[21], nut[21], fungus[25]	0.302	0.001	0.541
2-octen-1-ol	25.43	green[17], citrus[17]	<0.0001	<0.0001	<0.0001
2-ethylhexanol	20.25	rose[11], green[11,17], mushroom[12,23], resin[17], flower[17], cucumber[23], cooked vegetable[23]	0.231	0.003	0.224
1-octanol	23.04	penetrating[17], fat[17,23], wax[17], citrus[17], oil[17], walnut[17], moss[17], chemical[17], metal[17], burnt[17], lemon[23], toasted[23]	<0.0001	<0.0001	<0.0001
1-nonen-4-ol	26.84		0.028	0.002	0.064
Ketones					
2,3-butanedione (diacetyl)	4.37	sweet[4], butter[4,11,12,13,14,16,19,23,25,27], caramel[12,18,19,23,28], rotten[18], vanilla[19,28], cream[23], lactic[25], fruity[27], diacetyl[13,27]	0.792	<0.0001	0.147
3-hydroxy-2-butanone (acetoin)	13.11	butter[16,23], yoghurt[16], fat[23], sweaty[23], sour[23]	0.249	<0.0001	0.003
6-methyl-5-hepten-2-one	14.8		nd	nd	nd
2,3-octanedione	14.08	warmed over[21], oxidised fat[21]	0.459	<0.0001	0.615
3-octanone	11.7	moss[16]	0.192	<0.0001	0.106

Table 3.5 continued

Volatile compounds*	RT	Aroma description	FxG	Farm	Gender
Benzene compounds					
benzaldehyde	22.66	bitter almond[11,14,17,19,22,28], burnt sugar[11], popcorn[15,24], caramel[15,24], herbaceous[15,24], sulphur[15], chemical[15], spicy[15], liver-like[17], penetrating[19,28], roasted pepper[23], nut[23], metallic[24]	0.862	0.500	0.065
4-ethylbenzaldehyde	29.34		<0.0001	<0.0001	0.000
Carboxylic acids					
2-pentylfuran	10.73	fat[2], green[2,19,21,23,24,28], green bean[17,21], butter[17], fruit[19,23,28], earth[21,24], metallic[21,24], sweet[23], pungent[23]	0.896	<0.0001	0.959
Carboxylic acids					
acetic acid (ethanoic acid)	19.39	sour[5,11,20], vinegar[16,20]	0.731	0.016	0.585
butanoic acid (butyric acid)	26.13	sweet[4], unpleasant[4], sweaty[5,11], rancid[11,19,28], cheese[11,14,16,19,20,28], fat[14], vomit[16], feet[16], faecal[20]	0.999	<0.0001	0.975
pentanoic acid (valeric acid)	26.04	sweaty[11], faecal[20], rancid[20]	nd	nd	nd
hexanoic acid (caproic acid)	32.88	fat[14,28], cheese[14,28], sweaty[14,28], goat-like[17,23], sour[20], pungent[23], rancid[24]	0.120	<0.0001	0.296
heptanoic acid (enanthic acid)	33.11	animal[25], pungent[25], rancid[25]	0.120	<0.0001	0.178
Esters					
2-propenoic acid, butyl ester (butyl acrylate)	9.03		0.828	<0.0001	0.415
propanoic acid, butyl ester (butyl propanoate)	7.97		0.682	<0.0001	0.596
Ethers					
propane, 2-(ethenyloxy)- (vinyl isopropyl ether)	4.50		0.310	<0.0001	0.297
Sulphur-containing compounds					
dimethyl sulphone	34.61	sulphur[11], burnt[11]	0.018	<0.0001	0.003
Sulphur- and nitrogen-containing compounds					
4-methylthiazole	26.45	roasted meat[11]	0.112	<0.0001	0.153

*Volatile compounds are grouped together into respective chemical classes; RT, retention time (min); nd, not detected in springbok meat; [1]Badings, 1970; [2]Farmer *et al.*, 1989; [3]Barbieri *et al.*, 1992; [4]Specht & Baltes, 1994; [5]Kerler & Grosch, 1996; [6]Flores *et al.*, 1997; [7]Elmore *et al.*, 1999; [8]Meynier *et al.*, 1999; [9]Van Ruth & Roozen, 2000; [10]Machiels *et al.*, 2003; [11]Acree & Arn, 2004; [12]Prost *et al.*, 2004; [13]Rochat & Chaintreau, [14]Sánchez-Peña *et al.*, 2005; [15]Moon *et al.*, 2006; [16]Berdagué *et al.*, 2007; [17]Calkins & Hodgen, 2007; [18]Ganeko *et al.*, 2008; [19]García-González *et al.*, 2008; [20]Song & Cadwallader, 2008; [21]Stetzer *et al.*, 2008; [22]Belitz *et al.*, 2009; [23]Madruga *et al.*, 2010; [24]Song *et al.*, 2010; [25]Théron *et al.*, 2010; [26]Ma *et al.*, 2012; [27]Resconi *et al.*, 2012; [28]García-González *et al.*, 2014.

Table 3.6 Influence of the interaction between the main effects (farm and gender) on the percentages of volatile compounds in springbok meat (Means ± SE)

	Farm A		Farm B		Farm C	
Volatile compounds	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
Aldehydes						
heptanal*	$0.46^{c} \pm 0.072$	$0.40^{c} \pm 0.025$	$3.65^{a} \pm 0.252$	$0.94^{b} \pm 0.121$	$0.00^{d} \pm 0.000$	$0.00^{d} \pm 0.000$
nonanal**	$2.58^{a} \pm 0.292$	$2.45^{a} \pm 0.327$	$2.61^{a} \pm 0.177$	$1.34^{b} \pm 0.110$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$
Alcohols						
1-hexanol*	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.60^{a} \pm 0.243$	$0.14^{b} \pm 0.057$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$
1-heptanol*	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.84^{a} \pm 0.345$	$0.20^{b} \pm 0.082$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$
2-octen-1-ol *	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.42^{a} \pm 0.209$	$0.07^{b} \pm 0.028$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$
1-octanol*	$0.27^{b} \pm 0.109$	$0.17^{bc} \pm 0.068$	$0.71^{a} \pm 0.288$	$0.08^{c} \pm 0.032$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$
1-nonen-4-ol**	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.38^{a} \pm 0.168$	$0.07^{b} \pm 0.029$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$
Benzene compounds						
4-ethylbenzaldehyde*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.42^{a} \pm 0.075$	$0.04^{b} \pm 0.044$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$
Sulphur-containing compounds						
dimethyl sulphone**	$0.05^{bc} \pm 0.026$	$0.11^{b} \pm 0.036$	$0.07^{bc} \pm 0.023$	$0.23^{a} \pm 0.039$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$

[a-d]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$) between farms and/or genders; SE, standard error.

Table 3.7 Influence of farm (diet) on the percentages of volatile compounds in springbok meat (Means ± SE)

Volatile compounds	Farm A	Farm B	Farm C
Aldehydes			
hexanal*	$3.22^{b} \pm 0.256$	$6.93^{a} \pm 0.937$	$1.17^{c} \pm 0.148$
Alcohols			
2,3-butanediol**	$0.24^{a} \pm 0.073$	$0.13^{ab} \pm 0.050$	$0.00^{b} \pm 0.000$
1-pentanol*	$0.19^{b} \pm 0.022$	$0.49^{a} \pm 0.053$	$0.18^{b} \pm 0.076$
1-octen-3-ol*	$0.96^{b} \pm 0.130$	$2.13^{a} \pm 0.286$	$0.79^{b} \pm 0.247$
2-ethylhexanol*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.19^{a} \pm 0.056$
Ketones			
2,3-butanedione (diacetyl)*	$3.76^{a} \pm 0.197$	$0.97^{c} \pm 0.188$	$2.37^{b} \pm 0.200$
3-hydroxy-2-butanone (acetoin)*	$19.02^{a} \pm 1.080$	$13.04^{b} \pm 0.566$	$17.75^{a} \pm 0.892$
2,3-octanedione*	$0.16^{b} \pm 0.038$	$0.64^{a} \pm 0.089$	$0.00^{b} \pm 0.000$
3-octanone*	$3.57^{b} \pm 0.481$	$4.90^{a} \pm 0.460$	$2.01^{c} \pm 0.311$
Furans			
2-pentylfuran*	$0.36^{b} \pm 0.025$	$0.97^{a} \pm 0.102$	$0.00^{c} \pm 0.000$
Carboxylic acids			
acetic acid (ethanoic acid)**	$0.43^{ab} \pm 0.089$	$0.29^{b} \pm 0.071$	$0.67^{a} \pm 0.091$
butanoic acid (butyric acid)*	$0.00^{b} \pm 0.000$	$0.16^{a} \pm 0.047$	$0.00^{b} \pm 0.000$
hexanoic acid (caproic acid)*	$0.03^{b} \pm 0.017$	$0.34^{a} \pm 0.073$	$0.00^{b} \pm 0.000$
heptanoic acid (enanthic acid)*	$0.00^{b} \pm 0.000$	$0.36^{a} \pm 0.017$	$0.00^{b} \pm 0.000$
Esters			
2-propenoic acid, butyl ester*	$0.00^{c} \pm 0.000$	$0.12^{b} \pm 0.025$	$0.32^{a} \pm 0.028$
propanoic acid, butyl ester*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.22^{a} \pm 0.010$
Ethers			
propane, 2-(ethenyloxy)-*	$0.00^{b} \pm 0.000$	$2.19^{a} \pm 0.245$	$0.00^{b} \pm 0.000$
Sulphur- and nitrogen-containing compounds			
4-methylthiazole*	$0.00^{b} \pm 0.000$	$0.20^{a} \pm 0.050$	$0.00^{b} \pm 0.000$

[a-c]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$) between farms; SE, standard error.

Saturated aldehydes (such as hexanal, heptanal, octanal and nonanal) and alcohols are primarily derived from the oxidation of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) (Elmore *et al.*, 1999; Belitz *et al.*, 2009). In addition, hexanal and 1-octen-3-ol can be derived from the oxidation of C20:4n6 (arachidonic acid) (Blank *et al.*, 2001; Lorenzo, 2014; Marušić *et al.*, 2014). The furan, 2-pentylfuran, is also a product of the thermal degradation of C18:2n6c (linoleic acid) (Mottram, 1985; Elmore *et al.*, 1999). A higher content of these n6 PUFA (oleic and linoleic acids) has been linked to higher levels of saturated aldehydes, alcohols and 2-pentylfuran in beef meat (Elmore *et al.*, 1999).

Even though there was a significant interaction between the main effects (farm and gender) for C18:1n9c (oleic acid), the content of this MUFA was higher in the meat derived from female springbok ($p<0.05$ for farms B and C) (Table 3.2), which could have resulted in the higher heptanal ($p<0.01$), nonanal ($p<0.05$), 1-hexanol ($p<0.01$), 1-heptanol ($p<0.01$), 2-octen-1-ol ($p<0.01$), 1-octanol ($p<0.01$) and 1-nonen-4-ol ($p<0.01$) percentages in the meat from females as compared to males (significant only for farm B) (Table 3.6). Furthermore, the C18:2n6c (linoleic acid) content was higher in springbok meat derived from farm B (Table 3.3) and this possibly caused the formation of higher percentages of hexanal ($p<0.01$), heptanal ($p<0.01$ for both genders), 1-pentanol ($p<0.01$), 1-hexanol ($p<0.01$ for both genders), 1-heptanol ($p<0.01$ for both genders), 1-octen-3-ol ($p<0.01$), 2-octen-1-ol ($p<0.01$ for both genders), 1-octanol ($p<0.01$ for both genders), 1-nonen-4-ol ($p<0.05$ for both genders) and 2-pentylfuran ($p<0.01$) in springbok meat from farm B (Tables 3.6 and 3.7). Unfortunately no significant correlations existed between the content of C18:1n9c (oleic acid), C18:2n6c (linoleic acid) and C20:4n6 (arachidonic acid) and the percentages of aldehydes, alcohols and 2-pentylfuran in this study.

Selected compounds are derived from the degradation or fermentation of carbohydrates, such as 2,3-butanediol, 2,3-butanedione (diacetyl), benzaldehyde, acetic and butanoic acids, as well as dimethyl sulphone (Gandemer, 2002; Spaziani *et al.*, 2009). Ketones can be derived from the microbial degradation and autoxidation of fatty acids and aldehydes (Gao *et al.*, 1998; Ganesan *et al.*, 2014). In addition, 2,3-butanedione can be formed by means of bacterial degradation during meat storage (Resconi *et al.*, 2012). Hydroxyketones (such as 3-hydroxy-2-butanone/acetoin) are sugar degradation products from the Maillard reaction (Elmore *et al.*, 2005; Roldán *et al.*, 2015). The higher ($p<0.01$) percentages of 2,3-octanedione and 3-octanone (Table 3.7) can be derived from the higher ($p<0.10$) C18:2n6c (linoleic acid) content of springbok meat derived from farm B (Table 3.3).

The formation of the two benzene compounds (benzaldehyde and 4-ethylbenzaldehyde) found in springbok meat may be linked to the oxidation of C18:3n3 (α-linolenic acid) (Elmore *et al.*, 2005). Ba *et al.* (2014) found a positive correlation between the benzaldehyde content (µg per g) and the C18:3n3 (α-linolenic acid) percentage in beef. However, in this study there was a significant interaction between the main effects (farm and gender) for C18:3n3 (α-linolenic acid) (Table 3.2), while farm and gender had no significant effect on the benzaldehyde percentages of springbok meat (Table 3.5). Nonetheless, benzaldehyde can also be a product of the Strecker degradation of certain amino acids (Mottram & Edwards, 1983).

The use of the SPME technique for the extraction of volatile compounds is generally efficient at extracting low molecular weight compounds with high volatility (Watkins *et al.*, 2012), however, this technique is not used for the absolute quantification of volatile compounds (Lorenzo & Domínguez, 2014). The volatile compound data are therefore reported as semi-quantitative, as the percentage area of the peak for the total ion count (TIC) was used.

The significance of the contribution of volatile compounds to the aroma and flavour of cooked meat is linked to their concentration, as well as their odour threshold value (Moon *et al.*, 2006; Lu *et al.*, 2008). Aldehydes are especially of great importance for the aroma and flavour of cooked meat due to their abundance in the volatile compound profile of cooked meat, as well as their low odour threshold values (Mottram, 1998a; Elmore *et al.*, 1999; Resconi *et al.*, 2012; Van Ba *et al.*, 2013). Additionally, the unsaturated alcohols (such as 1-penten-3-ol, 1-octen-3-ol, 2-octen-1-ol and 1-nonen-4-ol) (Calkins & Hodgen, 2007; Song *et al.*, 2011, 2014), ketones (Mottram, 1998a; Van Ba *et al.*, 2013), 2-pentylfuran (Elmore *et al.*, 1999; Song *et al.*, 2010) and sulphur-containing compounds (Resconi *et al.*, 2012) have low odour threshold values and could contribute significantly to the aroma and/or flavour of cooked meat. Compounds containing a benzene ring (such as benzaldehyde and 4-ethylbenzaldehyde) are aromatic in nature (Raes *et al.*, 2003). Little information could be sourced on the odour threshold values of carboxylic acids and esters, though Song *et al.* (2014) reported that butanoic and pentanoic acids possessed odour activity and Um *et al.* (1992) noted that hexanoic acid has a relatively low odour threshold values.

It can be postulated from the above-mentioned odour threshold values, that the aldehydes, 1-octen-3-ol, 2-octen-1-ol, 1-nonen-4-ol, ketones, benzene compounds, 2-pentylfuran, carboxylic acids, dimethyl sulphone and 4-methylthiazole could possibly contribute to the aroma and/or flavour of springbok meat. Springbok meat derived from farm B had the highest percentages of the majority of the latter compounds, including hexanal ($p<0.01$), heptanal ($p<0.01$ for both genders), 1-octen-3-ol ($p<0.01$), 2-octen-1-ol ($p<0.01$ for both genders), 1-nonen-4-ol ($p<0.05$ for both genders), 2,3-octanedione ($p<0.01$), 3-octanone ($p<0.01$), 4-ethylbenzaldehyde ($p<0.01$ for both genders), 2-pentylfuran ($p<0.01$), butanoic acid ($p<0.01$), hexanoic acid ($p<0.01$), heptanoic acid ($p<0.01$), dimethyl sulphone ($p<0.05$ for males only) and 4-methylthiazole ($p<0.01$) (Tables 3.6 and 3.7). Consequently, springbok meat derived from farm B could possibly differ in aroma and/or flavour as compared to springbok meat derived from farms A and C.

Gender differences were most prominent for springbok meat derived from farm B, as the percentages of the volatile compounds listed in Table 3.6 were significantly higher in the meat derived from female springbok from farm B (except for dimethyl sulphone) as compared to male springbok. As PUFA are more susceptible to lipid oxidation during cooking (Mottram, 1998a) and the total PUFA content was higher ($p<0.01$) for the meat derived from male springbok (Table 3.4), it was unexpected that the percentage of lipid-derived volatile compounds was significantly higher in the meat from female springbok derived from farm B (Table 3.6). Additionally, the 3-hydroxy-2-butanone (acetoin) percentage was also higher ($p<0.01$) in springbok meat derived from females. Consequently, the aroma and/or flavour of the meat derived from female springbok from farm B will most probably differ from the meat derived from males from farm B.

The PUFA:SFA and n6:n3 PUFA ratios should be taken into account when considering the nutritional properties of springbok meat. The recommended values for the former and latter are above 0.7 and below 4.0, respectively (Wood *et al.*, 1999; Raes *et al.*, 2004). The PUFA:SFA ratio of the meat derived from female springbok from farms A, B and C was below the recommended value, which is attributable to the high total SFA (Table 3.2) and low total PUFA content (Table 3.4). The opposite was true for the meat derived from male springbok from farms A, B and C, as the PUFA:SFA ratio was well above the recommended value (Table 3.2). The n6:n3 PUFA ratio differed ($p<0.01$) between farms (Table 3.3). The latter ratio was for springbok meat derived from farm A, as a result of a lower ($p<0.05$) total n3 PUFA content in the meat derived from farm A (Table 3.3). Nonetheless, the n6:n3 PUFA ratios of all springbok meat (farms A, B and C) was below the recommended value of 4.0 (Table 3.3).

3.5 Conclusions

The extraction temperature used in this study resembled a moderate cooking method and temperature, and together with the high PUFA content of springbok meat, resulted in the formation of primarily lipid-derived volatile compounds. Farm location (diet) and gender had a significant influence on the fatty acid content and volatile compound profile of springbok meat. Higher oleic acid and linoleic acid levels were linked to higher percentages of selected aldehydes, alcohols, ketones and 2-pentylfuran in springbok meat. The α-linolenic acid content of springbok meat seemed not play an important role in the formation of volatile compounds.

The aroma and/or flavour of springbok meat could be different between farms (diets) and genders, however, descriptive sensory analysis is required to establish what the extent of the differences in the volatile compound profile will be on the sensory quality of springbok meat from the different farms (diets) and genders. The latter will establish whether the red meat industry should take the harvesting location and gender into account for the commercial production of springbok meat.

3.6 References

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Chapter 4

Influence of farm location and gender on the sensory quality of springbok (*Antidorcas marsupialis*) meat

Abstract

As springbok are found distributed widely throughout southern Africa, in addition to variations in vegetation types and climates between regions, the dietary regime of springbok could also vary between regions which may influence the sensory quality of springbok meat. The aim of this study was to quantify the influence of farm location (dietary regime) and gender on the sensory quality of springbok *longissimus thoracis et lumborum*. Springbok were harvested from three farms situated in different regions of South Africa. The sensory profile of springbok meat was determined by descriptive sensory analysis (DSA), in addition to some physical measurements (thaw and cooking loss percentages, ultimate pH and Warner-Bratzler shear force values) and determining the proximate composition (moisture, protein, intramuscular lipid and ash content), so as to establish the sensory quality of springbok meat. Springbok *longissimus thoracis et lumborum* can be classified as tender, as the WBSF values were generally <42.87 N. Farm location had a significant influence on the sensory quality of springbok meat, while the influence of gender was minor. Farm location and vegetation type should therefore be taken into account when harvesting springbok meat for game meat consumption.

Keywords: Game meat; Descriptive sensory analysis; Meat aroma; Meat flavour; Meat tenderness

4.1 Introduction

The meat derived from South African game species is unique, as the animals are extensively reared in contrast to the numerous farmed game species derived from America, Europe, Australia and New Zealand (Hoffman & Wiklund, 2006). The dietary regime of South African game species is therefore determined by the type and quality of the naturally occurring vegetation in the habitat with some ungulate species being predominantly grazers, others browsers and some species mixed feeders. However, the dietary regime of an animal influences its fatty acid content (Nuernberg *et al.*, 2005) and consequently the sensory quality of the meat (Wood *et al.*, 1999; Calkins & Hodgen, 2007).

Researchers have established the influence of dietary regime on the sensory quality of the meat derived from various game species, although the bulk of the reports have been on the meat derived from deer species (Wiklund *et al.*, 2000, 2003a, 2003b; Wiklund & Johansson, 2011; Hutchison *et al.*, 2012), with limited work on African wild ungulates (Hoffman *et al.*, 2007c). Descriptive sensory analysis (DSA) is an important testing method to establish differences in the sensory profile of foods. The sensory profile should include all perceived sensory attributes and not only selected ones (Murray *et al.*, 2001), however, the amount of perceived sensory attributes used in the studies investigating the sensory quality difference for game meat derived from different dietary regimes, is often limited (five to eight attributes) (Wiklund *et al.*, 2000, 2003a, 2003b; Hoffman *et al.*, 2007c; Wiklund & Johansson, 2011).

The sensory quality of meat is fundamental for consumer satisfaction (Oltra *et al.*, 2015). Although DSA identifies the sensory profile of meat products, it does not contribute any information on consumer preference and acceptance of a product (Resurreccion, 2003). Consumer perception of the sensory quality of meat can vary as a result of differences in beliefs, personality types, as well as past experiences (Calkins & Hodgen, 2007; Piqueras-Fiszman & Spence, 2015). Nonetheless, consumers tend to view the sensory quality of game meat in the same manner as meat derived from domesticated species (Hoffman & Wiklund, 2006).

In general, consumer preference for meat products is influenced by appearance, flavour, juiciness and tenderness (Resurreccion, 2003; Legako *et al.*, 2015). Higher ratings for sensory attributes such as sweet-associated aroma, beef aroma and flavour, sweet taste, juiciness, as well as tenderness have been positively correlated to consumer liking of meat (Eilers *et al.*, 1994; Oltra *et al.*, 2015). Conversely, sensory attributes such as gamey, metallic and liver-like aroma and flavours, manure-like taint, sour taste, mealiness, residue and a rubber or liver-like texture are generally perceived as negative sensory attributes of meat (Wiklund *et al.*, 2003b; North & Hoffman, 2015; Oltra *et al.*, 2015).

Some of the above-mentioned sensory attributes such as gamey, metallic and liver-like aroma and flavour, beef-like flavour, sour-associated aroma, sour taste, manure-like taint, juiciness, mealiness, residue and tenderness have been associated with the sensory quality of springbok meat (Hoffman *et al.*, 2007c; North & Hoffman, 2015). As springbok meat contains high proportions of polyunsaturated fatty acids (PUFA) (Hoffman & Wiklund, 2006; Hoffman *et al.*, 2007b; Chapters 2 and 3), the meat is more susceptible to lipid oxidation during storage and cooking, resulting in the development of volatile aroma compounds linked to off-aroma and flavours (Wood *et al.*, 1999, 2003). In addition, Wiklund *et al.* (2003b) found higher sensory intensities for gamey flavour with increased proportions of grazing in the diet of red deer (*Cervus elaphus*), this result was partly explained by the fatty acid content associating with higher proportions of grazing in the diet (Wiklund *et al.*, 2003a).

As the springbok is known to be a mixed feeder (graze and browse), the aim of the present study was to investigate the influence of farm location (dietary regime) and gender on the physical measurements, proximate composition and sensory profile of springbok meat derived from animals sourced from various farms located in regions with different naturally occurring vegetation types (graze and browse).

4.2 Materials and methods

4.2.1 Experimental layout and harvesting

The experimental layout and harvesting information is as described in Chapter 3, with the exception that only nine (five males and four females) of the mature springbok that were randomly selected and harvested per farm were used in this study.

4.2.2 Sampling

The *longissimus thoracis et lumborum* (LTL) muscle was sampled from the left and right side of the cooled springbok carcasses. All visible connective tissue was removed from the LTL muscles. The *longissimus*

thoracis (LT) and *longissimus lumborum* (LL) sections were sub-sampled from the left LTL muscle, vacuum-packed and frozen at -20°C until the training and testing phases of descriptive sensory analysis (DSA), respectively. The LL section was sub-sampled from the right LTL muscle, homogenised, vacuum-packed and frozen at -20°C for the analysis of the proximate composition. Physical measurements (thaw and cooking loss percentages, ultimate pH and WBSF values) were conducted on the sensory testing samples (left LL section).

4.2.3 Physical measurements

4.2.3.1 Ultimate pH (pHu)

A Crison PH25 portable handheld pH metre (Lasec (Pty) Ltd, Cape Town, South Africa) was calibrated with standard buffers (pH 7.0 and pH 4.0) prior to each DSA session, where after the final, ultimate pH (pHu) was measured in the thawed meat samples.

4.2.3.2 Thaw and cooking loss percentages

The left LL meat samples were weighed after the removal of the visible connective tissue and prior to being vacuum-packed and frozen (W_1). The samples were blotted dry and weighed again after thawing under 4°C for 24 h prior to the respective DSA sessions (W_2). The thawing loss of each sample was calculated as a percentage of the original weight (W_1).

The cooled and blotted dry, cooked meat samples for DSA were weighed before being cut into the meat cubes. The cooking loss percentage was calculated as a percentage of the thawed weight (W_2) (Honikel, 1998).

4.2.3.3 Warner-Bratzler shear force (WBSF)

Sub-samples (± 2 cm wide) was taken from the cranial end of the cooked LL meat samples, wrapped in thick aluminium foil and stored at 4°C (± 1°C) for 24 h, prior to the analysis of instrumental tenderness. The WBSF test, as described by Honikel (1998) and North and Hoffman (2015) was used to measure the instrumental tenderness of the cooked meat samples.

4.2.4 Proximate composition

The moisture content (g.100 g^{-1}) of the springbok meat was determined by drying 2.5 g of each of the homogenised meat samples at 100°C for 24 h. The loss in weight is reported as moisture content. The moisture free samples were consequently placed in a furnace at 500°C for 6 h, so as to determine the ash content (g.100 g^{-1}) according to the AOAC official method 942.05 (AOAC, 2002a). The intramuscular lipid (IML) content (g.100 g^{-1}) was determined on 5 g meat samples by use of a rapid solvent extraction method (Lee *et al.*, 1996) using chloroform/methanol (1:2 v/v).

The crude protein content (g.100 g^{-1}) was determined by the Dumas combustion method 992.15 (AOAC, 2002b). The defatted filtrate from the rapid solvent extraction method was dried (moisture free), homogenised and analysed in a Leco Nitrogen/Protein Analyser (Leco Fp-528, Leco Corporation, Michigan, USA). The results were given as a nitrogen percentage which was multiplied by a conversion factor of 6.25, so as to

determine the total crude protein content within each sample (McDonald *et al.*, 2002). The proximate analysis methods are tested regularly for accuracy and repeatability as part of a National Inter-laboratory Scheme (AgriLASA: Agricultural Laboratory Association of South Africa).

4.2.5 Sample preparation for descriptive sensory analysis

The vacuum-packed LL samples were thawed for 24 h at 4°C (± 1°C) prior to the scheduled DSA training or testing sessions. Meat samples were placed onto similar sized stainless steel grids and then inserted into oven bags (Glad®). No seasoning was added to the meat samples during DSA. A thermocouple probe attached to a handheld digital temperature monitor (Hanna Instruments, South Africa) was inserted in the centre of each meat sample (AMSA, 1995). The oven bags containing the meat and inserted probes were closed with a twist tie. Three meat samples were placed onto an oven roasting pan. The meat samples were prepared as described by Geldenhuys *et al.* (2014), with the exception of cooking the meat to an internal temperature of 76°C, where after allowing the cooked meat to rest (cool) for 10 min before cutting it into 1 cm x 1 cm x 1 cm cubes and individually wrapping each meat cube in aluminium foil. Four of the wrapped meat cubes were placed into coded (using randomised three-digit codes) ramekins and re-heated at 100°C for 10 min, in an industrial oven (Hobart, Paris, France). The ramekins with the meat samples were placed into scientific water baths (70°C) near the panellists, so as to ensure that each panellist evaluated each sample at a constant temperature.

4.2.6 Descriptive sensory analysis (DSA)

Descriptive sensory analysis of the meat samples derived from the three farms (randomly grouped for gender) was conducted by a panel of 10 judges, trained as described by Geldenhuys *et al.* (2014) and with previous experience in the sensory analysis of meat products.

The panel was trained for six sessions, during which each panellist received four 1 cm x 1 cm x 1 cm meat cubes from the three treatments (farms). Reference standards (Table 4.1) were selected to clarify aroma, flavour and texture attributes relevant to springbok meat. The panel decided on 24 sensory attributes: overall aroma; gamey, beef-like, metallic, liver-like, herbaceous and lamb-like aroma and flavour; sweet-associated aroma; lamb-like fatty aroma; sour, sweet and salty tastes; initial and sustained juiciness; tenderness; residue; mealiness; and liver-like texture. The definitions and scales used for the sensory attributes are listed in Table 4.2.

Table 4.1 Reference standards used during training for descriptive sensory analysis of springbok meat

Reference standard	Description	Internal temperature	Scale
Fallow deer[a]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Ostrich[b]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Beef[c]	Aroma and flavour associated with cooked beef loin	72°C	0 = low intensity; 100 = high intensity
Beef ox liver	Aroma, flavour and texture associated with cooked beef liver	Pan-fried over high heat	0 = low intensity; 100 = high intensity
Springbok with herbs[d]	Aroma and flavour associated with a combination of herbs (sage, thyme, parsley and oregano)	76°C	0 = low intensity; 100 = high intensity
Lamb[e]	Aroma and flavour associated with cooked lamb loin	72°C	0 = low intensity; 100 = high intensity
Lamb[f]	Fatty aroma associated with cooked lamb fat	Melted at 160°C	0 = low intensity; 100 = high intensity
Beef[g]	Fatty aroma associated with cooked beef fat	Melted at 160°C	0 = low intensity; 100 = high intensity
Sour solution[h]	Sour taste	-	0 = low intensity; 100 = high intensity
Sweet solution[i]	Sweet taste	-	0 = low intensity; 100 = high intensity
Salty solution[j]	Salty taste	-	0 = low intensity; 100 = high intensity
Bitter solution[k]	Bitter taste	-	0 = low intensity; 100 = high intensity
Springbok[l]	Texture associated with very tender game meat	76°C	0 = extremely tough; 100 = extremely tender
Giraffe[m]	Texture associated with very tough game meat	76°C	0 = extremely tough; 100 = extremely tender
Beef[c]	Texture associated with over-matured meat (mealiness)	72°C	0 = none; 100 = prominent

[a]fallow deer (*Dama dama*) *longissimus lumborum* muscle; [b]ostrich (*Struthio camelus*) moon steak; [c]beef *longissimus lumborum* muscle aged for 28 days (fat removed); [d]springbok (*Antidorcas marsupialis*) *longissimus lumborum* muscle prepared with a combination of herbs (sage, thyme, parsley and oregano); [e]lamb *longissimus lumborum* muscle; [f]subcutaneous fat removed from lamb *longissimus lumborum* muscle; [g]subcutaneous fat removed from beef *longissimus lumborum* muscle; [h]0.07% citric acid solution; [i]2.0% sucrose solution; [j]0.2% sodium chloride solution; [k]0.07% caffeine solution; [l]springbok *psoas major* muscle; [m]giraffe (*Giraffa camelopardalis*) rump steak.

Table 4.2 Definition and scale of descriptive sensory analysis attributes (aroma, flavour, taste and texture)

Sensory attribute	Description	Scale
Overall aroma	Intensity of the overall aroma in the first few sniffs	0 = low intensity; 100 = high intensity
Gamey aroma	Aroma associated with meat from wild animal species – sometimes a combination of liver-like and metallic aromas	0 = low intensity; 100 = high intensity
Beef-like aroma	Aroma associated with cooked beef loin*	0 = low intensity; 100 = high intensity
Metallic aroma	Aroma associated with raw meat/blood-like	0 = low intensity; 100 = high intensity
Liver-like aroma	Aroma associated with pan-fried beef ox liver	0 = low intensity; 100 = high intensity
Sweet-associated aroma	Aroma associated with the browning of a cooked meat surface (Maillard reaction)	0 = low intensity; 100 = high intensity
Herbaceous aroma	Aroma associated with the vegetation of the farms	0 = low intensity; 100 = high intensity
Lamb-like aroma	Aroma associated with cooked lamb loin*	0 = low intensity; 100 = high intensity
Lamb-like fatty aroma	Aroma associated with melted fat of the lamb loin*	0 = low intensity; 100 = high intensity
Gamey flavour	Flavour associated with meat from wild animal species – sometimes a combination of liver-like and metallic flavours	0 = low intensity; 100 = high intensity
Beef flavour	Flavour associated with cooked beef loin*	0 = low intensity; 100 = high intensity
Metallic flavour	Associated with raw meat or a blood-like taste	0 = low intensity; 100 = high intensity
Liver-like flavour	Flavour associated with pan-fried beef ox liver	0 = low intensity; 100 = high intensity
Lamb flavour	Flavour associated with cooked lamb loin*	0 = low intensity; 100 = high intensity
Herbaceous flavour	Flavour associated with the vegetation of the farms	0 = low intensity; 100 = high intensity
Sour taste	Taste associated with a citric acid solution	0 = low intensity; 100 = high intensity
Sweet taste	Taste associated with a sucrose solution	0 = low intensity; 100 = high intensity
Salty taste	Taste associated with sodium ions	0 = low intensity; 100 = high intensity
Initial juiciness	Amount of fluid extruded on surface of meat when pressed between thumb and forefinger (perpendicular to fibres)	0 = extremely dry; 100 = extremely juicy

Table 4.2 continued

Sensory attribute	Description	Scale
Sustained juiciness	Amount of moisture perceived during mastication	0 = extremely dry; 100 = extremely juicy
Tenderness	Impression of tenderness after mastication	0 = extremely tough; 100 = extremely tender
Residue	Residual tissue remaining after mastication (difficult to chew through)	0 = none; 100 = prominent
Mealiness	Disintegration of muscle fibres into very small particles (perception within the first few chews)	0 = none; 100 = prominent
Liver-like texture	Texture similar to that of pan-fried beef ox liver (spongy/pasty)	0 = none; 100 = prominent

**longissimus lumborum* muscle.

The panel used the test re-test method for DSA with nine replications per treatment. The sensory analysis room was light- (artificial daylight) and temperature-controlled (21°C) (AMSA, 1995). Each panellist was seated at an individual tasting booth at a computer equipped with the Compusense® *five* software programme (Compusense, Guelph, Canada). The panellists received the meat samples for the three treatments in a complete randomised order and analysed each sample for the intensity of the respective sensory attributes (Table 4.2). An unstructured line scale was used for scoring, where zero indicated "low intensity" and 100 indicated "high intensity" (AMSA, 1995). Still mineral water (aQuellé), apple segments (Fuji) and water biscuits (Carr, UK) were available to panellists to refresh their palate between samples.

4.2.7 Statistical analysis

The experimental design was a completely randomised factorial design with six springbok harvested at random from each of the three farms and two genders. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed, using General Linear Models (GLM) Procedure of SAS software (Version 9.2; SAS Institute Inc, Cary, USA). The model for the statistical design is indicated by the following equation:

Model: $y_{ijk} = \mu + f_i + g_j + fg_{ij} + \varepsilon_{ijk}$

where terms within the model are defined as: the response obtained for the k^{th} observation from the i^{th} farm and the j^{th} gender (y_{ijk}), the overall mean (μ); the farm main effect (f_i); the gender main effect (g_j); the farm by gender interaction effect (fg_{ij}); and the random error (ε_{ijk}) associated with response on the k^{th} observation in the i^{th} farm and the j^{th} gender.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In cases where there was significant deviation from normality, the outliers were removed when the standardised residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to compare means (Ott, 1998). A probability level of 5% was considered significant for all significance tests, while 10% was considered significant where biologically relevant. Where applicable, correlation coefficients were calculated for the physical, proximate and sensory data by means of the Pearson's correlation coefficient (r) (Snedecor & Cochran, 1980).

4.3 Results

Table 4.3 depicts the level of statistical significance (p-values) for the influence of the main effects of farm (F) and gender (G) and their interaction (FxG) on the physical measurements (thaw and cooking loss percentages, pHu and WBSF values), proximate composition (moisture, protein, IML and ash content) and sensory attributes (Table 4.2) of springbok meat. The average, minimum and maximum values for above-mentioned attributes are also included in Table 4.3.

A significant interaction existed between the main effects (farm and gender) for the WBSF values, protein and IML contents, as well as the sensory attributes sweet taste and residue of springbok meat (Table 4.4). The

WBSF values of springbok meat did not differ significantly between genders for the meat derived from the three farms, however, the meat derived from female animals from farm A had higher ($p<0.05$) WBSF values compared to females from farms B and C (Table 4.4). Additionally, the WBSF values of springbok meat derived from male animals did not differ significantly between farms (Table 4.4). The protein and IML contents of springbok meat did not differ significantly between genders for the meat derived from farm A (Table 4.4). The protein content was higher ($p<0.05$) in the meat derived from male animals from farms B and C, while the IML content was higher ($p<0.05$) in the meat derived from female animals from farms B and C (Table 4.4). The protein content of the meat derived from female springbok was higher ($p<0.05$) for farm A, lower for farm B and lowest for farm C, while for the meat derived from male springbok the protein content was highest ($p<0.05$) for farm B, lower for farm C and lowest for farm A (Table 4.4). The IML content of the meat derived from female animals was higher ($p<0.05$) for farms B and C, i.e. compared to farm A, while no significant farm differences in the IML content was present for the meat derived from male springbok (Table 4.4).

A significant interaction existed between the main effects (farm and gender) for selected sensory attributes (sweet taste and residue) of springbok meat (Table 4.4). The sweet taste differed ($p<0.05$) between genders for springbok meat derived from farms B and C, while the residue scores differed ($p<0.10$) between genders for springbok meat derived from farm A (Table 4.4). The sweet taste was higher ($p<0.05$) in the meat derived from female springbok from farms B and C, as compared to females from farm A, while the residue scores were higher ($p<0.10$) in the meat derived from females from farm A as compared to farms B and C (Table 4.4). The sweet taste did not differ significantly between farms for the meat derived from male animals, whereas the residue ratings were higher ($p<0.10$) for the meat derived from male animals from farm A, lower for farm B and lowest for farm C (Table 4.4).

Table 4.5 depicts the influence of farm location on the moisture content ($p<0.01$), as well as the sensory attributes gamey ($p<0.05$) and liver-like ($p<0.05$) aroma, beef ($p<0.01$), liver-like ($p<0.05$), lamb-like ($p<0.01$) and herbaceous ($p<0.01$) flavour, tenderness ($p<0.01$), mealiness ($p<0.01$), liver-like texture ($p<0.10$) of springbok meat. The moisture content was highest in the meat derived from farm A and differed significantly from farm B (Table 4.5). In addition, the moisture content was highest ($p<0.01$) in meat derived from male springbok (74.3 ± 0.14) as compared to females (73.2 ± 0.34). The gamey and liver-like aroma, as well as the liver-like flavour was highest in springbok meat derived from farm B (Table 4.5). The beef flavour was highest in the meat derived from farms A and B, while the lamb-like flavour was highest in the meat derived from farms B and C (Table 4.5). Herbaceous flavour was only detected in the meat from farm A (Table 4.5). The sensory tenderness, mealiness and liver-like texture was highest for the meat derived from farm C, lower for meat from farm B and the lowest for the meat from farm A (Table 4.5).

Table 4.3 Level of statistical significance (p-values) for the main effects of farm (F) and gender (G), their interaction (FxG), average, minimum and maximum values of the physical measurements, proximate composition (g.100 g^{-1}) and sensory attributes of springbok meat (Means ± SE)

	FxG	Farm	Gender	Average*	Min	Max
Physical measurements						
Thaw loss %	0.886	0.091	0.404	10.2 ± 0.46	7.4	13.6
Cooking loss %	0.452	0.757	0.058	27.9 ± 1.42	18.8	35.2
pHu	0.846	0.116	0.565	5.5 ± 0.02	5.4	5.8
WBSF (N)	0.049	0.004	0.740	39.8 ± 2.77	23.2	71.9
Proximate composition						
Moisture content	0.389	0.030	0.001	73.8 ± 0.33	71.5	75.4
Protein content	0.026	0.045	0.052	22.1 ± 0.20	20.8	23.3
IML content	0.011	0.041	<0.0001	3.1 ± 0.23	2.0	4.5
Ash content	0.172	0.189	0.365	1.1 ± 0.03	1.0	1.6
Sensory attributes						
Overall aroma	0.656	0.204	0.618	63.6 ± 0.89	58.0	69.2
Gamey aroma	0.795	0.010	0.635	36.2 ± 0.98	31.1	43.3
Beef-like aroma	0.114	0.227	0.901	25.2 ± 1.03	17.7	30.1
Metallic aroma	0.601	0.393	0.490	17.8 ± 0.82	12.2	23.6
Liver-like aroma	0.888	0.020	0.745	17.7 ± 0.79	13.1	21.6
Sweet-associated aroma	0.338	0.565	0.560	11.2 ± 0.45	6.1	14.0
Herbaceous aroma	0.788	0.188	0.921	0.5 ± 0.23	0.0	3.0
Lamb-like aroma	0.954	0.137	0.610	12.4 ± 0.78	7.0	16.1
Fatty (lamb-like) aroma	0.675	0.838	0.333	0.9 ± 0.26	0.0	2.0
Gamey flavour	0.360	0.309	0.074	32.1 ± 1.36	23.1	38.0
Beef flavour	0.400	0.006	0.157	26.6 ± 0.95	20.1	33.5
Metallic flavour	0.351	0.136	0.862	17.9 ± 1.05	11.1	25.0
Liver-like flavour	0.852	0.038	0.304	13.2 ± 1.05	6.1	21.1
Lamb-like flavour	0.192	0.004	0.092	3.2 ± 0.38	1.0	6.2
Herbaceous flavour	0.894	0.001	0.740	0.3 ± 0.09	0.0	2.0
Sour taste	0.240	0.425	0.872	7.8 ± 0.44	5.5	10.5
Sweet taste	0.031	0.795	0.064	5.1 ± 0.54	1.1	8.1
Salty taste	nd	nd	nd	nd	nd	nd
Initial juiciness	0.900	0.525	0.760	68.7 ± 2.49	55.9	86.5
Sustained juiciness	0.533	0.531	0.999	57.4 ± 1.84	49.0	68.0
Tenderness	0.455	0.000	0.610	76.1 ± 2.17	59.7	91.9
Residue	0.090	<0.0001	0.149	2.9 ± 0.59	0.0	11.0
Mealiness	0.312	0.000	0.378	8.2 ± 1.18	1.1	21.0
Liver-like texture	0.577	0.080	0.499	4.9 ± 0.63	1.0	9.0

*average values were calculated irrespective of significant effects of farm (F) and/or gender (G) or interactions (FxG); FxG, farm and gender interaction; SE, standard error; Min, minimum; Max, maximum; nd, not detected in springbok meat; pHu, ultimate pH; WBSF, Warner-Bratzler shear force; IML, intramuscular lipid.

Table 4.4 Influence of the interaction between the main effects of farm (F) and gender (G) on the Warner-Bratzler shear force value, protein and intramuscular lipid content (g.100 g^{-1}) and selected sensory attributes of springbok meat (Means ± SE)

	Farm A		Farm B		Farm C	
	Female	**Male**	**Female**	**Male**	**Female**	**Male**
Physical measurements						
WBSF (N)**	53.2^{a} ± 7.30	42.7^{ab} ± 3.78	36.0^{bc} ± 4.03	41.6^{b} ± 2.18	28.4^{c} ± 1.95	36.5^{bc} ± 2.31
Proximate composition						
Protein content **	22.1^{ab} ± 0.28	21.7^{bc} ± 0.16	22.0^{bc} ± 0.34	22.8^{a} ± 0.24	21.3^{c} ± 0.23	22.3^{ab} ± 0.23
IML content**	3.0^{b} ± 0.31	2.7^{bc} ± 0.23	3.9^{a} ± 0.24	2.4^{c} ± 0.08	4.0^{a} ± 0.14	2.7^{bc} ± 0.09
Sensory attributes						
Sweet taste**	4.3^{b} ± 0.48	5.4^{ab} ± 0.51	6.5^{a} ± 0.66	4.4^{b} ± 0.68	6.4^{a} ± 0.37	4.1^{b} ± 0.96
Residue***	7.5^{a} ± 1.49	4.2^{b} ± 0.92	2.0^{bc} ± 0.71	2.0^{bc} ± 0.63	1.0^{c} ± 0.71	1.2^{c} ± 0.37

$^{a-c}$Means within a variable with superscripts that do not have a common letter indicate significant differences **($p<0.05$), ***($p<0.10$) between farms and/or genders; SE, standard error; WBSF, Warner-Bratzler shear force; IML, intramuscular lipid.

Table 4.5 Influence of farm location on the moisture content (g.100 g^{-1}) and selected sensory attributes of springbok meat (Means ± SE)

	Farm A	Farm B	Farm C
Proximate composition			
Moisture content**	74.4^{a} ± 0.27	73.3^{b} ± 0.34	73.7^{ab} ± 0.37
Sensory attributes			
Gamey aroma**	34.7^{b} ± 0.75	39.1^{a} ± 1.13	34.8^{b} ± 1.05
Liver-like aroma**	15.9^{b} ± 0.83	19.6^{a} ± 0.71	17.6^{ab} ± 0.84
Beef flavour*	28.9^{a} ± 0.83	26.8^{a} ± 1.24	24.0^{b} ± 0.78
Liver-like flavour**	10.8^{b} ± 1.11	14.9^{a} ± 0.93	13.9^{ab} ± 1.12
Lamb-like flavour*	2.2^{b} ± 0.34	4.0^{a} ± 0.48	3.6^{a} ± 0.32
Herbaceous flavour*	0.9^{a} ± 0.26	0.0^{b} ± 0.00	0.0^{b} ± 0.00
Tenderness*	67.5^{c} ± 1.47	75.9^{b} ± 3.02	85.0^{a} ± 2.02
Mealiness*	3.9^{c} ± 0.72	7.7^{b} ± 1.15	13.2^{a} ± 1.67
Liver-like texture***	3.9^{b} ± 0.55	4.7^{ab} ± 0.66	6.1^{a} ± 0.67

$^{a-c}$Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between farms; SE, standard error.

4.4 Discussion

Meat flavour is an important component of the sensory quality of meat (James & Calkins, 2008). In this study, meat aroma refers to the orthonasal aroma (experienced through the external nares in the nasal cavity), while meat flavour refers to retronasal aroma (experienced on consumption of meat) (Roberts & Acree, 1995). Furthermore, the term 'game meat' refers to the meat derived from wild and free-living species, generally derived from South African game species (Hoffman *et al.*, 2005).

The pHu of meat can influence the water-holding capacity (WHC), flavour and tenderness of the meat. A normal range for the pHu of red meat is 5.3 to 5.8 (Honikel, 2004). The harvesting of springbok for this study was conducted at night, so as to minimise ante-mortem stress. The meat derived from springbok in this study therefore had pHu values within the normal range (Table 4.3), minimising the possibility of the negative impact of pHu on the sensory quality of springbok meat. The thaw and cooking loss percentages of springbok meat did not differ significantly between farms or genders (Table 4.3), which can be attributed to standardised freezing and thawing processes (Leygonie *et al.*, 2012), as well as constant cooking methods for all springbok meat samples, respectively. Moreover, the sensory ratings for initial and sustained juiciness of springbok meat also did not differ between farms or genders.

The moisture content of springbok meat differed between farms ($p<0.05$) and genders ($p<0.01$). The latter differences could be linked to the IML content, as a negative correlation often exists between the moisture and IML content of meat (Keeton & Eddy, 2004; Legako *et al.*, 2015); in this investigation a strong negative correlation existed between the moisture and IML content of the springbok meat ($r = -0.817$; $p<0.05$). As was noted in Chapter 3, differences in the fatty acid content and selected volatile compounds between genders were greater for springbok meat derived from farms B and C, as compared to farm A, as was also noted in this study for selected physical, proximate and sensory attributes (Table 4.4). The latter is attributable to the season in which springbok were harvested on the respective farms, as farm A was subject to the dry season, while farms B and C were subject to the wet season. Furthermore, the harvesting periods for farms B and C were in the mating season for springbok, which is an energetically draining period for male animals, resulting in weight loss and significant reductions in the IML levels within muscles (Renecker *et al.*, 2005), in addition to males spending less time feeding during this period (Hoffman, 2000; Mysterud *et al.*, 2004). As weight loss starts with the mobilisation of fat before lean tissue for energy reserves (Lawrie & Ledward, 2006), the meat derived from male springbok from farms B and C therefore had significantly lower levels of IML, while the protein content was still higher ($p<0.05$) in the meat derived from males as compared to females (Table 4.4).

The IML content of springbok meat in this study is higher than values found in previous studies (Du Buisson, 2006; Hoffman *et al.*, 2007a; North & Hoffman, 2015). Nonetheless, the IML content of springbok meat is still low, with high proportions of PUFA (Hoffman & Wiklund, 2006; Chapter 3: polyunsaturated to saturated fatty acid ratio of 0.71). Furthermore, PUFA are more susceptible to lipid oxidation during cooking (Mottram, 1998), which could result in the formation of rancid or off-flavours.

As mentioned previously, gamey, metallic and liver-like aroma and flavours are often perceived as negative sensory attributes, i.e. attributes that are usually not associated with domesticated species such as lamb and

beef. Gamey aroma and flavour have been defined by various authors through the use of the following descriptions: "an aroma and flavour associated with a wild animal species" (Rødbotten *et al.*, 2004; Hoffman *et al.*, 2007c; Van Schalkwyk *et al.*, 2011; Hoffman *et al.*, 2014; North & Hoffman, 2015); "an aroma and flavour associated with a strong game meat aroma and flavour" (Jones *et al.*, 2015); and "typical game meat aroma and flavour" (Hoffman *et al.*, 2009). In this study, gamey aroma and flavour was linked to the aroma and flavour of the meat derived from a wild animal species, in addition it could be linked to metallic and liver-like sensory attributes (Table 4.2). However, in this study, gamey, metallic and liver-like aroma and flavours were perceived as three distinct attributes during DSA of springbok meat (Table 4.3). Gamey aroma contributed the greatest to the overall aroma intensity of springbok meat (Table 4.3). Nonetheless, gamey aroma and flavour was positively correlated to liver-like aroma and flavour of springbok meat ($r = 0.755$ and $r = 0.497$; $p<0.05$, respectively). Wiklund *et al.* (2003a) suggested that a 'wild' attribute (referred to as 'gamey' in this study) in meat is linked to the fatty acid composition as influenced by higher quantities of natural grazing in the diets of deer species. Furthermore, meat with higher proportions of C18:3n3 (α-linolenic acid) will have more intense aroma and flavours as compared to meat with higher proportions of C18:2n6c (linoleic acid) (Wood *et al.*, 1999). Springbok meat derived from farms B and C had higher ($p<0.01$) levels of C18:3n3 (α-linolenic acid), while springbok meat from farm B had higher ($p<0.10$) levels of C18:2n6 (linoleic acid) (Chapter 3: Means ± SE: farm A, 4.84 ± 0.493; farm B, 5.51 ± 0.596; farm C, 4.25 ± 0.213). The latter could have attributed to higher ($p<0.05$) ratings for gamey and liver-like aroma, as well as liver-like flavours in springbok meat derived from farms B and C, as compared to farm A (Table 4.5).

Unfortunately, no literature is available on the volatile aroma compounds linked to a gamey sensory attribute of meat, although a liver-like sensory attribute has been associated with volatile aroma compounds such as 1-octen-3-ol, pentanal, hexanal, 3-hydroxy-2-butanone and hexanoic acid percentages (Hodgen, 2006; Stetzer *et al.*, 2008). It was postulated that the higher gamey aroma and liver-like aroma and flavour of springbok meat, was attributed to the higher percentages of 1-octen-3-ol, a lipid-derived volatile aroma compound (Hodgen, 2006), found at higher ($p<0.01$) percentages in springbok meat derived from farm B (Chapter 3: Means ± SE: farm A, 0.96 ± 0.130; farm B, 2.13 ± 0.286; farm C, 0.79 ± 0.247).

A great number of volatile aroma compounds have been linked to beef-like characteristics of meat, however, only selected compounds are aroma active and contribute to beef-like sensory attributes (Moon *et al.*, 2006; Song *et al.*, 2010). Nonanal and 2-pentylfuran have been linked to beef-like sensory attributes in meat (Moon *et al.*, 2006; Song *et al.*, 2010) and both compounds were present at higher percentages in springbok meat derived from farms A and B (Chapter 3), which is in agreement with higher sensory ratings for beef flavour in springbok meat derived from these farms (Table 4.5). However, springbok meat derived from farm C also had beef flavour characteristics (Table 4.5), although nonanal and 2-pentylfuran were not detected in springbok meat from farm C (Chapter 3). It is therefore postulated that another compound or combinations of compounds attributed to a beef flavour of springbok meat in this study (Moon *et al.*, 2006).

A sweet taste is generally associated with the desirable sensory attributes contributing to meat flavour (Spanier *et al.*, 1997). A higher sweet taste in meat has been linked to higher pHu values of dark, firm and dry

(DFD) meat (Flores *et al.*, 1999; Byrne *et al.*, 2001). However, the pHu values of springbok meat in this study were classified as normal with an average value of 5.5 (Table 4.3). The volatile aroma compounds associated with a sweet-associated aroma and sweet taste in meat are hexanal, heptanal, nonanal, 2,3-butanedione, butanoic acid and 2-pentylfuran (Specht & Baltes, 1994; Madruga *et al.*, 2010). Unfortunately, no significant correlations were present between the sweet taste and the percentage of these volatile aroma compounds.

A lamb-like flavour is often higher in the meat derived from grass-fed (primarily omega-3 polyunsaturated fatty acids, n3 PUFA), as compared to grain-fed (omega-6 polyunsaturated fatty acids, n6 PUFA) animals (Saňudo *et al.*, 1998; Fisher *et al.*, 2000). Springbok meat derived from farms B and C had higher ratings for lamb-like flavour compared to meat from farm A (Table 4.5), which could be attributed to higher ($p<0.05$) levels of total n3 PUFA in springbok meat derived from farms B and C (Chapter 3: Means ± SE: farm A, 1.76 ± 0.191; farm B, 2.45 ± 0.262; farm C, 2.51 ± 0.160).

Herbaceous flavour was only present in springbok meat derived from farm A (Table 4.5). The herbaceous aroma and flavour was most probably associated with the vegetation found at farm A (Table 4.2). The latter had onion and garlic-like characteristics. Hexanal has been associated with a garlic-like aroma (Prost *et al.*, 2004), however, hexanal was detected in springbok meat from all three farms (Chapter 3) and was therefore not solely responsible for the herbaceous flavour of springbok meat from farm A. Furthermore, dihydro-3(2H)-thiophenone and 2-furanmethanethiol have been associated with a garlic-like aroma and flavour (Farmer *et al.*, 1989), while 1-methylthio-ethanethiol has been associated with a fresh onion-like aroma (Brinkman *et al.*, 1972). However, none of the latter volatile aroma compounds were detected in springbok meat (Chapter 3).

Due to the complex nature of flavour development, the volatile aroma compound profile is often poorly associated with the sensory profile of meat (Chambers IV & Koppel, 2013). Moreover, Laird *et al.* (2015) established that multiple volatile aroma compounds were required to predict the sensory aroma and flavour attributes of beef. In addition, a combination of volatile aroma compounds may yield different aroma and flavour sensations as compared to individual compounds; the impact of a volatile compound on the aroma and flavour of meat being influenced by the odour threshold value (Chambers IV & Koppel, 2013).

Tenderness is an important sensory quality attribute of meat (Wood *et al.*, 1999). Springbok meat in this study can be classified as tender (excluding the meat derived from female springbok from farm A) due to WBSF values of <42.87 N (Destefanis *et al.*, 2008). A strong negative correlation often exists between the WBSF values (instrumental tenderness measured in N) and the sensory tenderness ratings (trained panel) of meat (Hoffman *et al.*, 2007c; Destefanis *et al.*, 2008; Sullivan & Calkins, 2011; Oltra *et al.*, 2015); depending on the scale used during DSA. In this study, higher sensory ratings for tenderness indicated a higher degree of tenderness for springbok meat, which had a strong negative correlation with the WBSF values ($r = -0.710$; $p<0.05$), as lower WBSF values indicate a higher degree of tenderness.

Sensory tenderness and flavour are often correlated to the overall liking of meat (Neely *et al.*, 1998; Hutchison *et al.*, 2010). Higher ratings for sensory tenderness are therefore favourable for consumer perception of springbok meat. A positive correlation existed between sensory tenderness and mealiness ratings

(r = 0.642; p<0.05) of springbok meat. Springbok meat derived from farm C was perceived to be most tender, in addition to having the highest mealiness ratings compared to springbok meat from farms A and B (Table 4.5). Mealiness is often not perceived as a positive sensory attribute. Nonetheless, the ratings for mealiness was very low (Table 4.5) and it can be postulated that it will not have a significant impact on the tenderness of springbok meat. The ratings for residue was negatively correlated with sensory tenderness (r = -0.630; p<0.05) and mealiness (r = -0.593; p<0.05). Springbok meat with the highest tenderness and mealiness therefore had the lowest residue ratings (Tables 4.4 and 4.5).

4.5 Conclusions

In this study, gamey aroma dominated the overall aroma intensity of springbok meat and the former was defined as a combination of metallic and liver-like aroma. Moreover, a strong positive correlation existed between gamey and liver-like aroma of springbok meat, which could negatively influence consumer perception of springbok meat as liver-like characteristics are often not preferred by consumers. A strong negative correlation existed between the sensory and instrumental tenderness values of springbok meat, indicating that WBSF could be used to determine the toughness/tenderness of springbok meat with reasonable accuracy. This study clearly showed that the *longissimus thoracis et lumborum* of springbok can be classified as tender. Farm location had a significant influence on the sensory quality of springbok meat and should therefore be taken into consideration when harvesting springbok for the commercial production of game meat. However, gender had a minor influence on the sensory quality of springbok meat. It is therefore postulated that gender related differences will not influence consumer perception of springbok meat.

4.6 References

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Chapter 5

Influence of farm location and gender on the fatty acid content and volatile compound profile of blesbok (*Damaliscus pygargus phillipsi*) meat

Abstract

Blesbok is a strictly grazing game species found widely throughout South Africa, even though the vegetation types differ between regions/farms where they are found. Mature animals irrespective of their gender are usually harvested for commercial meat production. However, gender and dietary regime can influence the fatty acid content and volatile compound profile of the meat derived from ruminant species, and consequently meat flavour. The aim of this study was to quantify the influence of farm location and gender on the fatty acid content (mg.g^{-1} of meat) and volatile compound profile of blesbok meat. Twelve mature blesbok (six males and females) were randomly harvested from each of two farms situated in different regions of South Africa. The essential fatty acid, C18:3n3 (α-linolenic acid) of the *longissimus thoracis et lumborum* (LTL) muscle, differed between farms ($p<0.01$) and genders ($p<0.10$), however, only significant farm differences were present for total omega-3 polyunsaturated fatty acids (farm A, 2.59 ± 0.141; farm B, 3.10 ± 0.190 mg.g^{-1} of meat) and omega-6 to omega-3 polyunsaturated fatty acid ratios (farm A, 3.38 ± 0.166; farm B, 2.81 ± 0.046 mg.g^{-1} of meat). The total saturated fatty acid content was highest ($p<0.01$) in blesbok meat derived from female animals (females, 13.87 ± 0.547; males, 10.64 ± 0.659 mg.g^{-1} of meat) and consequently the polyunsaturated to saturated fatty acid ratio was lower ($p<0.01$) for females (females, 0.81 ± 0.068; males, 1.17 ± 0.070 mg.g^{-1} of meat). The volatile compound profile of the LTL muscle of blesbok was dominated by lipid-derived compounds such as aldehydes, alcohols and 2-pentylfuran. These results indicate that farm location and gender influences the fatty acid content and volatile compound profile of blesbok meat.

Keywords: Game meat; Volatile compounds; α-Linolenic acid; Linoleic acid

5.1 Introduction

Flavour is a key sensory attribute contributing to the acceptability of meat and meat products (Pegg & Shahidi, 2004). Meat flavour is thermally derived with the volatile compounds contributing orthonasally but also retronasally to the sensation of aroma. However, there is no single compound or group of compounds that is exclusively responsible for meat flavour.

Meat flavour can be influenced by manipulating the dietary regime of animals (Elmore *et al.*, 2005; Resconi *et al.*, 2010, 2012). Differences in the dietary regime result in differences in the fatty acid profile of the adipose and intramuscular lipids (IML) (Lorenz *et al.*, 2002; Pegg & Shahidi, 2004; Descalzo *et al.*, 2005), in addition flavour precursors (Lorenz *et al.*, 2002) and the antioxidant content of meat is also changed (Descalzo *et al.*, 2005). Dietary differences in the fatty acid profile of meat influences flavour development during thermal processing, as unsaturated fatty acids (SFA) are more readily oxidised, generating lipid-derived aroma precursors (Pegg & Shahidi, 2004). As a result, dietary regime influences the sensory attributes and ultimately

also the consumer acceptability of meat products (Resconi *et al.*, 2010; Maughan *et al.*, 2012; Resconi *et al.*, 2012).

The majority of studies investigating the influence of dietary regime on the composition and flavour of meat, focus on grass (higher in C18:3n3, α-linolenic acid) compared to concentrate or grain-based (higher in C18:2n6, linoleic acid) diets in domesticated species (Lorenz *et al.*, 2002; Descalzo *et al.*, 2005; Nuernberg *et al.*, 2005; Vasta & Priolo, 2006; Vasta *et al.*, 2011, 2012). Diets containing a higher amount of unsaturated fatty acids can result in an increase in the total content of SFA, as unsaturated fats in the diets of ruminants are bio-hydrogenated to SFA (Wood *et al.*, 1999). Furthermore, some researchers have found a general decrease in the total polyunsaturated fatty acid (PUFA) content (Lorenz *et al.*, 2002), while others have found an increased in the total PUFA content of meat, as a result of grass-based diets (Descalzo *et al.*, 2005). The omega-6 to omega-3 polyunsaturated fatty acid (n6:n3) ratio is also affected by dietary regime. This ratio is generally lower in the meat from grass-fed animals (Lorenz *et al.*, 2002).

Moreover, higher concentrations of the aldehydes (*E*,*Z*)-2,6-nonadienal, as well as nonanal and octanal have been found in beef from grass-based diets with higher levels of C18:3n3 (α-linolenic acid) and C18:1n9c (oleic acid), respectively (Lorenz *et al.*, 2002). However, other researchers have found significantly lower concentrations of selected aldehydes (pentanal, hexanal, heptanal, octanal and 3-methylbutanal) as a result of grass-based, as compared to grain-based diets (Descalzo *et al.*, 2005).

The blesbok is one of the most popular South African game species harvested annually for meat production purposes (Neethling *et al.*, 2014a). Blesbok is a wild and free-ranging game species that feeds selectively on short grass species (Du Plessis, 1972; Bothma *et al.*, 2010). Consequently, the dietary regime of blesbok might not differ greatly between regions/farms in South Africa. Although South African consumers have found the sensory quality of blesbok meat acceptable (Hoffman *et al.*, 2010), regional/farm differences in the composition and flavour of blesbok meat can influence consumer acceptability. Neethling *et al.* (2014a) established that the fatty acid profile of blesbok meat differed between genders, but differences between harvesting seasons (diets) were minor. However, the influence of dietary regime on the volatile compound profile of blesbok meat has not been investigated.

The aim of the present study was to investigate the influence of farm location (and thus indirectly diet) and gender on the fatty acid content and volatile compound profile of blesbok meat derived from two farms, located in different regions (vegetation types) of South Africa.

5.2 Materials and methods

5.2.1 Experimental layout and harvesting

In this study blesbok were harvested from two farms in South Africa: farm A, Kimberley District in the Northern Cape Province (28° 49’ 12.0” S, 25° 07’ 53.4” E); and farm B, Coastline of the Western Cape Province near Witsand (34° 18’ 24.0” S, 20° 49’ 3.9” E). The details on the location and vegetation types of farms A and B are discussed in Chapter 3, with the exception of blesbok from farm B not having access to the cultivated lands.

All blesbok were harvested during July of 2013. July is characterised as the dry season for farm A, while for farm B, July is generally the middle of the wet season. Twelve mature animals were randomly selected and harvested per farm, of which six were male and six were female. Harvesting occurred at night (ethical clearance number: SU-ACUM14-001SOP) in accordance with the *Guidelines for the Harvesting of Game for Meat Export* (Van Schalkwyk & Hoffman, 2010). The bled, undressed carcasses were weighed to obtain the undressed carcass weights (means ± standard error; farm A, 58.25 kg ± 1.299; farm B, 53.60 kg ± 2.164; female, 54.25 kg ± 1.851; male, 57.61 kg ± 1.848), where after the head, legs and skin was removed and evisceration occurred (Van Schalkwyk & Hoffman, 2010). After 24 h of refrigeration (4 ± 1°C) the dressed carcasses were weighed to obtain the cold carcass weight (farm A, 32.26 kg ± 0.773; farm B, 27.47 kg ± 1.125; female, 29.38 kg ± 1.284; male, 30.34 kg ± 1.102) and the dressing percentages were calculated (farm A, 55.4% ± 0.517; farm B, 51.2% ± 0.347; female, 54.0% ± 0.809; male, 52.6% ± 0.651).

5.2.2 Sampling and sample preparation

The sampling and sample preparation is as described in Chapter 3.

5.2.3 Analysis of fatty acids

The analysis of the fatty acid content is as described in Chapter 3.

5.2.4 Analysis of volatile compounds using SPME-GC-MS

The analysis of the volatile compound profile is as described in Chapter 3.

5.2.5 Statistical analysis

The experimental design was a completely randomised factorial design with six blesbok harvested at random from each of the two farms and two genders. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed, using General Linear Models (GLM) Procedure of SAS software (Version 9.2; SAS Institute Inc, Cary, USA). The model for the statistical design is indicated by the following equation:

Model: $y_{ijk} = \mu + f_i + g_j + fg_{ij} + \varepsilon_{ijk}$

where terms within the model are defined as: the response obtained for the k^{th} observation from the i^{th} farm and the j^{th} gender (y_{ijk}), the overall mean (μ); the farm main effect (f_i); the gender main effect (g_j); the farm by gender interaction effect (fg_{ij}); and the random error (ε_{ijk}) associated with response on the k^{th} observation in the i^{th} farm and the j^{th} gender.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In cases where there was significant deviation from normality, the outliers were removed when the standardised residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to

compare means (Ott, 1998). A probability level of 5% was considered significant for all significance tests, while 10% was considered significant where biologically relevant.

5.3 Results

5.3.1 Fatty acid content

Table 5.1 indicates the level of statistical significance (p-values) for the influence of the main effects of farm (F) and gender (G), and their interaction (FxG) on the fatty acid content (mg.g^{-1} of meat) of blesbok meat. The average means ± standard error (Means ± SE), minimum and maximum values for the fatty acid content of blesbok meat is also indicated in Table 5.1, so as to provide insight into the importance of each fatty acid. The IML content (g.100 g^{-1} of meat) of blesbok meat was low and did not differ ($p>0.05$) between farms (farm A, 2.84 g ± 0.157; farm B, 2.76 g ± 0.095), while the IML was higher ($p<0.01$) in the meat derived from female animals (3.05 g ± 0.121) as compared to males (2.55 g ± 0.086). Due to the low IML content of blesbok meat, the fatty acids present at very low levels (<10 mg.g^{-1} of meat) will not be discussed further. However, the essential fatty acids (C18:2n6c, linoleic acid and C18:3n3, α-linolenic acid) and fatty acid totals will be discussed irrespective of their presence at low levels in blesbok meat.

A significant interaction existed between the main effects (farm and gender) for the C15:1n9t (*cis*-10-pentadecenoic acid), C18:1n9t (elaidic acid), C18:3n6 (gamma-linolenic acid) and C20:3n6 (dihomo-gamma-linolenic acid) content of blesbok meat (Tables 5.1 and 5.2). However, as these fatty acids were present at very low levels in blesbok meat, they will not be discussed further in detail (Table 5.2).

Table 5.3 depicts the significant effect of farm (diet) on the content of C18:0 (stearic acid), C18:3n3 (α-linolenic acid), total monounsaturated fatty acids (MUFA), total omega-3 polyunsaturated fatty acids (n3 PUFA) and the omega-6 to omega-3 polyunsaturated fatty acid ratio (n6:n3 PUFA ratio) in blesbok meat. The C18:0 (stearic acid), C18:3n3 (α-linolenic acid) and total n3 PUFA content was significantly higher in blesbok meat derived from farm B, while the total MUFA and n6:n3 PUFA ratio was higher ($p<0.01$) in blesbok meat derived from farm A (Table 5.3).

Table 5.4 depicts the significant effect of gender on the content of C16:0 (palmitic acid), C18:0 (stearic acid), C18:1n9c (oleic acid), C18:2n6c (linoleic acid), C18:3n3 (α-linolenic acid), total saturated fatty acids (SFA), total monounsaturated fatty acids (MUFA) and the polyunsaturated to saturated fatty acid ratio (PUFA:SFA ratio) in blesbok meat. The C16:0 (palmitic acid), C18:0 (stearic acid), C18:1n9c (oleic acid), total SFA and total MUFA content was higher ($p<0.01$) in blesbok meat derived from female animals, while the C18:2n6c (linoleic acid), C18:3n3 (α-linolenic acid) and PUFA:SFA ratio was significantly higher in blesbok meat derived from male animals (Table 5.4).

Table 5.1 Level of statistical significance (p-values) for the main effects of farm (F) and gender (G) and their interaction (FxG) on the fatty acid content (mg.g^{-1} of meat) of blesbok meat

Fatty acid	Common name	FxG	Farm	Gender	Average*	Min	Max
C14:0	Myristic acid	0.679	0.370	0.000	0.22 ± 0.025	0.10	0.39
C15:0	Pentadecylic acid	0.577	0.024	0.026	0.11 ± 0.006	0.06	0.15
C16:0	Palmitic acid	0.535	0.975	<0.0001	5.02 ± 0.266	3.69	7.14
C18:0	Stearic acid	0.371	0.010	0.000	6.47 ± 0.448	3.93	8.81
C20:0	Arachidic acid	0.150	0.366	0.509	0.08 ± 0.007	0.05	0.14
C21:0	Heneicosylic acid	0.249	0.863	0.067	0.06 ± 0.005	0.03	0.09
C22:0	Behenic acid	nd	nd	nd	nd	nd	nd
C23:0	Tricosylic acid	0.312	0.517	0.191	0.03 ± 0.003	0.01	0.05
C24:0	Lignoceric acid	0.553	0.450	0.044	0.16 ± 0.011	0.10	0.23
C14:1n9c	Myristoleic acid	0.538	0.191	0.289	0.03 ± 0.003	0.01	0.05
C15:1n9t	*cis*-10-Pentadecenoic acid	0.013	<0.0001	0.667	0.10 ± 0.008	0.00	0.18
C16:1n7	Palmitoleic acid	nd	nd	nd	nd	nd	nd
C18:1n9c	Oleic acid	0.549	0.154	0.001	3.67 ± 0.604	1.17	8.42
C18:1n9t	Elaidic acid	0.087	0.526	0.061	0.04 ± 0.013	0.00	0.14
C20:1n9	Gondoic acid	nd	nd	nd	nd	nd	nd
C22:1n9	Erucic acid	0.276	0.193	0.473	0.05 ± 0.004	0.03	0.08
C24:1n9	Nervonic acid	0.529	0.524	0.070	0.09 ± 0.009	0.03	0.16
C18:2n6c	Linoleic acid	0.154	0.366	0.022	5.49 ± 0.278	1.60	7.67
C18:2n6t	Linolelaidic acid	nd	nd	nd	nd	nd	nd
C18:3n6	Gamma-linolenic acid	0.018	0.092	0.022	0.04 ± 0.005	0.00	0.07
C18:3n3	Alpha-linolenic acid	0.171	0.002	0.071	1.83 ± 0.115	1.10	2.80
C20:2n6	Eicosadienoic acid	0.264	0.478	0.311	0.05 ± 0.006	0.02	0.13
C20:3n6	Dihomo-gamma-linolenic acid	0.045	0.234	0.000	0.25 ± 0.017	0.07	0.36
C20:3n3	Eicosatrienoic acid	0.807	0.816	0.158	0.12 ± 0.023	0.04	0.31
C20:4n6	Arachidonic acid	0.267	0.607	0.326	2.56 ± 0.156	1.69	3.75
C20:5n3	Eicosapentaenoic acid, EPA	0.161	0.909	0.267	0.72 ± 0.039	0.49	0.98
C22:2n6	Docosadienoic acid	0.375	0.545	0.035	0.22 ± 0.017	0.13	0.32
C22:6n3	Docosahexaenoic acid, DHA	0.249	0.586	0.107	0.24 ± 0.012	0.17	0.31
SFA		0.256	0.131	0.001	12.16 ± 0.763	8.16	16.85
MUFA		0.389	0.074	0.000	4.06 ± 0.571	1.93	8.76
PUFA		0.317	0.461	0.167	11.53 ± 0.590	8.22	16.31
PUFA:SFA ratio		0.862	0.575	0.002	1.00 ± 0.088	0.49	1.42
n6 PUFA		0.413	0.926	0.145	8.71 ± 0.468	6.00	12.15
n3 PUFA		0.354	0.048	0.216	2.88 ± 0.165	1.98	4.16
n6:n3 PUFA ratio		0.756	0.003	0.693	3.07 ± 0.106	2.50	4.44

*Average values (Means ± SE) were calculated irrespective of significant effects of farm (F) and/or gender (G) or their interaction (FxG); SE, standard error; Min, Minimum; Max, Maximum; nd, not detected in blesbok meat; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

Table 5.2 Influence of the interaction (FxG) between the main effects of farm (F) and gender (G) on the content (mg.g^{-1} of meat) of selected fatty acids in blesbok meat (Means ± SE)

	Farm A		Farm B	
Fatty acid	**Female**	**Male**	**Female**	**Male**
C15:1n9t**	0.13^{a} ± 0.003	0.16^{a} ± 0.008	0.08^{b} ± 0.005	0.05^{b} ± 0.021
C18:1n9t***	0.00^{b} ± 0.000	0.06^{a} ± 0.018	0.04^{ab} ± 0.021	0.05^{ab} ± 0.010
C18:3n6**	0.02^{b} ± 0.011	0.06^{a} ± 0.005	0.05^{a} ± 0.004	0.05^{a} ± 0.002
C20:3n6**	0.23^{b} ± 0.018	0.28^{ab} ± 0.010	0.18^{c} ± 0.021	0.30^{a} ± 0.020

[a-c]Means within a variable with superscripts that do not have a common letter indicate significant differences **($p<0.05$), ***($p<0.10$) between farms; SE, standard error.

Table 5.3 Influence of farm (diet) on the content (mg.g^{-1} of meat) of selected fatty acids in blesbok meat (Means ± SE)

Fatty acid	**Farm A**	**Farm B**
C15:0**	0.11^{a} ± 0.006	0.10^{b} ± 0.006
C18:0**	5.79^{b} ± 0.531	7.06^{a} ± 0.365
C18:3n3*	1.54^{b} ± 0.101	2.09^{a} ± 0.129
MUFA***	4.74^{a} ± 0.710	3.61^{b} ± 0.433
n3 PUFA**	2.59^{b} ± 0.141	3.10^{a} ± 0.190
n6:n3 PUFA ratio*	3.38^{a} ± 0.166	2.81^{b} ± 0.046

[a-b]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between farms; SE, standard error; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

Table 5.4 Influence of gender on the content (mg.g^{-1} of meat) of selected fatty acids in blesbok meat (Means ± SE)

Fatty acid	Female	Male
C14:0*	0.28^{a} ± 0.023	0.16^{b} ± 0.011
C15:0**	0.09^{b} ± 0.006	0.12^{a} ± 0.005
C16:0*	5.71^{a} ± 0.182	4.31^{b} ± 0.122
C18:0*	7.59^{a} ± 0.350	5.37^{b} ± 0.346
C21:0***	0.06^{b} ± 0.005	0.07^{a} ± 0.004
C24:0**	0.14^{b} ± 0.011	0.17^{a} ± 0.009
C18:1n9c*	5.00^{a} ± 0.658	2.50^{b} ± 0.211
C24:1n9***	0.08^{b} ± 0.009	0.10^{a} ± 0.009
C18:2n6c**	5.22^{b} ± 0.283	6.08^{a} ± 0.232
C18:3n3***	1.70^{b} ± 0.109	1.97^{a} ± 0.172
C22:2n6**	0.19^{b} ± 0.016	0.24^{a} ± 0.015
SFA*	13.87^{a} ± 0.547	10.64^{b} ± 0.659
MUFA*	2.38^{a} ± 0.613	2.88^{b} ± 0.198
PUFA:SFA ratio*	0.81^{b} ± 0.068	1.17^{a} ± 0.070

$^{a-b}$Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between genders; SE, standard error; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0).

5.3.2 Volatile compounds

Table 5.5 depicts the profile of volatile compounds present in blesbok meat, as arranged by chemical classes: aldehydes; alcohols; ketones; benzene compounds; furans; carboxylic acids; esters; sulphur-containing compounds; and sulphur- and nitrogen containing compounds. Table 5.5 also indicates the retention times, aroma descriptions from literature and level of statistical significance (p-values) for the influence of the main effects of farm (F) and gender (G), and their interaction (FxG) on the quantity (semi-quantitative data) of the volatile compounds (percentage area of the peak) present in blesbok meat.

A significant interaction existed between the main effects (farm and gender) for the percentages of some aldehydes (hexanal, heptanal and nonanal), alcohols (2,3-butanediol, 1-pentanol and 1-octanol), ketones (2-heptanone and 2,3-octanedione), furans (2-pentylfuran), carboxylic acids (heptanoic acid) and esters (2-propenoic acid, butyl ester and propanoic acid, butyl ester) in blesbok meat (Table 5.6). Table 5.7 depicts the significant effect of farm location on the percentages of some alcohols (1-octen-3-ol), ketones (3-hydroxy-2-

butanone and 3-methyl-2-butanone), benzene compounds (benzaldehyde) and carboxylic acids (acetic acid) in blesbok meat. Table 5.8 depicts the significant effect of gender on the percentages of some benzene compounds (benzaldehyde), sulphur-containing compounds (dimethyl sulphone) and sulphur- and nitrogen-containing compounds (2-acetyl-2-thiazoline) in blesbok meat. The potential role/effect of these interactions, as well as the main effects of farm and gender on the flavour and aroma of blesbok meat will be mentioned where applicable in the Discussion section.

5.4 Discussion

Lipids and water-soluble compounds are two major categories of precursors of meat flavour (Mottram, 1998a). Moreover, the primary reactions responsible for the formation of volatile compounds during cooking, are the thermal degradation of lipids and the Maillard reaction between amino acids and reducing sugars (Mottram, 1998a). The lean portion of meat contributes to a general meat-like flavour (non-species-specific), while the intramuscular lipids (IML – phospholipids and to a lesser degree the triglycerides) contribute to species-specific flavours of cooked meat (Wasserman & Spinelli, 1972; Mottram, 1998b).

A total of 22 volatile compounds were tentatively identified in blesbok meat derived from the two farms (Table 5.5). The extraction temperature used in this study (70°C) resembled a mild cooking method and temperature, both of which have been associated with the formation of primarily lipid degradation/oxidation products. The more intense cooking methods (higher temperature for longer times) have been associated with a decrease in lipid degradation/oxidation and an increase in Maillard reaction and Strecker degradation products (Mottram, 1985; Roldán *et al.*, 2015). Consequently, the volatile compound profile of blesbok meat was dominated by lipid-derived compounds, as aldehydes, alcohols, ketones, benzene compounds, furans and carboxylic acids are formed by the thermal oxidation of fatty acids from phospholipids and triglycerides (Forss, 1973; Ladikos & Lougovois, 1990; Mottram, 1998a; Elmore *et al.*, 1999; Song *et al.*, 2011). Esters are derived from the esterification of various alcohols and carboxylic acids in meat (Um *et al.*, 1992). Additionally, a number of volatile compounds in blesbok meat were possibly Maillard reaction products, such as the heterocyclic sulphur-containing compounds, as well as the sulphur- and nitrogen-containing compounds (Forss, 1973; Mottram, 1998a; Machiels *et al.*, 2004).

Blesbok meat is low in fat and high in PUFA (Hoffman *et al.*, 2008; Neethling *et al.*, 2014a, 2014b). In meat with a low IML content, the highest quantity of PUFA occur in the polar lipid fraction of the phospholipids (Igene *et al.*, 1980) and these PUFA are extremely reactive and therefore highly susceptible to oxidation (Igene *et al.*, 1980). Consequently, PUFA play an important role in the development of rancidity in frozen and cooked meats (Igene *et al.*, 1980). A higher PUFA content of beef has been linked to the formation of higher concentrations of aliphatic aldehydes (such as hexanal, heptanal and nonanal) and alcohols (such as 1-pentanol and 1-octanol) (Elmore *et al.*, 1999; Machiels *et al.*, 2004), as PUFA induces the increased thermal degradation of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) (Elmore *et al.*, 1999). As a result, the saturated aldehydes (such as hexanal, heptanal and nonanal) and alcohols are primarily derived from the oxidation of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) (Elmore *et al.*, 1999; Belitz *et al.*, 2009). In

addition, hexanal and 1-octen-3-ol can be derived from the oxidation of C20:4n6 (arachidonic acid) (Blank *et al.*, 2001; Lorenzo, 2014; Marušić *et al.*, 2014), while 2-pentylfuran is also a product of the thermal degradation of C18:2n6c (linoleic acid) (Mottram, 1985; Elmore *et al.*, 1999). Elmore *et al.* (1999) established that a higher content of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) are linked to higher levels of saturated aldehydes, alcohols and 2-pentylfuran in beef. In addition, a higher content of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) have been linked to higher percentages of aldehydes, alcohols, ketones and 2-pentylfuran in springbok meat (Chapter 3).

A number of compounds are derived from the degradation or fermentation of carbohydrates, such as 2,3-butanediol, 2,3-butanedione (diacetyl), benzaldehyde, acetic and butanoic acids, as well as dimethyl sulphone (Gandemer, 2002; Spaziani *et al.*, 2009). Ketones are derived from the autoxidation of fatty acids and aldehydes, in addition to microbial degradation (Gao *et al.*, 1998; Ganesan *et al.*, 2014). 2,3-Butanedione (diacetyl) can also be formed by means of bacterial degradation during the storage of meat (Resconi *et al.*, 2012). Hydroxyketones (such as 3-hydroxy-2-butanone/acetoin) are sugar degradation products from the Maillard reaction (Elmore *et al.*, 2005; Roldán *et al.*, 2015).

In springbok meat, the C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) content was linked to higher percentages of selected aldehydes, alcohols, ketones and 2-pentylfuran (Chapter 3). However, no such link was present for blesbok meat (Tables 5.4 and 5.6). Saturated and unsaturated aldehydes can participate in amino acid-carbonyl compound interactions (Adams *et al.*, 2009), which could have attributed to the absence of a link between the percentages of selected aldehydes, aliphatic alcohols, ketones, 2-pentylfuran and heptanoic acid with the C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) content of blesbok meat.

The formation of benzaldehyde has been linked to the oxidation of C18:3n3 (α-linolenic acid) (Elmore *et al.*, 2005). In addition, Ba *et al.* (2014) found a positive correlation between the benzaldehyde content (µg per g) and the C18:3n3 (α-linolenic acid) percentage in beef. In this study, the benzaldehyde percentage was different between farms ($p<0.01$) (Table 5.7) and genders ($p<0.05$) (Table 5.8). Similarly, the C18:3n3 (α-linolenic acid) content was different between farms ($p<0.01$) (Table 5.3) and genders ($p<0.10$) (Table 5.4). The content of the latter fatty acid was higher in blesbok meat derived from farm B (similar to the benzaldehyde percentage) (Tables 5.3 and 5.7), however, the gender differences were opposite as the C18:3n3 (α-linolenic acid) content was higher in blesbok meat derived from male animals (Table 5.4), while the benzaldehyde percentage was higher in blesbok meat derived from female animals (Table 5.8). Benzaldehyde can also be a product of the Strecker degradation of certain amino acids (Mottram & Edwards, 1983). The formation of benzaldehyde in blesbok meat could therefore be partly attributed to the degradation of C18:3n3 (α-linolenic acid).

Table 5.5 Level of statistical significance (p-values) for the main effects of farm (F) and gender (G) and their interaction (FxG) on the percentages of volatile compounds in blesbok meat

Volatile compounds*	RT	Aroma description	FxG	Farm	Gender
Aldehydes					
Hexanal	6.70	green[1,5,6,7,16,17,20,21,22,23,26,27,30,31], sweet[5], fat[5,6,8,13,20,22,24,31], grass[5,7,8,9,10,13,14,16,17,20,22,24,26,30,31], tallow[13,20], garlic[14], rancid[17], green apple[19,28], liver-like[20], fruit[27,28], vegetable[28]	0.000	0.034	0.369
Heptanal	9.51	oil[1,17,20,26], putty[1], fruit[5,17,19,26,27,28], fat[5,13,17,20,22,26,31], sweet[5], green[5,14,16,26], grass[5], potatoes[9], citrus[13,21,26], rancid[13,20], floral[14], cured ham-like[17,22,31], toasted[17], unpleasant[20], grease[22,31], nut[27]	0.006	0.710	0.222
Nonanal	17.06	tallow[1,6,24], floral[2,20,26], fruit[2], herbaceous[2], lemon[2,18], fragrant[5], sweet[5], fat[5,13,17,19,20,22,26,31], green[5,6,7,11,13,16,20,23,26,27,28], pungent[3], gravy[11], citrus[13,16,20], sea[16], citronella grass[16], rancid[17,19,22,28,31], grass[18,20,27], tea[18], vegetable[18], sour[18], beef-like[18,27], wax[20], stale[23], orange[23,30], soap[24], plastic[28], toast[30]	0.021	0.008	0.525
unidentified aldehyde	32.09		0.018	0.183	0.242
unidentified aldehyde	36.07		0.137	0.076	0.061
unidentified aldehyde	37.20		0.411	0.534	0.015
unidentified aldehyde	39.40		<0.0001	0.740	0.003
Alcohols					
2,3-butanediol	23.86		0.019	0.650	0.994
1-pentanol	11.23	mild[20], fusel oil[20], fruit[20], balsamic[20,26], alcoholic[26], sharp[26]	0.003	0.022	0.431
1-octen-3-ol	18.74	mushroom[1,3,9,14,17,19,20,22,24,25,26,27,29,31], liver-like[20], earth[22,31], dust[22], moss[24], nut[24], fungus[28]	0.268	0.014	0.265
1-octanol	23.05	penetrating[20], fat[20,26], wax[20], citrus[20], oil[20], walnut[20], moss[20], chemical[20], metal[20], burnt[20], lemon[26], toasted[26]	0.002	0.159	0.056
Ketones					
2,3-butanedione (diacetyl)	4.37	sweet[5], butter[5,13,14,16,17,19,22,26,28,30], caramel[14,21,22,26,31], rotten[21], vanilla[22,31], cream[26], lactic[28], fruit[30], diacetyl[16]	0.322	0.133	0.669
3-hydroxy-2-butanone (acetoin)	13.06	butter[12,19,26], yoghurt[19], fat[26], sweaty[26], sour[26]	0.761	0.043	0.946
3-methyl-2-butanone	4.50		0.538	0.025	0.500
2-heptanone	9.41	citrus[16], grapefruit[16], limonene[16], floral[16], cheese[16], barbecue[30], vegetable[30], herb[30]	0.000	0.000	0.010
2,3-octanedione	14.08	warmed over[24], oxidised fat[24]	0.014	0.496	0.785
Benzene compounds					
Benzaldehyde	22.64	bitter almond[13,17,20,22,25,31], burnt sugar[13], popcorn[18,27], caramel[18,27], herbaceous[18,27], sulphur[18], chemical[18], spicy[18], liver-like[20], penetrating[22,31], roasted pepper[26], nut[26], metallic[27]	0.212	0.005	0.033
Acetophenone	27.42		0.557	0.312	0.108
Furans					
2-pentylfuran	10.82	fat[2], green[2,22,24,26,27,31], green bean[20,24], butter[20], fruit[22,26,31], earth[24,27], metallic[24,27], sweet[26], pungent[26]	0.046	0.099	0.037

Table 5.5 continued

Volatile compounds*	RT	Aroma description	FxG	Farm	Gender
Carboxylic acids					
acetic acid (ethanoic acid)	19.36	sour[6,13,23], vinegar[19,23]	0.426	0.001	0.093
hexanoic acid (caproic acid)	32.90	fat[17,31], cheese[17,31], sweaty[17,31], goat-like[20,26], sour[23], pungent[26], rancid[27]	0.520	0.253	0.515
heptanoic acid (enanthic acid)	33.13	animal[28], pungent[28], rancid[28]	0.001	0.987	0.866
Esters					
2-propenoic acid, butyl ester (butyl acrylate)	8.98		0.070	<0.0001	0.070
propanoic acid, butyl ester	7.89		0.080	<0.0001	0.084
Sulphur-containing compounds					
dimethyl sulphone	34.77	sulphur[13], burnt[13]	0.171	0.138	0.027
Sulphur- and nitrogen-containing compounds					
2-acetyl-2-thiazoline	30.78	roasted meat[4,13], green onion[15], herbal[15], grass[15], sweet[30], potato[30], anise[30]	0.399	0.392	0.011

*Volatile compounds are grouped together into respective chemical classes; RT, retention time (min); [1]Badings, 1970; [2]Farmer *et al.*, 1989; [3]Barbieri *et al.*, 1992; [4]Cerny & Grosch, 1992; [5]Specht & Baltes, 1994; [6]Kerler & Grosch, 1996; [7]Flores *et al.*, 1997; [8]Elmore *et al.*, 1999; [9]Meynier *et al.*, 1999; [10]Van Ruth & Roozen, 2000; [11]Machiels *et al.*, 2003; [12]Raes *et al.*, 2003; [13]Acree & Arn, 2004; [14]Prost *et al.*, 2004; [15]Burdock, 2005; [16]Rochat & Chaintreau, 2005; [17]Sánchez-Peña *et al.*, 2005; [18]Moon *et al.*, 2006; [19]Berdagué *et al.*, 2007; [20]Calkins & Hodgen, 2007; [21]Ganeko *et al.*, 2008; [22]García-González *et al.*, 2008; [23]Song & Cadwallader, 2008; [24]Stetzer *et al.*, 2008; [25]Belitz *et al.*, 2009; [26]Madruga *et al.*, 2010; [27]Song *et al.*, 2010; [28]Théron *et al.*, 2010; [29]Ma *et al.*, 2012; [30]Resconi *et al.*, 2012; [31]García-González *et al.*, 2014.

Table 5.6 Influence of the interaction between the main effects (farm and gender) on the percentages of volatile compounds in blesbok meat (Means ± SE)

Volatile compounds	Farm A		Farm B	
	Female	Male	Female	Male
Aldehydes				
hexanal*	$6.83^{a} \pm 0.619$	$4.55^{b} \pm 0.780$	$2.68^{b} \pm 0.633$	$6.73^{a} \pm 0.466$
heptanal*	$0.32^{a} \pm 0.069$	$0.17^{ab} \pm 0.086$	$0.06^{b} \pm 0.060$	$0.39^{a} \pm 0.096$
nonanal**	$1.84^{a} \pm 0.105$	$1.33^{a} \pm 0.225$	$0.57^{b} \pm 0.282$	$1.28^{ab} \pm 0.274$
Alcohols				
2,3-butanediol**	$0.17^{ab} \pm 0.060$	$0.00^{b} \pm 0.000$	$0.04^{ab} \pm 0.040$	$0.19^{a} \pm 0.107$
1-pentanol*	$0.36^{a} \pm 0.033$	$0.27^{a} \pm 0.027$	$0.17^{b} \pm 0.026$	$0.32^{a} \pm 0.052$
1-octanol*	$0.20^{a} \pm 0.032$	$0.00^{b} \pm 0.000$	$0.03^{b} \pm 0.026$	$0.07^{b} \pm 0.058$
Ketones				
2-heptanone*	$0.08^{b} \pm 0.020$	$0.12^{b} \pm 0.040$	$0.28^{a} \pm 0.006$	$0.13^{b} \pm 0.017$
2,3-octanedione**	$0.68^{ab} \pm 0.120$	$0.47^{ab} \pm 0.087$	$0.41^{b} \pm 0.060$	$0.70^{a} \pm 0.077$
Furans				
2-pentylfuran**	$0.76^{a} \pm 0.078$	$0.79^{a} \pm 0.081$	$0.45^{b} \pm 0.103$	$0.89^{a} \pm 0.119$
Carboxylic acids				
heptanoic acid (enanthic acid)*	$0.30^{a} \pm 0.045$	$0.07^{b} \pm 0.048$	$0.08^{b} \pm 0.053$	$0.31^{a} \pm 0.073$
Esters				
2-propenoic acid, butyl ester (butyl acrylate)***	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.29^{a} \pm 0.013$	$0.24^{b} \pm 0.025$
propanoic acid, butyl ester (butyl propanoate)***	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.16^{a} \pm 0.019$	$0.08^{b} \pm 0.047$

[a-c]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between farms and/or genders; SE, standard error.

Table 5.7 Influence of farm (diet) on the percentages of volatile compounds in blesbok meat (Means ± SE)

Volatile compounds	Farm A	Farm B
Alcohols		
1-octen-3-ol**	$1.64^{a} \pm 0.165$	$1.10^{b} \pm 0.124$
Ketones		
3-hydroxy-2-butanone (acetoin)**	$14.56^{b} \pm 0.971$	$17.56^{a} \pm 0.897$
3-methyl-2-butanone**	$0.00^{b} \pm 0.000$	$0.27^{a} \pm 0.098$
Benzene compounds		
benzaldehyde*	$1.64^{b} \pm 0.118$	$2.20^{a} \pm 0.161$
Carboxylic acids		
acetic acid (ethanoic acid)*	$0.33^{b} \pm 0.074$	$0.82^{a} \pm 0.094$

[a-b]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$) between farms; SE, standard error.

Table 5.8 Influence of gender on the percentages of volatile compounds in blesbok meat (Means ± SE)

Volatile compounds	Female	Male
Benzene compounds		
benzaldehyde**	$2.12^{a} \pm 0.143$	$1.63^{b} \pm 0.149$
Sulphur-containing compounds		
dimethyl sulphone**	$0.54^{b} \pm 0.069$	$0.80^{a} \pm 0.086$
Sulphur- and nitrogen-containing compounds		
2-acetyl-2-thiazoline**	$0.32^{a} \pm 0.055$	$0.10^{b} \pm 0.047$

[a-b]Means within a variable with superscripts that do not have a common letter indicate significant differences **($p<0.05$) between genders; SE, standard error.

Solid-phase microextraction (SPME) is generally used for the efficient extraction of low molecular weight compounds with high volatility (Watkins *et al.*, 2012), yet this technique is not used for the absolute quantification of volatile compounds (Lorenzo & Domínguez, 2014). The volatile compound data for blesbok meat are therefore reported as semi-quantitative, as the percentage area of the peak for the total ion count (TIC) was used.

The significance of the contribution of volatile compounds to the aroma and flavour of cooked meat is linked to their concentrations, as well as their odour threshold values (Moon *et al.*, 2006; Lu *et al.*, 2008). Aldehydes are generally the most abundant volatile compounds in cooked meat and therefore, together with their low odour threshold values, important contributors to meat aroma and/or flavour (Mottram, 1998a;

Elmore *et al.*, 1999; Resconi *et al.*, 2012; Van Ba *et al.*, 2013). Likewise, the unsaturated alcohols (such as 1-octen-3-ol) (Calkins & Hodgen, 2007; Song *et al.*, 2011, 2014), ketones (Mottram, 1998a; Van Ba *et al.*, 2013), 2-pentylfuran (Elmore *et al.*, 1999; Song *et al.*, 2010) and sulphur-containing compounds (Resconi *et al.*, 2012) have low odour threshold values and can contribute significantly to the aroma and/or flavour of cooked meat. Compounds containing a benzene ring (such as benzaldehyde and acetophenone) are aromatic in nature (Raes *et al.*, 2003). Limited information could be sourced on the odour threshold values of carboxylic acids and esters, though Um *et al.* (1992) noted that hexanoic acid has a relatively low odour threshold value.

It can be postulated from the above-mentioned odour threshold values, that the aldehydes, 1-octen-3-ol, ketones, benzene compounds, 2-pentylfuran, carboxylic acids, dimethyl sulphone and 2-acetyl-2-thiazoline can contribute to the aroma and/or flavour of blesbok meat. For farm A, the percentages of the aldehydes, selected ketones, 2-pentylfuran and heptanoic acid was significantly higher in the meat derived from female blesbok, as compared to males, while for farm B, the percentages of these compounds were significantly higher in the meat derived from male blesbok (Table 5.6). The influence of gender on the volatile compound profile of blesbok meat was therefore different between farm locations, which will result in differences in the aroma and/or flavour of, for example, blesbok meat derived from female animals from different farms. Furthermore, the benzaldehyde and 2-acetyl-2-thiazoline percentages were higher ($p<0.05$) in blesbok meat derived from female animals, which could contribute a variety of aroma and/or flavour attributes to blesbok meat (Table 5.5). The dimethyl sulphone percentage was highest ($p<0.05$) in the meat derived from male blesbok, which could possibly contribute unpleasant sulphur and burnt aroma and/or flavour attributes to blesbok meat (Table 5.5).

The percentage of 1-octen-3-ol, a compound known to contribute to a mushroom aroma in meat (Calkins & Hodgen, 2007), was higher ($p<0.05$) in blesbok meat derived from farm A (Table 5.7). Blesbok meat derived from farm B contained significantly higher percentages of 3-hydroxy-2-butanone (acetoin), 3-methyl-2-butanone, benzaldehyde and acetic acid, these compounds could contribute positively to the aroma and/or flavour attributes of blesbok meat from this farm (Table 5.5).

The PUFA:SFA and n6:n3 PUFA ratios should be taken into account with regard to the nutritional properties of blesbok meat. These ratios should be above 0.7 and below 4.0, respectively (Wood *et al.*, 1999; Raes *et al.*, 2004). The PUFA:SFA ratio differed ($p<0.01$) between genders (Table 5.4), while the n6:n3 PUFA ratio differed ($p<0.01$) between farms (Table 5.3). Regardless of the significant impact of the two main effects, the former and the latter ratios were above and below the recommended 0.7 and 4.0, respectively in blesbok meat.

5.5 Conclusions

The volatile compounds of blesbok meat were dominated by lipid-derived compounds as the meat was high in PUFA content. The extraction temperature resembled a moderate cooking method and temperature. Farm location and gender had a significant influence on the fatty acid content and volatile compound profile of blesbok meat. No clear link was present between the percentages of the lipid-derived compounds and the oleic

and linoleic acid content of blesbok meat, while the α-linolenic acid content was partly linked to the benzaldehyde percentage.

The aroma and/or flavour of blesbok meat could be different between farms and genders, however, descriptive sensory analysis is required to establish to what extent the differences in the volatile compound profile would impact the sensory quality of blesbok meat from the different farms and genders. The latter will establish whether the red meat industry should take the harvesting location and gender into account for the commercial production of blesbok meat.

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Chapter 6

Influence of farm location and gender on the sensory quality of blesbok (*Damaliscus pygargus phillipsi*) meat

Abstract

The aim of this study was to quantify the influence of farm location (dietary regime) and gender on the sensory, physical and chemical quality of blesbok *longissimus thoracis et lumborum* muscle. Blesbok were harvested from two farms situated in different regions of South Africa. The sensory quality of blesbok meat was determined by using descriptive sensory analysis (DSA), physical measurements (thaw and cooking loss percentages, ultimate pH and Warner-Bratzler shear force values) and the proximate composition (moisture, protein, intramuscular lipid and ash content). A gamey aroma dominated the overall aroma intensity ($r = 0.730$; $p<0.05$) of blesbok meat and was positively correlated to liver-like ($r = 0.739$; $p<0.05$) and metallic ($r = 0.792$; $p<0.05$) aroma. The influence of farm location on the sensory quality of blesbok meat was minor, however, gender had a more pronounced influence on selected physical measurements, the protein and intramuscular lipid content and selected sensory attributes, of which the texture attributes will most likely affect consumer perception of blesbok meat. The lack of major farm differences could be linked to the specialised grazing habits of blesbok; therefore farm location need not be considered when harvesting blesbok for game meat production purposes.

Keywords: Game meat; Descriptive sensory analysis; Meat aroma; Meat flavour; Meat tenderness

6.1 Introduction

Meat flavour is a vital driver of the overall acceptability of muscles foods, especially for game meat with its prominent, but varying flavour. Diet plays an important role in influencing the inherent flavour of meat from ruminants (Calkins & Hodgen, 2007). Moreover, diets high in polyunsaturated fatty acids (PUFA) can contribute to the development of off-flavours in cooked meat (Elmore *et al.*, 2002), as PUFA are highly susceptible to oxidation (Wood *et al.*, 1999, 2003). The meat derived from South African game species is generally low in fat and high in PUFA content (Hoffman & Wiklund, 2006; Chapter 2). Consequently, game meat is more susceptible to oxidation and thus the development of off-flavours.

Sensory attributes often associated with game meat/venison include: overall aroma intensity; gamey aroma/flavour; liver-like aroma/flavour; metallic aroma/flavour; beef-like aroma/flavour; sour aroma/taste; sweet-associated aroma; off/manure aroma/flavour; fatty aroma/flavour; sweet and bitter taste; juiciness; tenderness; residue; mealiness; coarseness; and hardness (Rødbotten *et al.*, 2004; Hoffman *et al.*, 2007b; Daszkiewicz *et al.*, 2009; Hoffman *et al.*, 2009, 2010; Daszkiewicz *et al.*, 2012; North & Hoffman, 2015). Unfortunately not all of the latter attributes contribute positively to consumer perception of meat, as liver-like, metallic, fishy, sour, oxidised, fatty and rancid attributes are often perceived as off-flavours (Nuernberg *et al.*, 2005; Meisinger *et al.*, 2006; Calkins & Hodgen, 2007).

The evaluation of the sensory quality of the meat derived from South African game species is limited, especially for blesbok. Blesbok is a popular South African game species that feeds selectively on short grass species (Du Plessis, 1972; Bothma, 2002). A previous study investigating the sensory quality of blesbok meat, used a limited number of sensory attributes (aroma, game flavour, initial and sustained juiciness, first bite and residue) (Hoffman *et al.*, 2010). Additionally, the sensory quality of blesbok meat can differ between regions/farms, as South Africa has a range of biomes (Mucina & Rutherford, 2006) which may result in differences in the grass species consumed by blesbok. Furthermore, seasonal differences in the plane of nutrition of blesbok has resulted in significant variations in the protein and intramuscular lipid (IML) content of blesbok meat (Neethling *et al.*, 2014). The influence of gender on the chemical composition of blesbok meat has been found to be minor (Neethling *et al.*, 2014).

No research has been conducted to investigate the influence of gender and farm location (dietary regime) on the full sensory quality of blesbok meat. The aim of the present study was therefore to investigate the influence of farm location (dietary regime) and gender on the physical measurements, proximate composition and sensory profile of blesbok meat derived from two farms located in regions with different naturally occurring vegetation types.

6.2 Materials and methods

6.2.1 Experimental layout and harvesting

The experimental layout and harvesting information is as described in Chapter 5.

6.2.2 Sampling

The sampling information is as described in Chapter 4.

6.2.3 Physical measurements

6.2.3.1 Ultimate pH (pHu)

The pHu measurement was measured as described in Chapter 4.

6.2.3.2 Thaw and cooking loss percentages

The thaw and cooking loss percentages were measured and calculated as described in Chapter 4.

6.2.3.3 Warner-Bratzler shear force (WBSF)

The Warner-Bratzler shear force (WBSF) measurement was conducted as described in Chapter 4.

6.2.4 Proximate composition

The proximate composition was determined as described in Chapter 4.

6.2.5 Sample preparation for descriptive sensory analysis

The sample preparation was processed as described in Chapter 4.

6.2.6 Descriptive sensory analysis (DSA)

The descriptive sensory analysis information is as described in Chapter 4, with the exception of two treatments (farms). Reference standards (Table 6.1) were selected to clarify aroma, flavour and texture attributes relevant to blesbok meat. The definitions and scales used for the sensory attributes are listed in Table 6.2. The panel used the test re-test method for DSA with 12 replications per treatment.

6.2.7 Statistical analysis

The experimental design was a completely randomised factorial design with six blesbok harvested at random from each of the two farms and two genders. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed, using General Linear Models (GLM) Procedure of SAS software (Version 9.2; SAS Institute Inc, Cary, USA). The model for the statistical design is indicated by the following equation:

Model: $y_{ijk} = \mu + f_i + g_j + fg_{ij} + \varepsilon_{ijk}$

where terms within the model are defined as: the response obtained for the k^{th} observation from the i^{th} farm and the j^{th} gender (y_{ijk}), the overall mean (μ); the farm main effect (f_i); the gender main effect (g_j); the farm by gender interaction effect (fg_{ij}); and the random error (ε_{ijk}) associated with response on the k^{th} observation in the i^{th} farm and the j^{th} gender.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In cases where there was significant deviation from normality, the outliers were removed when the standardised residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to compare means (Ott, 1998). A probability level of 5% was considered significant for all significance tests, while 10% was considered significant where biologically relevant. Where applicable, correlation coefficients were calculated for the physical, proximate and sensory data by means of the Pearson's correlation coefficient (r) (Snedecor & Cochran, 1980).

6.3 Results

Table 6.3 depicts the level of statistical significance (p-values) for the influence of the main effects of farm (F) and gender (G) and their interaction (FxG) on the physical measurements (thaw and cooking loss percentages, pHu and WBSF values), proximate composition (moisture, protein, IML and ash content) and sensory attributes (Table 6.2) of blesbok meat. The average, minimum and maximum values for above-mentioned attributes are also included in Table 6.3.

Table 6.1 Reference standards used during training for descriptive sensory analysis of blesbok meat

Reference standard	Description	Internal temperature	Scale
Fallow deer[a]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Nyala[b]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Ostrich[c]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Beef[d]	Aroma and flavour associated with cooked beef loin	72°C	0 = low intensity; 100 = high intensity
Beef ox liver	Aroma, flavour and texture associated with cooked beef liver	Pan-fried over high heat	0 = low intensity; 100 = high intensity
Mutton[e]	Aroma and flavour associated with cooked mutton loin	72°C	0 = low intensity; 100 = high intensity
Lamb[f]	Fatty aroma associated with cooked lamb loin subcutaneous fat	Melted at 160°C	0 = low intensity; 100 = high intensity
Beef[g]	Fatty aroma associated with cooked beef loin subcutaneous fat	Melted at 160°C	0 = low intensity; 100 = high intensity
Sour solution[h]	Sour taste	-	0 = low intensity; 100 = high intensity
Sweet solution[i]	Sweet taste	-	0 = low intensity; 100 = high intensity
Salty solution[j]	Salty taste	-	0 = low intensity; 100 = high intensity
Bitter solution[k]	Bitter taste	-	0 = low intensity; 100 = high intensity
Blesbok[l]	Texture associated with very tender game meat	76°C	0 = extremely tough; 100 = extremely tender
Giraffe[m]	Texture associated with very tough game meat	76°C	0 = extremely tough; 100 = extremely tender
Beef[d]	Texture associated with over-matured meat (mealiness)	72°C	0 = none; 100 = prominent

[a]fallow deer (*Dama dama*) *longissimus lumborum* muscle; [b]nyala (*Tragelaphus angasii*) *longissimus lumborum* muscle; [c]ostrich (*Struthio camelus*) moon steak; [d]beef *longissimus lumborum* muscle aged for 28 days (fat removed); [e]mutton (feedlot Merino AB2) *longissimus lumborum* muscle; [f]subcutaneous fat removed from lamb *longissimus lumborum* muscle; [g]subcutaneous fat removed from beef *longissimus lumborum* muscle; [h]0.07% citric acid solution; [i]2.0% sucrose solution; [j]0.2% sodium chloride solution; [k]0.07% caffeine solution; [l]blesbok *psoas major* muscle; [m]giraffe (*Giraffa camelopardalis*) rump steak.

Table 6.2 Definition and scale of descriptive sensory analysis attributes (aroma, flavour, taste and texture)

Sensory attribute	Description	Scale
Overall aroma	Intensity of the overall aroma in the first few sniffs	0 = low intensity; 100 = high intensity
Gamey aroma	Aroma associated with meat from wild animal species – sometimes a combination of liver-like and metallic aromas	0 = low intensity; 100 = high intensity
Beef-like aroma	Aroma associated with cooked beef loin*	0 = low intensity; 100 = high intensity
Metallic aroma	Aroma associated with raw meat/blood-like	0 = low intensity; 100 = high intensity
Liver-like aroma	Aroma associated with pan-fried beef ox liver	0 = low intensity; 100 = high intensity
Sweet-associated aroma	Aroma associated with the browning of a cooked meat surface (Maillard reaction)	0 = low intensity; 100 = high intensity
Herbaceous aroma	Aroma associated with the vegetation of the farms	0 = low intensity; 100 = high intensity
Lamb-like aroma	Aroma associated with cooked lamb loin*	0 = low intensity; 100 = high intensity
Lamb-like fatty aroma	Aroma associated with melted fat of the lamb loin*	0 = low intensity; 100 = high intensity
Gamey flavour	Flavour associated with meat from wild animal species – sometimes a combination of liver-like and metallic flavours	0 = low intensity; 100 = high intensity
Beef flavour	Flavour associated with cooked beef loin*	0 = low intensity; 100 = high intensity
Metallic flavour	Associated with raw meat or a blood-like taste	0 = low intensity; 100 = high intensity
Liver-like flavour	Flavour associated with pan-fried beef ox liver	0 = low intensity; 100 = high intensity
Lamb flavour	Flavour associated with cooked lamb loin*	0 = low intensity; 100 = high intensity
Herbaceous flavour	Flavour associated with the vegetation of the farms	0 = low intensity; 100 = high intensity
Sour taste	Taste associated with a citric acid solution	0 = low intensity; 100 = high intensity
Sweet taste	Taste associated with a sucrose solution	0 = low intensity; 100 = high intensity

Table 6.2 continued

Sensory attribute	Description	Scale
Salty taste	Taste associated with sodium ions	0 = low intensity; 100 = high intensity
Initial juiciness	Amount of fluid extruded on surface of meat when pressed between thumb and forefinger (perpendicular to fibres)	0 = extremely dry; 100 = extremely juicy
Sustained juiciness	Amount of moisture perceived during mastication	0 = extremely dry; 100 = extremely juicy
Tenderness	Impression of tenderness after mastication	0 = extremely tough; 100 = extremely tender
Residue	Residual tissue remaining after mastication (difficult to chew through)	0 = none; 100 = prominent
Mealiness	Disintegration of muscle fibres into very small particles (perception within the first few chews)	0 = none; 100 = prominent
Liver-like texture	Texture similar to that of pan-fried beef ox liver (spongy/pasty)	0 = none; 100 = prominent

**longissimus lumborum* muscle.

Table 6.3 Level of statistical significance (p-values) for the main effects of farm (F) and gender (G), their interaction (FxG), average, minimum and maximum values of the physical measurements, proximate composition (g.100 g^{-1}) and sensory attributes of blesbok meat (Means ± SE)

	FxG	Farm	Gender	Average*	Min	Max
Physical measurements						
Thaw loss %	0.172	0.168	0.013	13.0 ± 0.62	7.5	17.0
Cooking loss %	0.048	0.470	0.455	28.0 ± 2.50	14.6	40.8
pHu	0.440	0.189	0.224	5.6 ± 0.03	5.3	5.9
WBSF (N)	0.060	0.408	0.036	48.0 ± 2.98	25.0	66.7
Proximate composition						
Moisture content	0.511	0.131	0.003	75.1 ± 0.26	74.2	77.3
Protein content	0.001	0.052	0.314	20.7 ± 0.25	19.1	22.5
IML content	0.018	0.594	0.001	2.8 ± 0.13	2.1	3.6
Ash content	0.300	0.779	0.611	1.1 ± 0.01	1.0	1.2
Sensory attributes						
Overall aroma	0.928	0.195	0.825	64.2 ± 0.80	59.1	59.1
Gamey aroma	0.642	0.441	0.623	49.0 ± 1.23	41.1	56.1
Beef-like aroma	0.494	0.056	0.185	23.8 ± 0.53	20.1	29.1
Metallic aroma	0.816	0.300	0.514	19.7 ± 0.94	13.0	26.0
Liver-like aroma	0.274	0.913	0.749	22.0 ± 0.81	16.0	26.0
Sweet-associated aroma	0.289	0.125	0.991	10.5 ± 0.51	6.0	14.0
Herbaceous aroma	0.072	0.807	0.131	1.1 ± 0.38	0.0	4.3
Lamb-like aroma	0.541	0.113	0.982	8.4 ± 0.55	4.1	12.1
Fatty (lamb-like) aroma	nd	nd	nd	nd	nd	nd
Gamey flavour	0.370	0.791	0.695	49.7 ± 0.88	43.0	55.0
Beef flavour	0.110	0.784	0.023	27.6 ± 0.83	23.5	34.1
Metallic flavour	0.678	0.569	0.586	24.3 ± 1.06	14.1	32.0
Liver-like flavour	0.431	0.549	0.793	12.8 ± 1.06	5.1	20.0
Lamb-like flavour	nd	nd	nd	nd	nd	nd
Herbaceous flavour	0.241	0.073	0.890	0.7 ± 0.30	0.0	5.6
Sour taste	0.456	0.696	0.874	12.3 ± 0.80	8.0	18.1
Sweet taste	0.154	0.357	0.184	1.5 ± 0.25	0.0	4.0
Salty taste	0.042	0.313	0.302	1.5 ± 0.33	0.0	4.4
Initial juiciness	0.657	0.148	0.923	67.6 ± 1.39	59.1	77.1
Sustained juiciness	0.647	0.183	0.764	62.2 ± 1.35	55.0	69.1
Tenderness	0.054	0.505	0.233	66.2 ± 2.80	47.8	83.5
Residue	0.081	0.937	0.071	6.8 ± 1.73	0.0	21.2
Mealiness	0.230	0.550	0.196	0.9 ± 0.39	0.0	5.1
Liver-like texture	0.373	0.056	0.980	0.7 ± 0.24	0.0	2.2

*average values were calculated irrespective of significant effects of farm (F) and/or gender (G) or interactions (FxG); FxG, farm and gender interaction; nd, not detected in blesbok meat; SE, standard error; Min, minimum; Max, maximum; pHu, ultimate pH; WBSF, Warner-Bratzler shear force; IML, intramuscular lipid.

A significant interaction existed between the main effects (farm and gender) for the WBSF value, protein and IML content, as well as the herbaceous aroma, salty taste, tenderness and residue of blesbok meat (Table 6.4). The WBSF values of the meat derived from female and male blesbok did not differ significantly between farms, however, the WBSF values were higher ($p<0.10$) for the meat derived from female blesbok as compared to males (not significant for farm B) (Table 6.4). The protein and IML content of blesbok meat differed significantly between farms for the meat derived from female animals, but not for male animals (Table 6.4). Blesbok meat derived from female animals from farm B had a higher ($p<0.01$) protein content compared to females from farm A, while the opposite was found for the IML content of the meat derived from female blesbok (Table 6.4). The protein and IML content differed significantly ($p<0.01$ and $p<0.05$, respectively) between genders for blesbok meat derived from farm B and A, respectively, being higher for the meat from female animals within farm (Table 6.4).

The salty taste of blesbok meat differed ($p<0.05$) between farms for the meat derived from male animals, being higher for farm B (Table 6.4). The herbaceous aroma, tenderness and residue of the meat derived from female and male blesbok did not differ significantly between farms (Table 6.4). The herbaceous aroma and residue of blesbok meat was higher ($p<0.10$) for the meat derived from female animals from farm A, as compared to males from farm A (Table 6.4). The salty taste of blesbok meat was higher ($p<0.05$) for the meat derived from male animals from farm B, as compared to females from farm B (Table 6.4). The sensorial tenderness of blesbok meat was higher ($p<0.10$) for meat derived from male animals from farm A, as compared to females from farm A (Table 6.4).

Table 6.4 Influence of the interaction between the main effects of farm (F) and gender (G) on the Warner-Bratzler shear force value, protein and intramuscular lipid content (g.100 g^{-1}) and selected sensory attributes of blesbok meat (Means ± SE)

	Farm A		**Farm B**	
	Female	**Male**	**Female**	**Male**
Physical measurements				
WBSF (N)***	$54.5^{a} \pm 4.26$	$38.3^{b} \pm 4.68$	$50.1^{a} \pm 2.21$	$49.1^{ab} \pm 3.71$
Proximate composition				
Protein content*	$20.0^{b} \pm 0.35$	$20.8^{b} \pm 0.32$	$21.6^{a} \pm 0.18$	$20.3^{b} \pm 0.19$
IML content**	$3.3^{a} \pm 0.15$	$2.4^{c} \pm 0.12$	$2.8^{b} \pm 0.16$	$2.7^{bc} \pm 0.11$
Sensory attributes				
Herbaceous aroma***	$1.9^{a} \pm 0.48$	$0.2^{b} \pm 0.17$	$1.1^{ab} \pm 0.56$	$1.2^{ab} \pm 0.65$
Salty taste**	$1.5^{ab} \pm 0.43$	$1.0^{b} \pm 0.37$	$1.0^{b} \pm 0.26$	$2.4^{a} \pm 0.60$
Tenderness***	$61.4^{b} \pm 4.08$	$73.5^{a} \pm 3.13$	$66.4^{ab} \pm 4.03$	$63.4^{ab} \pm 3.36$
Residue***	$11.0^{a} \pm 3.30$	$2.5^{b} \pm 1.26$	$7.0^{ab} \pm 2.41$	$6.9^{ab} \pm 1.45$

[a-c]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between farms and/or genders; SE, standard error; WBSF, Warner-Bratzler shear force; IML, intramuscular lipid.

Table 6.5 depicts the influence of gender on the thaw loss percentage, moisture content and beef flavour of blesbok meat. The thaw loss percentage and beef flavour of blesbok meat was higher ($p<0.05$) for the meat derived from female animals as compared to males, while the moisture content was higher ($p<0.01$) for the meat derived from male animals (Table 6.5).

Table 6.5 Influence of gender on the thaw loss percentage, moisture content (g.100 g^{-1}) and selected sensory attributes of blesbok meat (Means ± SE)

	Female	**Male**
Physical measurements		
Thaw loss %**	14.0^{a} ± 0.54	11.9^{b} ± 0.59
Proximate composition		
Moisture content*	75.1^{b} ± 0.25	76.1^{a} ± 0.18
Sensory attributes		
Beef flavour**	28.9^{a} ± 0.91	26.3^{b} ± 0.52

$^{a\text{-}b}$Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$) between genders; SE, standard error.

6.4 Discussion

The harvesting procedures used in this study were aimed at minimising the ante-mortem stress experienced by blesbok. Stressful harvesting procedures can influence the glycogen reserves of blesbok muscles and consequently the pHu of the meat. However, female and male blesbok derived from the two farms had average pHu values within the 'normal' range of 5.3 to 5.8 (Table 6.3) (Honikel, 2004). Moreover, the pHu of blesbok meat did not differ as a result of farm location (dietary regime) or gender (Table 6.3). As pHu is known to influence the water-holding capacity (WHC), flavour and tenderness of meat (Honikel, 2004), the farm location and gender differences in the ratings of selected aroma and flavour attributes and tenderness of blesbok meat (Tables 6.3) was therefore not attributed to pHu.

In South Africa, large quantities of game meat becomes available in a short period of time, as a result of the hunting season which is only open during the winter months (May to August) (Hoffman, 2003). Consequently, game meat is often deboned, vacuum-packed and sold or exported as frozen muscles/muscle cuts. Dahlan and Hanoon (2008) reported that the moisture content of imported venison (the meat generally derived from deer species) was lower as a result of freezing and refreezing procedures during air freight. Freezing and thawing of meat modifies the WHC, moisture content, as well as the distribution of moisture in meat (Leygonie *et al.*, 2012). The loss of WHC due to freezing and thawing processes will therefore affect the thaw and cooking loss percentages of meat (Brewer, 2004). To our knowledge, no other studies have reported the thaw loss percentage of blesbok meat, however, Hoffman *et al.* (2010) reported cooking loss percentages between 29.2% and 40.6% for blesbok meat derived from different regions. The cooking loss percentage of blesbok meat in the current study was within the latter range, with an average value of 28.0% (Table 6.3). The thaw and cooking loss percentages can often be linked to the initial and sustained juiciness

of meat, however, no significant correlations were present between any of these attributes for blesbok meat in this study. Hoffman *et al.* (2010) also found no significant correlation between the cooking loss percentage and sustained juiciness of blesbok meat.

Meat derived from female blesbok had lower ($p<0.01$) moisture content as compared to males (Table 6.5), while gender differences in the protein content was only evident for blesbok meat derived from farm B, i.e. being higher ($p<0.01$) for the meat from female animals (Table 6.4). A strong negative correlation generally exists between the moisture and IML content of red meat (Keeton & Eddy, 2004; Legako *et al.*, 2015), however, Neethling *et al.* (2014) established a strong negative correlation between the moisture and protein content of blesbok meat ($r = -0.820$; $p\leq0.05$). A moderate negative correlation existed between the moisture and protein content of blesbok meat in this study ($r = -0.615$; $p<0.05$). The presence of a negative correlation between the moisture and protein content, as opposed to the moisture and IML content, is attributable to the low IML content of blesbok meat (Table 6.4).

The harvesting period was characterised as the dry season for farm A and the wet season for farm B. The higher ($p<0.05$) IML content of female blesbok from farm A can be attributed to the storage of energy as lipids after the wet season (higher plane of nutrition prior to harvesting), while female blesbok from farm B were most probably still recovering and building their IML depots after the dry, warm summer (Table 6.4). However, the IML content of blesbok meat did not differ significantly between farm locations for male animals (Table 6.4). The latter can be attributed to the mating season (generally March to May), which is regarded as an energetically draining period for male animals resulting in weight loss, which will start with the mobilisation of fat reserves from muscles (IML) (Hoffman, 2000; Mysterud *et al.*, 2004; Renecker *et al.*, 2005). In addition, significant gender differences were present in the IML content of blesbok meat derived from farm A, but not for farm B. The latter could also be attributable to the differences in the plane of nutrition at the two farm location.

Low IML content negatively influences the palatability (flavour, juiciness and tenderness) of red meat (Miller, 2004). As blesbok meat contains low levels of IML, a 'dryness' due to a lack of a fatty mouthfeel generally supplied by the IML, can be wrongly perceived as tougher meat. This phenomenon is referred to as the so-called 'halo' effect (Warriss, 2000; Dhanda *et al.*, 2003; Miller, 2004). A moderate negative correlation existed between the sensory tenderness and WBSF value ($r = -0.536$; $p<0.05$) of blesbok meat, which would seems to indicate that WBSF values might not always be a good predictor of the sensory tenderness of blesbok meat. Moreover, Destefanis *et al.* (2008) classified WBSF values >52.68 N and <42.87 N as being tough and tender, respectively. The meat derived from female and male blesbok from farm B had WBSF values between these values (Table 6.4) and can therefore be classified as moderate in tenderness, while the meat derived from female and male blesbok from farm A could be classified as tough (54.5 N) and tender (38.3 N), respectively (Table 6.4). The significant gender difference in the WBSF values and sensory tenderness of the meat derived from female and male blesbok from farm A (Table 6.4), could be attributed to differences in age. Hunting was a regular practice on farm A, while no hunting (recreational or trophy) occurred on farm B. Although only mature animals were selected for this study, it could be possible that the female blesbok selected on farm A

were older while the male blesbok from farm A were younger (non-trophy animals). An increase in animal age has a negative effect on the quality of collagen (more thermally stable cross-linkages) and therefore results in tougher meat (Hoffman, 2001; Webb & O'Neill, 2008). Furthermore, a very strong negative correlation existed between the sensory tenderness and residue ($r = -0.933$; $p<0.05$) of blesbok meat, which means that less tender blesbok meat will have higher ratings for residue, as was the case with the meat derived from female blesbok from farm A (Table 6.4). It is, however, debatable whether the residue ratings in this study can be classified as being 'high', as a very high residue rating would be closer to 100 (Table 6.2).

A more extensive list of aroma, flavour and taste attributes was used for descriptive sensory analysis of blesbok meat (Table 6.2), as compared to the two attributes (aroma and game flavour) used in a previous sensory study on blesbok meat (Hoffman *et al.*, 2010). In this study, meat aroma refers to the orthonasal aroma (experienced through the external nares in the nasal cavity), while meat flavour refers to retronasal aroma (experienced on consumption of meat) (Roberts & Acree, 1995). The overall aroma intensity of blesbok meat was positively correlated to gamey aroma ($r = 0.730$; $p<0.05$). Gamey aroma was characterised as a combination of liver-like and metallic aroma, and both of these aroma attributes were strongly correlated to gamey aroma of blesbok meat ($r = 0.739$; $p<0.05$ and $r = 0.792$; $p<0.05$, respectively). However, liver-like and metallic sensory attributes are not always perceived as positive attributes of meat (Yancey *et al.*, 2006; Stetzer *et al.*, 2008).

Herbaceous aroma differed ($p<0.10$) between genders for the meat derived from farm A, but not for blesbok derived from farm B (Table 6.4). The gender differences in the herbaceous aroma of blesbok meat derived from farm A could be attributed to the differences in the grazing areas. As male blesbok are territorial, these animals will only graze close to their territories, whereas female blesbok will graze a larger area(s). The female blesbok from farm A could therefore have grazed an area(s) with grass species that contained a higher quantity of volatile aroma compounds, responsible for the herbaceous aroma.

A salty taste is a positive characteristic of meat. Potassium and sodium have been found to possess 'taste activity values' greater than 1, contributing to the salty taste (Chen & Zhang, 2007). Verma and Banerjee (2012) reported that sodium and lithium are the only two cations with a primarily salty taste, while potassium and calcium have some salty characteristics, although these minerals have characteristic flavours such as 'metallic' or 'bitter'. The differences in the salty taste between farm locations for the meat derived from male blesbok, as well as between genders for the meat derived from farm B, could therefore be attributed to differences in the content of the above-mentioned minerals. Unfortunately, the mineral content of blesbok meat was not investigated in this study.

Numerous volatile aroma compounds have been related to a beef-like characteristic of meat, however, only selected compounds are aroma active and actually contribute beef-like sensory characteristics (aroma or flavour) to meat (Moon *et al.*, 2006; Song *et al.*, 2010). Nonanal and 2-pentylfuran have been linked to beef-like sensory attributes of meat (Moon *et al.*, 2006; Song *et al.*, 2010). However, these volatile aroma compounds were not present at significantly higher percentages in the meat derived from female blesbok

(Chapter 5), as was the case with a beef flavour (Table 6.5). It is therefore postulated that another compound or combinations of compounds attributed to a beef flavour of blesbok meat (Moon *et al.*, 2006).

Although the ratings for selected aroma and flavour attributes of blesbok meat (herbaceous aroma, salty taste, beef flavour) differed significantly between farms and/or genders, the impact of these on consumer perception is debatable. The overall lack of significant differences in the ratings for the investigated aroma, flavour and taste attributes could be attributed to the very selective grazing habits of blesbok, which means that the dietary regime of blesbok might not differ as greatly between farm locations as with springbok, for example (Chapter 4). The gender differences in the WBSF values, tenderness and residue of blesbok meat could possibly affect consumer perception (Moloney *et al.*, 2001) and warrants further research.

6.5 Conclusions

The influence of farm location was minor, while gender had a greater influence on the sensory quality of blesbok meat. Gamey aroma was the main aroma attribute contributing to the overall aroma intensity of blesbok meat. Due to the strong positive correlation between the gamey aroma and liver-like and metallic aroma attributes of blesbok meat; these two sensory attributes might negatively influence consumer perception of blesbok meat. However, it is debatable whether the gender differences in the herbaceous aroma, salty taste and beef flavour will influence consumer perception of blesbok meat. Nonetheless, it is postulated that gender differences in the WBSF values, tenderness and residue ratings could influence consumer perception of blesbok meat. Consequently, farm location does not have to be taken into account when harvesting only male or female blesbok for meat production purposes. However, when harvesting both genders, farm location is an important consideration as the magnitude of the gender differences in the sensory quality of blesbok meat could differ between farms.

6.6 References

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Chapter 7

Comparison of the fatty acid content and volatile compound profile of the meat derived from six South African game species

Abstract

South Africa has a rich variety of wild and free-living game species whose meat is utilised in the formal an informal market. Gender is usually not taken into account during the commercial harvesting of game species, as only mature animals are selected. Limited research is available that compares the fatty acid content and volatile compound profile between genders, as well as between game species. The aim of this study was to quantify the influence of species and gender on the fatty acid content ($mg.g^{-1}$ of meat) and volatile compound profile of the meat derived from six regularly hunted South African game species (springbok, *Antidorcas marsupialis*; gemsbok, *Oryx gazella;* blesbok, *Damaliscus pygargus phillipsi*; impala, *Aepyceros melampus*; red hartebeest, *Alcelaphus buselaphus caama*; and kudu, *Tragelaphus strepsiceros*). The content of the essential fatty acids (C18:2n6c, linoleic acid; and C18:3n3, α-linolenic acid), fatty acid totals (saturated, monounsaturated and polyunsaturated fatty acids) and ratios (polyunsaturated to saturated fatty acids and omega-6 to omega-3 polyunsaturated) of game meat differed significantly between species, however, gender differences were species-specific. The volatile compound profile of the meat derived from the six game species was primarily lipid-derived, containing compounds such as aldehydes, alcohols, ketones, furans and esters. An intermediate positive correlation ($r = 0.608$; $p<0.05$) existed between the 3-hydroxy-2-butanone percentage and C18:2n6c (linoleic acid) content. Negative correlations existed between the percentages of selected alcohols (1-penten-3-ol, 1-pentanol, 1-hexanol, 1-heptanol, 1-octen-3-ol, 2-octen-1-ol and 1-octanol) and esters. Species influenced the volatile compound profile of game meat, while gender differences were more prominent within species.

Keywords: Game meat; Volatile compounds; Oleic acid, Linoleic acid; α-Linolenic acid

7.1 Introduction

Flavour is a very important factor contributing to the sensory quality of meat (Wood *et al.*, 1999). Whilst hundreds of volatile compounds have been identified which contribute to the characteristic aroma and flavour of meat the intrinsic flavour of meat can be influenced by the metabolic pathway, dietary regime, lipid content, level of oxidation, as well as the species from which the meat was derived (Shahidi, 1998; Calkins & Hodgen, 2007).

South Africa has a rich variety of wild and free-living game species, which are found distributed throughout the various vegetation types/biomes (Van Der Merwe *et al.*, 2014). The carcass weights of game species, as well as the lipid content of the meat, can vary between regions/farms in accordance with the nutritional resources available, irrespective of whether the animals are grazers, browsers, mixed feeders, selective or generalists (Liversidge & Van Eck, 1994). The meat derived from South African game species generally have a low intramuscular lipid (IML) content, which primarily consists of structural lipids (phospholipids and

cholesterol) with high levels of polyunsaturated fatty acids (PUFA) (Apps *et al.*, 1994; Hoffman & Wiklund, 2006; Chapter 2). These PUFA are extremely reactive and highly susceptible to oxidation (Igene *et al.*, 1980). Furthermore, the differences in the diet of ruminants can influence the aroma and/or flavour of meat, as dietary regime is known to influence the fatty acid content, as well as the volatile compound profile (Melton, 1990; Nuernberg *et al.*, 2005; Calkins & Hodgen, 2007; Chapters 3 and 5).

Some researchers have found significant gender differences in the fatty acid profile (percentage of total fatty acids) of the meat derived from the *longissimus thoracis et lumborum* (LTL) muscle of springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus pygargus phillipsi*) and impala (*Aepyceros melampus*) (Hoffman *et al.*, 2005, 2007; Neethling *et al.*, 2014), while other researchers have found no significant gender differences in the fatty acid profile of the LTL muscle derived from red hartebeest (*Alcelaphus buselaphus caama*) and kudu (*Tragelaphus strepsiceros*) (Smit, 2004; Hoffman *et al.*, 2009). Nonetheless, the main fatty acids identified in the meat derived from the above-mentioned species are C16:0 (palmitic acid), C18:0 (stearic acid), C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) (Hoffman *et al.*, 2005, 2007, 2009, 2010; Neethling *et al.*, 2014). In South Africa, the gender of game species during the commercial harvesting of the animals in the field is often not considered or is crudely selected for (young males may be targeted leaving older mature males to be hunted by the trophy hunting industry) (Apps *et al.*, 1994).

No research has yet been conducted on the volatile compound profile of any African ungulate species (with the exception of that in Chapters 3 and 5) and due to the influence of these compounds on the sensory attributes of meat, research is urgently required in this aspect. However, it is known in traditionally farmed/domesticated species that various factors influence this profile. These factors include species, gender and diet (Wasserman & Spinelli, 1972; Shahidi, 1998; Priolo *et al.*, 2001; Pegg & Shahidi, 2004; Wood *et al.*, 2003; Young *et al.*, 2003; Vasta & Priolo, 2006; Calkins & Hodgen, 2007; Chapters 2, 3 and 5).

The aim of the present study was therefore to investigate the influence of species and gender on the fatty acid content and volatile compound profile of the meat derived from six regularly hunted/harvested South African game species: springbok (*Antidorcas marsupialis*), gemsbok (*Oryx gazella*), blesbok (*Damaliscus pygargus phillipsi*), impala (*Aepyceros melampus*), red hartebeest (*Alcelaphus buselaphus caama*) and kudu (*Tragelaphus strepsiceros*). The dietary requirements of these game species differ from some being selective grazers, to mixed feeders to specialised browsers.

7.2 Materials and methods

7.2.1 Experimental layout and harvesting

Six game species were randomly selected and harvested/hunted from different farms in South Africa. The majority of the farms are situated in the Savanna Biome and contained Kimberley Thornveld, which formed part of the Eastern Kalahari Bushveld Bioregion (Mucina & Rutherford, 2006). This region generally receives seasonal rainfall which primarily (>66%) occurs between October and April and peaks from January to March (Kruger, 2007). Important vegetation in this region includes *Acacia* tree species, as well as primarily C_4 grass species (Mucina & Rutherford, 2006). Twelve mature springbok and gemsbok (Table 7.1) were harvested

from one farm in the Kimberley District, Northern Cape Province of South Africa (28° 49' 12.0" S, 25° 07' 53.4" E). In addition, eleven mature red hartebeest and twelve mature kudu (Table 7.1) were also hunted in the Kimberley District (in close proximity to the farm where the springbok and gemsbok were harvested) in the Northern Cape Province of South Africa. The meat from the red hartebeest and kudu was sourced from a commercial game meat supplier in Kimberley. The meat from all these species were frozen immediately, due to the great distance for transportation to Stellenbosch University, however, the meat derived from red hartebeesrt and kudu was previously frozen and thawed.

Additionally, twelve mature impala (Table 7.1) were harvested on a farm situated near Pongola in KwaZulu-Natal, South Africa (27° 25' 12.1" S, 31° 50' 33.1" E). This farm was also situated in the Savanna biome and contained Zululand Lowveld, which formed part of the Lowveld Bioregion and primarily received rainfall in the summer months (October to March) (Mucina & Rutherford, 2006). Although impala also occur in the Kimberley region, the large amount of animals required for this study (12, six males and six females) could not be sourced from that region. Nonetheless, the vegetation on the farm consisted of dense thickets of *Dichrostachys cinerea* and *Acacia*, as well as tall C_4 grass species, which was similar to the vegetation in the Kimberley region.

Twelve mature blesbok (Table 7.1) were harvested on a farm situated on the coastline of the Western Cape Province near Witsand, South Africa (34° 18' 24.0" S, 20° 49' 3.9" E). This farm was situated in the Fynbos biome and contained Eastern Rûens Shale Renosterveld, which formed part of the East Coast Renosterveld Bioregion (Mucina & Rutherford, 2006). The region in which this farm was situated received rain more or less throughout the year, with the majority (>66%) of the rainfall occurring between April and September, in addition to receiving some rainfall in summer (December to February) and autumn (March to May) (Acocks & Momberg, 1988; Kruger, 2007). As blesbok are strict and very selective grazers and there was an overall lack of significant differences in the sensory profile between farms (Witsand vs. Kimberley) (Chapter 5), it was deemed acceptable to harvest blesbok for this study in near Witsand (as opposed to Kimberley).

Table 7.1 Species, gender and dietary regime of animals harvested

Species	Gender		Dietary regime
	Female	Male	(graze:browse ratio)
Springbok[1,2]	6	6	Mixed feeder (50:50)
Gemsbok[1,2]	6	6	Selective grazer (100:00)
Blesbok[1,2]	6	6	Mixed feeder (75:25)
Impala[1,2]	6	6	Mixed feeder (50:50)
Red Hartebeest[1,2]	5	6	Mixed feeder (75:25)
Kudu[2]	4	8	Pure browser (00:100)

Springbok, *Antidorcas marsupialis*; gemsbok, *Oryx gazella*; blesbok, *Damaliscus pygargus phillipsi*; impala, *Aepyceros melampus*; red hartebeest, *Alcelaphus buselaphus caama*; kudu, *Tragelaphus strepsiceros*; [1]Van Zyl, 1965; [2]Bothma, 2002.

All of the animals were harvested/hunted between April and June of 2014, which is characterised as the winter months in South Africa. This period was characterised as the dry season for the areas in which springbok, gemsbok, impala, red hartebeest and kudu were harvested/hunted, whilst it is in the wet season for the farm

from which blesbok were harvested. Most of the harvesting occurred at night (ethical clearance number: SU-ACUM14-001SOP) in accordance with the *Guidelines for the Harvesting of Game for Meat Export* (Van Schalkwyk & Hoffman, 2010).

7.2.2 Sampling and sample preparation

The sampling and sample preparation is as described in Chapter 3.

7.2.3 Analysis of fatty acids

The homogenised meat samples were thawed for 24 h at 4°C (± 1°C) prior to fatty acid analysis. Two grams of each sample was extracted according to the method by Folch *et al.* (1957) and as described in detail by Neethling *et al.* (2014), with the exception of 100 µl hexane which was added to the dried sample before transferring 1 µl to the vial for injection. Fatty acid methyl esters (FAMES) were analysed on a Thermo Trace 1300 gas chromatograph (GC) flame ionisation detector. Separation was performed on a Thermo TR-FAME (30 m, 0.25 mm internal diameter, 0.25 µm film thickness) capillary column (part number 260M142P). The oven temperature was initially held at 50°C for 1 min, then increased to 175°C at 25°C.min^{-1}. Once the latter temperature was reached, a further temperature increase up to 200°C followed at 1.5°C.min^{-1} and was held for 6 min, followed by a final temperature increase to 240°C at 10°C.min^{-1}, held for 2 min. Hydrogen was used as carrier gas at a flow rate of 0.7 ml.min^{-1}. The injection temperature was maintained at 240°C with a split of 5:1. The FAMES in the total lipids of each sample (mg.g^{-1} of sample) were identified by comparing their retention times with those of a standard FAME mixture (Supelco™ 37 Component FAME Mix, 10 mg.ml^{-1} in CH_2Cl_2, Catalogue Number 47885-U, Supelco™, North Harrison Road, Bellefonte, PA 16823-0048, USA). To enable quantification of the individual fatty acids in the original muscle sample, heptadecanoic acid (C17:0) was used as an internal standard (Neethling *et al*., 2014).

7.2.4 Analysis of volatile compounds using SPME-GC-MS

The analysis of the volatile compound profile is as described in Chapter 3.

7.2.5 Statistical analysis

The experimental design was a completely randomised factorial with ± six animals harvested at random from each of the six species (within specific areas) and two genders. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed, using General Linear Models (GLM) Procedure of SAS software (Version 9.2; SAS Institute Inc, Cary, USA). The model for the statistical design is indicated by the following equation:

Model: $y_{ijk} = \mu + s_i + g_j + sg_{ij} + \varepsilon_{ijk}$

where terms within the model are defined as: the response obtained for the kth observation from the ith species and the jth gender (y_{ijk}), the overall mean (μ), the species main effect (s_i), the gender main effect (g_j),

the species by gender interaction effect (sg_{ij}) and the random error (ε_{ijk}) associated with response on the k^{th} observation in the i^{th} species and the j^{th} gender.

A Shapiro-Wilk test was performed on the standardised residuals from the model to test for deviation from normality (Shapiro & Wilk, 1965). In cases where there was significant deviation from normality outliers were removed when the standardised residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to compare means (Ott, 1998). A probability level of 5% was considered significant for all significance tests, while 10% was considered significant where biologically relevant. Where applicable, correlation coefficients were calculated for the fatty acid and volatile compound data by means of the Pearson's correlation coefficient (r) (Snedecor & Cochran, 1980).

7.3 Results

7.3.1 Fatty acid content

Table 7.2 indicates the level of statistical significance (p-values) for the influence of the main effects, species (S) and gender (G), and their interaction (SxG) on the fatty acid content ($mg.g^{-1}$ of meat) of the meat derived from the six game species. The intermuscular lipid (IML) content ($g.100\ g^{-1}$ of meat; Means ± SE) of the meat derived from the six species was low and differed significantly between species, being highest ($p<0.01$) in the meat derived from springbok (2.99 g ± 0.084), lower for blesbok (2.21 g ± 0.088), impala (1.93 g ± 0.107) and red hartebeest (1.63 g ± 0.055) meat, and lowest for kudu (1.34 g ± 0.028) and gemsbok (1.33 g ± 0.068) meat. The IML content also differed between genders ($p<0.05$), being higher in the meat derived from female animals (1.97 g ± 0.110), as compared to males (1.81 g ± 0.105). As a result of the low IML content of the meat derived from the six game species, the fatty acids present at very low levels (<10 $mg.g^{-1}$ of meat) will not be discussed further. However, the essential fatty acids (C18:2n6c, linoleic acid and C18:3n3, α-linolenic acid) and the total fatty acids (e.g. SFA, MUFA and PUFA) will be discussed irrespective of their presence at low levels.

A significant interaction existed between the main effects (SxG) for the C18:1n9c (oleic acid), C18:2n6c (linoleic acid), C18:3n3 (α-linolenic acid), total monounsaturated fatty acids (MUFA), total polyunsaturated fatty acids (PUFA), polyunsaturated to saturated fatty acid (PUFA:SFA) ratio, total omega-6 polyunsaturated fatty acids (n6 PUFA), total omega-3 polyunsaturated fatty acids (n3 PUFA) and the omega-6 to omega-3 polyunsaturated fatty acid (n6:n3 PUFA) ratio of the meat derived from the six game species (Table 7.3). Species had the greatest effect on the content ($mg.g^{-1}$ of meat) the essential fatty acids (C18:2n6c, linoleic acid; and C18:3n3, α-linolenic acid), as well as the fatty acid totals (except total saturated fatty acids, SFA) and ratios in the IML of the meat derived from the six species (Table 7.3). Gender influenced the content of C18:1n9c (oleic acid) in gemsbok, blesbok, impala and red hartebeest meat, the content of C18:2n6c (linoleic acid) in springbok, blesbok and impala meat, as well as the content of C18:3n3 (α-linolenic acid) in springbok and blesbok meat (Table 7.3). Gender also influenced the total MUFA content in gemsbok, blesbok and impala meat, the total PUFA content in springbok and blesbok meat, the PUFA:SFA ratio of gemsbok and blesbok

meat, the total n6 PUFA content in blesbok and impala meat, the total n3 PUFA content in impala meat, as well as the n6:n3 PUFA ratio of kudu meat (Table 7.3).

Table 7.4 depicts the significant effect of species on the C16:0 (palmitic acid), C18:0 (stearic acid) and total saturated fatty acid (SFA) content (mg.g^{-1} of meat) of the meat derived from the six game species. The content of these fatty acids were higher ($p<0.01$) in springbok, lower for blesbok and impala and the lowest for gemsbok, red hartebeest and kudu meat (Table 7.4). The C23:0 (tricosylic acid) and C14:1n9c (myristoleic acid) content differed ($p<0.05$) between genders (C23:0, females, 0.03 ± 0.002, males, 0.03 ± 0.003; C14:1n9c, females, 0.03 ± 0.002, males, 0.02 ± 0.002), however, these fatty acids were present at very low levels and will not be discussed further in detail.

7.3.2 Volatile compounds

Table 7.5 depicts the volatile compound profile of the meat derived from the six game species, as arranged by the chemical classes: aldehydes; aliphatic hydrocarbons; alcohols; ketones; benzene compounds; furans; carboxylic acids; esters; cycloalkanes; sulphur-containing compounds; and terpenes. Table 7.5 also indicates the retention times, aroma descriptions from literature and level of statistical significance (p-values) for the influence of the main effects of species (S) and gender (G), and their interaction (SxG) on the quantity (semi-quantitative data) of the volatile compounds (percentage area of the peak) present in the meat derived from the six game species.

A significant interaction existed between the main effects (species and gender) for the percentages of some aldehydes (hexanal), aliphatic hydrocarbons (hexadecane), ketones (2,3-butanedione, 3-hydroxy-2-butanone and 2-heptanone) and carboxylic acids (acetic acid) in the meat derived from the six game species (Table 7.6). Table 7.7 depicts the significant effect of species on the percentages of some aldehydes (octanal and nonanal), alcohols (1-penten-3-ol, 1-pentanol, 1-hexanol, 1-heptanol, 1-octen-3-ol, 2-octen-1-ol, 2-ethylhexanol and 1-octanol), ketones (butyrolactone, 3-methyl-2-butanone, 3-hexanone, 6-methyl-5-hepten-2-one and 2,3-octanedione), benzene compounds (toluene, benzaldehyde, acetophenone and 4-ethylbenzaldehyde), furans (2-pentylfuran), carboxylic acids (butanoic acid), esters (butanoic acid, ethyl ester; 2-propenoic acid, butyl ester; propanoic acid, butyl ester and butanoic acid, butyl ester), sulphur-containing compounds (dimethyl sulphone) and terpenes (limonene) in the meat derived from the six game species. Red hartebeest and kudu meat had the highest ($p<0.01$) percentages of octanal, 1-penten-3-ol, 1-hexanol, 1-octen-3-ol, 2-octen-1-ol, 1-octanol, 2,3-octanedione and benzaldehyde (Table 7.7). Red hartebeest meat had the highest ($p<0.01$) percentages of nonanal, 1-pentanol and 6-methyl-5-hepten-2-one, while kudu meat had the highest ($p<0.01$) percentages of 1-heptanol, butyrolactone, 3-methyl-2-butanone, 4-ethylbenzaldehyde, 2-pentylfuran and dimethyl sulphone (Table 7.7). Impala meat had the highest ($p<0.01$) percentages of 2-ethylhexanol, 3-hexanone, butanoic acid and butanoic acid, ethyl ester (Table 7.7). On the other hand, blesbok meat had the highest percentages of acetophenone ($p<0.05$) and limonene ($p<0.10$), while gemsbok meat had the highest ($p<0.01$) percentages of toluene and esters (2-propenoic acid, butyl ester; propanoic acid, butyl ester; and butanoic acid, butyl ester) (Table 7.7).

Table 7.2 Level of statistical significance (p-values) for the main effects of species (S) and gender (G) and their interaction (SxG) on the fatty acid content (mg.g^{-1} of meat) of the meat derived from six game species

Fatty acid	Common name	SxG	Species	Gender
C14:0	Myristic acid	0.009	<0.0001	0.013
C15:0	Pentadecylic acid	0.036	<0.0001	0.859
C16:0	Palmitic acid	0.373	<0.0001	0.144
C18:0	Stearic acid	0.796	<0.0001	0.793
C20:0	Arachidic acid	0.232	<0.0001	0.099
C21:0	Heneicosylic acid	0.004	<0.0001	0.175
C22:0	Behenic acid	nd	nd	nd
C23:0	Tricosylic acid	0.720	0.003	0.041
C24:0	Lignoceric acid	0.093	<0.0001	0.289
C14:1n9c	Myristoleic acid	0.282	0.003	0.031
C15:1n9t	*cis*-10-Pentadecenoic acid	0.289	0.032	0.667
C16:1n7	Palmitoleic acid	nd	nd	nd
C18:1n9c	Oleic acid	0.001	<0.0001	0.000
C18:1n9t	Elaidic acid	0.862	0.004	0.137
C20:1n9	Gondoic acid	0.294	<0.0001	0.315
C22:1n9	Erucic acid	0.988	0.229	0.797
C24:1n9	Nervonic acid	0.674	0.001	0.809
C18:2n6c	Linoleic acid	0.000	<0.0001	0.016
C18:2n6t	Linolelaidic acid	nd	nd	nd
C18:3n6	Gamma-linolenic acid	0.077	<0.0001	0.638
C18:3n3	Alpha-linolenic acid	0.012	<0.0001	0.075
C20:2n6	Eicosadienoic acid	0.107	0.006	0.446
C20:3n6	Dihomo-gamma-linolenic acid	0.050	<0.0001	0.317
C20:3n3	Eicosatrienoic acid	0.656	0.002	0.298
C20:4n6	Arachidonic acid	0.062	<0.0001	0.040
C20:5n3	Eicosapentaenoic acid, EPA	0.382	<0.0001	0.620
C22:2n6	Docosadienoic acid	0.078	<0.0001	0.240
C22:6n3	Docosahexaenoic acid, DHA	0.0102	<0.0001	0.153
SFA		0.509	<0.0001	0.104
MUFA		0.001	<0.0001	<0.0001
PUFA		0.002	<0.0001	0.061
PUFA:SFA ratio		0.065	<0.0001	0.021
n6 PUFA		0.001	<0.0001	0.039
n3 PUFA		0.007	<0.0001	0.652
n6:n3 PUFA ratio		0.004	<0.0001	0.040

nd, not detected in the meat derived from springbok, gemsbok, blesbok, impala, red hartebeest or kudu; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

Table 7.3 Influence of the interaction (SxG) between the main effects of species (S) and gender (G) on the content (mg.g^{-1} of meat) of selected fatty acids of the meat derived from six game species (Means ± SE)

	Springbok		Gemsbok		Blesbok		Impala		Red Hartebeest		Kudu	
Fatty acid	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
C14:0*	1.03^{a} ± 0.216	0.56^{b} ± 0.074	0.13^{c} ± 0.011	0.08^{c} ± 0.013	0.21^{c} ± 0.036	0.21^{c} ± 0.049	0.26^{c} ± 0.033	0.13^{c} ± 0.024	0.09^{c} ± 0.016	0.14^{c} ± 0.013	0.12^{c} ± 0.009	0.10^{c} ± 0.005
C15:0**	0.15^{a} ± 0.021	0.13^{a} ± 0.009	0.07^{cd} ± 0.002	0.05^{d} ± 0.006	0.08^{cd} ± 0.012	0.13^{ab} ± 0.023	0.10^{bc} ± 0.005	0.08^{cd} ± 0.012	0.05^{d} ± 0.006	0.06^{d} ± 0.011	0.06^{d} ± 0.005	0.06^{d} ± 0.002
C21:0*	0.08^{a} ± 0.006	0.09^{a} ± 0.007	0.04^{b} ± 0.004	0.05^{b} ± 0.011	0.05^{b} ± 0.004	0.08^{a} ± 0.010	0.07^{a} ± 0.003	0.05^{b} ± 0.003	0.04^{b} ± 0.005	0.05^{b} ± 0.009	0.05^{b} ± 0.004	0.05^{b} ± 0.002
C18:1n9c*	5.51^{a} ± 0.233	5.11^{a} ± 0.567	3.76^{b} ± 0.393	2.23^{def} ± 0.273	3.43^{bc} ± 0.382	1.28^{f} ± 0.310	2.84^{bcd} ± 0.172	1.32^{ef} ± 0.276	2.50^{cd} ± 0.365	3.61^{b} ± 0.502	2.34^{de} ± 0.547	2.17^{def} ± 0.106
C18:2n6c*	4.37^{b} ± 0.449	5.87^{a} ± 0.445	1.96^{d} ± 0.200	2.54^{cd} ± 0.306	4.10^{b} ± 0.189	5.55^{a} ± 0.289	4.10^{b} ± 0.323	3.17^{c} ± 0.124	2.84^{c} ± 0.044	2.72^{cd} ± 0.253	2.55^{cd} ± 0.233	2.63^{cd} ± 0.133
C18:3n3**	1.10^{de} ± 0.159	1.43^{bc} ± 0.169	0.64^{f} ± 0.062	0.84^{def} ± 0.107	1.51^{b} ± 0.124	2.05^{a} ± 0.179	1.13^{cd} ± 0.089	0.93^{def} ± 0.024	0.96^{de} ± 0.046	1.02^{de} ± 0.086	0.78^{ef} ± 0.126	0.62^{f} ± 0.058
C20:3n6***	0.24^{a} ± 0.027	0.23^{ab} ± 0.031	0.09^{f} ± 0.008	0.13^{ef} ± 0.017	0.15^{de} ± 0.006	0.23^{a} ± 0.035	0.21^{abc} ± 0.013	0.20^{abcd} ± 0.015	0.23^{ab} ± 0.024	0.18^{bcde} ± 0.020	0.16^{cde} ± 0.012	0.17^{cde} ± 0.008
C20:4n6***	1.56^{bcd} ± 0.212	1.79^{b} ± 0.243	0.74^{e} ± 0.073	0.88^{e} ± 0.099	1.74^{bc} ± 0.108	2.39^{a} ± 0.110	1.50^{bcd} ± 0.117	1.37^{d} ± 0.072	1.51^{bcd} ± 0.046	1.42^{cd} ± 0.137	1.25^{d} ± 0.040	1.44^{bcd} ± 0.063
C22:2n6***	0.19^{ab} ± 0.013	0.20^{ab} ± 0.017	0.11^{d} ± 0.015	0.11^{d} ± 0.020	0.16^{bcd} ± 0.017	0.24^{a} ± 0.028	0.20^{ab} ± 0.011	0.18^{bc} ± 0.030	0.13^{cd} ± 0.014	0.15^{bcd} ± 0.030	0.12^{cd} ± 0.015	0.12^{d} ± 0.007
MUFA*	5.75^{a} ± 0.229	5.67^{a} ± 0.543	4.01^{b} ± 0.391	2.43^{def} ± 0.298	3.37^{b} ± 0.392	1.83^{ef} ± 0.232	3.21^{bcd} ± 0.165	1.63^{f} ± 0.290	2.76^{cd} ± 0.389	3.45^{bc} ± 0.178	2.59^{cde} ± 0.540	2.37^{def} ± 0.109
PUFA*	8.36^{bc} ± 0.917	10.35^{a} ± 0.777	4.08^{f} ± 0.391	5.11^{ef} ± 0.544	8.62^{b} ± 0.413	11.58^{a} ± 0.669	8.54^{bc} ± 0.611	7.03^{cd} ± 0.277	6.67^{de} ± 0.060	6.53^{de} ± 0.623	5.91^{de} ± 0.510	5.71^{de} ± 0.265
PUFA:SFA ratio**	0.53^{e} ± 0.106	0.63^{de} ± 0.135	0.68^{cde} ± 0.072	1.04^{ab} ± 0.111	0.86^{bcd} ± 0.085	1.27^{a} ± 0.101	0.90^{bcd} ± 0.097	0.93^{bc} ± 0.115	1.13^{ab} ± 0.107	0.99^{b} ± 0.062	1.09^{ab} ± 0.117	1.11^{ab} ± 0.060
n6 PUFA*	6.92^{bc} ± 0.586	7.96^{ab} ± 0.540	2.93^{f} ± 0.282	3.70^{ef} ± 0.407	6.23^{c} ± 0.271	8.51^{a} ± 0.444	6.12^{c} ± 0.436	5.03^{d} ± 0.218	4.80^{d} ± 0.071	4.57^{de} ± 0.449	4.14^{de} ± 0.295	4.39^{de} ± 0.196
n3 PUFA*	2.15^{bc} ± 0.144	2.39^{b} ± 0.248	1.15^{f} ± 0.120	1.41^{def} ± 0.151	2.39^{b} ± 0.194	3.07^{a} ± 0.241	2.42^{b} ± 0.181	2.01^{bc} ± 0.071	1.88^{cd} ± 0.111	1.95^{bc} ± 0.183	1.77^{cde} ± 0.217	1.32^{ef} ± 0.102
n6:n3 PUFA*	3.21^{ab} ± 0.138	3.36^{a} ± 0.147	2.56^{c} ± 0.147	2.63^{c} ± 0.130	2.67^{c} ± 0.174	2.80^{bc} ± 0.115	2.54^{c} ± 0.069	2.51^{c} ± 0.068	2.59^{c} ± 0.197	2.35^{c} ± 0.085	2.39^{c} ± 0.163	3.43^{a} ± 0.218

$^{a-f}$Means within a variable with superscripts that do not have a common letter indicate significant differences *(p<0.01), **(p<0.05), ***(p<0.10) between species and/or genders; SE, standard error; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

Table 7.4 Influence of species on the content (mg.g^{-1} of meat) of selected fatty acids in the meat derived from six game species (Means ± SE)

Fatty acid	Springbok	Gemsbok	Blesbok	Impala	Red Hartebeest	Kudu
C16:0*	6.90^{a} ± 0.496	2.58^{c} ± 0.115	4.27^{b} ± 0.286	3.97^{b} ± 0.330	3.07^{c} ± 0.024	2.33^{c} ± 0.085
C18:0*	7.17^{a} ± 0.519	2.51^{d} ± 0.145	5.84^{b} ± 0.461	4.42^{c} ± 0.403	3.47^{cd} ± 0.275	2.55^{d} ± 0.057
C20:0*	0.12^{a} ± 0.010	0.05^{c} ± 0.006	0.09^{b} ± 0.013	0.08^{b} ± 0.007	0.07^{bc} ± 0.008	0.06^{bc} ± 0.002
C23:0*	0.03^{ab} ± 0.003	0.02^{c} ± 0.003	0.03^{b} ± 0.004	0.04^{a} ± 0.004	0.03^{bc} ± 0.006	0.03^{b} ± 0.003
C24:0*	0.16^{a} ± 0.010	0.10^{cd} ± 0.007	0.18^{a} ± 0.020	0.16^{ab} ± 0.012	0.13^{bc} ± 0.016	0.09^{d} ± 0.006
C14:1n9c*	0.03^{a} ± 0.004	0.01^{c} ± 0.004	0.02^{c} ± 0.004	0.03^{ab} ± 0.004	0.02^{bc} ± 0.003	0.02^{bc} ± 0.002
C15:1n9t	0.11^{a} ± 0.022	0.06^{bc} ± 0.012	0.07^{abc} ± 0.018	0.05^{c} ± 0.009	0.09^{ab} ± 0.014	0.06^{bc} ± 0.010
C18:1n9t*	0.00^{c} ± 0.000	0.05^{bc} ± 0.020	0.08^{ab} ± 0.026	0.12^{a} ± 0.024	0.04^{bc} ± 0.024	0.06^{bc} ± 0.008
C20:1n9*	0.00^{b} ± 0.000	0.00^{b} ± 0.000	0.00^{b} ± 0.000	0.00^{b} ± 0.000	0.02^{a} ± 0.005	0.00^{b} ± 0.000
C24:1n9*	0.06^{bc} ± 0.007	0.07^{ab} ± 0.008	0.07^{ab} ± 0.014	0.09^{a} ± 0.008	0.08^{ab} ± 0.008	0.04^{c} ± 0.006
C18:3n6*	0.03^{bc} ± 0.008	0.01^{c} ± 0.006	0.03^{b} ± 0.007	0.04^{ab} ± 0.006	0.06^{a} ± 0.009	0.01^{c} ± 0.005
C20:2n6*	0.05^{a} ± 0.006	0.03^{c} ± 0.003	0.04^{abc} ± 0.005	0.04^{ab} ± 0.003	0.03^{bc} ± 0.004	0.03^{bc} ± 0.001
C20:3n3*	0.16^{a} ± 0.033	0.05^{d} ± 0.011	0.11^{abc} ± 0.021	0.15^{ab} ± 0.018	0.08^{cd} ± 0.020	0.09^{bcd} ± 0.011
C20:5n3*	0.51^{bc} ± 0.052	0.41^{c} ± 0.031	0.60^{ab} ± 0.044	0.66^{a} ± 0.040	0.66^{a} ± 0.044	0.40^{c} ± 0.039
C22:6n3*	0.18^{c} ± 0.027	0.09^{d} ± 0.008	0.17^{c} ± 0.017	0.38^{a} ± 0.033	0.16^{c} ± 0.014	0.31^{b} ± 0.029
SFA*	16.75^{a} ± 1.332	5.52^{c} ± 0.268	9.96^{b} ± 0.703	9.05^{b} ± 0.750	6.98^{c} ± 0.551	5.28^{c} ± 0.110

$^{a-d}$Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$) between species; SE, standard error; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0.

Table 7.5 Level of statistical significance (p-values) for the main effects of species (S) and gender (G) and their interaction (SxG) on the percentages of volatile compounds in the meat derived from six game species

Volatile compounds*	RT	Aroma description	SxG	Species	Gender
Aldehydes					
hexanal	6.62	green[1,4,5,6,15,16,19,20,21,22,25,26,29,30], sweet[4], fat[4,5,7,12,19,21,23,30], grass[4,6,7,8,9,12,13,15,16,19,21,23,25,29,30], tallow[12,19], garlic[13], rancid[16], green apple[18,27], liver-like[19], fruit[26,27], vegetable[27]	0.003	<0.0001	0.129
octanal	12.82	fat[1,12,19,25], soapy[5,12,19,25], green[6,12,15,16,19,210,22,25,27,30], fresh[6,16,21,30], lemon[12,15,19,25,29], citrus[13,15,18,20], fruit[13,18,27], harsh[19], orange peel[19,22], honey[19], meat-like[21,30], chemical[27], floral[29]	0.809	0.000	0.704
nonanal	16.80	tallow[1,5,23], floral[2,19,25], fruit[2,27], herbaceous[2], lemon[2,17], fragrant[4], sweet[4], fat[4,12,16,18,19,21,25,30], green[4,5,6,10,12,15,19,22,25,265,27], pungent[4], gravy[10], citrus[12,15,19], sea[15], citronella grass[15], rancid[16,18,21,30], grass[17,19,26], tea[17], vegetable[17], sour[17], beef-like[17,26], wax[19], stale[22], orange[22,29], soap[23], plastic[27], toast[29]	0.532	0.000	0.164
unidentified aldehyde	37.14		0.000	<0.0001	0.066
unidentified aldehyde	39.39		0.349	<0.0001	0.692
Aliphatic hydrocarbons					
hexadecane	15.98		0.064	0.276	0.607
Alcohols					
2,3-butanediol	24.02		0.506	0.400	0.368
1-penten-3-ol	8.54	sharp[1], irritating[1], penetrating[3], grass[3], ethereal[3], butter[25], green[25], pungent[25], diesel oil[29], cologne[29], toast[29], meat broth[29]	0.978	<0.0001	0.563
1-pentanol	11.43	mild[19], fusel oil[19], fruit[19], balsamic[19,25], alcoholic[25], sharp[25]	0.429	<0.0001	0.559
1-hexanol	15.12	floral[25], fat[25], green[25]	0.471	<0.0001	0.692
1-heptanol	19.02	fragrant[19,25], wood[19,25], oil[19,25], green[19], fat[19], wine[19], sap[19], herbaceous[19]	0.785	<0.0001	0.458
1-octen-3-ol	18.75	mushroom[1,3,8,13,16,18,19,21,23,24,25,26,28,30], liver-like[19], earth[21,30], dust[21], moss[23], nut[23], fungus[27]	0.839	<0.0001	0.981
2-octen-1-ol	25.42	green[19], citrus[19]	0.642	<0.0001	0.620
2-ethylhexanol	20.35	rose[12], green[12,19], mushroom[13,25], resin[19], flower[19], cucumber[25], cooked vegetable[25]	0.303	<0.0001	0.123
1-octanol	23.05	penetrating[19], fat[19,25], wax[19], citrus[19], oil[19], walnut[19], moss[19], chemical[19], metal[19], burnt[19], lemon[25], toasted[25]	0.762	<0.0001	0.781
Ketones					
butyrolactone	26.90		0.756	<0.0001	0.290
2,3-butanedione (diacetyl)	4.24	sweet[4], butter[4,12,13,15,16,18,21,25,27,29], caramel[13,20,21,25,30], rotten[20], vanilla[21,30], cream[25], lactic[27], fruit[29], diacetyl[15,29]	0.034	<0.0001	0.015
3-hydroxy-2-butanone (acetoin)	13.48	butter[11,18,25], yoghurt[18], fat[25], sweaty[25], sour[25]	0.012	<0.0001	0.124
3-methyl-2-butanone	4.38		0.192	0.004	0.374
3-hexanone	5.80		0.750	<0.0001	0.037
2-heptanone	9.28	citrus[15], grapefruit[15], limonene[15], floral[15], cheese[15], barbecue[29], vegetable[29], herb[29]	0.061	0.004	0.815
6-methyl-5-hepten-2-one	14.74		0.232	<0.0001	0.239
2,3-octanedione	14.04	warmed over[23], oxidised fat[23]	0.473	<0.0001	0.256
3-octanone	11.57	moss[18]	0.869	0.186	0.794

Table 7.5 continued

Volatile compounds*	RT	Aroma description	SxG	Species	Gender
Benzene compounds					
toluene	5.67	fruit[25], sweet[25]	0.278	<0.0001	0.485
benzaldehyde	22.73	bitter almond[12,16,19,21,24,30], burnt sugar[12], popcorn[17,26], caramel[17,26], herbaceous[17,26], sulphur[17], chemical[17], spice[17], liver-like[19], penetrating[21,30], roasted pepper[25], nut[25], metallic[26]	0.635	<0.0001	0.557
acetophenone	27.42		0.996	0.026	0.779
4-ethylbenzaldehyde	29.29		0.805	<0.0001	0.756
Furans					
2-pentylfuran	10.53	fat[2], green[2,21,23,25,26,30], green bean[19,23], butter[19], fruit[21,25,30], earth[23,26], metallic[23,26], sweet[25], pungent[25]	0.504	<0.0001	0.475
Carboxylic acids					
acetic acid (ethanoic acid)	19.56	sour[5,12,22], vinegar[18,22]	0.000	<0.0001	0.105
butanoic acid (butyric acid)	26.23	sweet[4], unpleasant[4], sweaty[5,12], rancid[12,21,30], cheese[12,16,18,21,22,30], fat[16], vomit[18], feet[18], faecal[22]	0.105	<0.0001	0.183
Esters					
butanoic acid, ethyl ester (ethyl butanoate)	5.36		0.807	<0.0001	0.832
2-propenoic acid, butyl ester (butyl acrylate)	8.91		0.168	<0.0001	0.540
propanoic acid, butyl ester (butyl propanoate)	7.71		0.114	<0.0001	0.684
butanoic acid, butyl ester (butyl butanoate)	10.05		0.799	<0.0001	0.085
Cycloalkanes					
borneol	28.62	pungent[14], camphor-like[14]	0.440	0.105	0.351
Sulphur-containing compounds					
dimethyl sulphone	34.72	sulphur[12], burnt[12]	0.450	<0.0001	0.948
Terpenes					
limonene	9.34	roasted meat[12], pleasant[14], lemon[14], grass[17], rancid[17], rubber[17], citrus[24]	0.448	0.097	0.914

*Volatile compounds are grouped together into respective chemical classes; RT, retention time (min); [1]Badings, 1970; [2]Farmer *et al.*, 1989; [3]Barbieri *et al.*, 1992; [4]Specht & Baltes, 1994; [5]Kerler & Grosch, 1996; [6]Flores *et al.*, 1997; [7]Elmore *et al.*, 1999; [8]Meynier *et al.*, 1999; [9]Van Ruth & Roozen, 2000; [10]Machiels *et al.*, 2003; [11]Raes *et al.*, 2003; [12]Acree & Arn, 2004; [13]Prost *et al.*, 2004; [14]Burdock, 2005; [15]Rochat & Chaintreau, 2005; [16]Sánchez-Peña *et al.*, 2005; [17]Moon *et al.*, 2006; [18]Berdagué *et al.*, 2007; [19]Calkins & Hodgen, 2007; [20]Ganeko *et al.*, 2008; [21]García-González *et al.*, 2008; [22]Song & Cadwallader, 2008; [23]Stetzer *et al.*, 2008; [24]Belitz *et al.*, 2009; [25]Madruga *et al.*, 2010; [26]Song *et al.*, 2010; [27]Théron *et al.*, 2010; [28]Ma *et al.*, 2012; [29]Resconi *et al.*, 2012; [30]García-González *et al.*, 2014.

Table 7.6 Influence of the interaction between the main effects (species and gender) on the percentages of volatile compounds in the meat derived from six game species (Means ± SE)

	Springbok		Gemsbok		Blesbok		Impala		Red Hartebeest		Kudu	
Volatile compounds	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
Aldehydes												
hexanal*	$0.83^{cde} \pm 0.123$	$2.70^{bcd} \pm 0.668$	$0.51^{e} \pm 0.060$	$0.93^{cde} \pm 0.240$	$0.72^{de} \pm 0.142$	$0.67^{de} \pm 0.097$	$1.65^{cde} \pm 0.612$	$0.54^{e} \pm 0.103$	$4.12^{b} \pm 0.631$	$2.92^{bc} \pm 0.756$	$4.81^{b} \pm 3.048$	$9.85^{a} \pm 1.456$
Aliphatic hydrocarbons												
hexadecane***	$0.00^{b} \pm 0.000$	$0.07^{a} \pm 0.023$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.06^{a} \pm 0.050$	$0.00^{b} \pm 0.000$	$0.05^{ab} \pm 0.028$	$0.00^{b} \pm 0.000$	$0.04^{ab} \pm 0.040$	$0.04^{ab} \pm 0.025$
Ketones												
2,3-butanedione (diacetyl)**	$2.90^{a} \pm 0.470$	$1.95^{bc} \pm 0.328$	$1.11^{def} \pm 0.140$	$0.91^{ef} \pm 0.156$	$1.70^{bcd} \pm 0.348$	$1.50^{cde} \pm 0.247$	$2.31^{ab} \pm 0.282$	$1.23^{cdef} \pm 0.104$	$0.18^{g} \pm 0.084$	$0.72^{fg} \pm 0.232$	$1.14^{def} \pm 0.401$	$0.67^{fg} \pm 0.163$
3-hydroxy-2-butanone (acetoin)**	$22.11^{a} \pm 2.670$	$17.21^{b} \pm 0.795$	$8.85^{c} \pm 0.921$	$6.76^{c} \pm 1.117$	$16.78^{b} \pm 0.895$	$14.38^{b} \pm 1.344$	$17.36^{b} \pm 1.662$	$14.47^{b} \pm 1.336$	$1.69^{d} \pm 0.839$	$7.12^{c} \pm 1.561$	$7.84^{c} \pm 0.871$	$7.73^{c} \pm 1.226$
2-heptanone***	$0.42^{b} \pm 0.092$	$0.59^{ab} \pm 0.050$	$0.77^{a} \pm 0.101$	$0.60^{ab} \pm 0.066$	$0.38^{b} \pm 0.061$	$0.43^{b} \pm 0.058$	$0.35^{b} \pm 0.116$	$0.32^{b} \pm 0.092$	$0.82^{a} \pm 0.130$	$0.44^{b} \pm 0.128$	$0.52^{ab} \pm 0.227$	$0.78^{a} \pm 0.127$
Carboxylic acids												
acetic acid (ethanoic acid)*	$0.44^{b} \pm 0.135$	$0.28^{bcd} \pm 0.106$	$0.28^{bcd} \pm 0.118$	$0.33^{bc} \pm 0.096$	$0.34^{bc} \pm 0.077$	$0.49^{b} \pm 0.115$	$1.23^{a} \pm 0.087$	$0.45^{b} \pm 0.114$	$0.09^{cd} \pm 0.057$	$0.22^{bcd} \pm 0.129$	$0.04^{d} \pm 0.044$	$0.09^{cd} \pm 0.049$

[a-g]Means within a variable with superscripts that do not have a common letter indicate significant differences *(p<0.01), **(p<0.05), ***(p<0.10) between species and/or genders; SE, standard error.

Table 7.7 Influence of species on the percentages of volatile compounds in the meat derived from six game species (Means ± SE)

Volatile compounds	Springbok	Gemsbok	Blesbok	Impala	Red Hartebeest	Kudu
Aldehydes						
octanal*	$0.00^{d} \pm 0.000$	$0.19^{ab} \pm 0.021$	$0.11^{bc} \pm 0.023$	$0.07^{cd} \pm 0.024$	$0.22^{a} \pm 0.058$	$0.22^{a} \pm 0.057$
nonanal*	$1.03^{bc} \pm 0.130$	$0.96^{bcd} \pm 0.164$	$0.46^{d} \pm 0.136$	$0.71^{cd} \pm 0.145$	$1.74^{a} \pm 0.271$	$1.30^{ab} \pm 0.271$
Alcohols						
1-penten-3-ol*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.21^{a} \pm 0.043$	$0.20^{a} \pm 0.040$
1-pentanol*	$0.06^{c} \pm 0.022$	$0.03^{c} \pm 0.018$	$0.07^{c} \pm 0.030$	$0.05^{c} \pm 0.025$	$0.95^{a} \pm 0.167$	$0.67^{b} \pm 0.143$
1-hexanol*	$0.00^{b} \pm 0.000$	$0.02^{b} \pm 0.012$	$0.00^{b} \pm 0.000$	$0.05^{b} \pm 0.042$	$0.18^{a} \pm 0.059$	$0.24^{a} \pm 0.069$
1-heptanol*	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.12^{b} \pm 0.049$	$0.22^{a} \pm 0.045$
1-octen-3-ol*	$0.36^{b} \pm 0.046$	$0.21^{b} \pm 0.047$	$0.34^{b} \pm 0.032$	$0.36^{b} \pm 0.083$	$2.24^{a} \pm 0.446$	$3.03^{a} \pm 0.602$
2-octen-1-ol*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.01^{b} \pm 0.013$	$0.23^{a} \pm 0.071$	$0.33^{a} \pm 0.076$
2-ethylhexanol*	$0.38^{cd} \pm 0.031$	$0.82^{b} \pm 0.040$	$0.44^{cd} \pm 0.051$	$1.36^{a} \pm 0.080$	$0.50^{c} \pm 0.047$	$0.34^{d} \pm 0.024$
1-octanol*	$0.02^{b} \pm 0.017$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.07^{b} \pm 0.042$	$0.20^{a} \pm 0.068$	$0.24^{a} \pm 0.060$
Ketones						
butyrolactone*	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.00^{c} \pm 0.000$	$0.12^{b} \pm 0.030$	$0.26^{a} \pm 0.075$
3-methyl-2-butanone*	$0.30^{d} \pm 0.099$	$0.74^{ab} \pm 0.116$	$0.35^{cd} \pm 0.131$	$0.54^{bcd} \pm 0.142$	$0.64^{abc} \pm 0.121$	$0.93^{a} \pm 0.119$
3-hexanone*	$0.00^{c} \pm 0.000$	$0.05^{bc} \pm 0.020$	$0.09^{ab} \pm 0.020$	$0.12^{a} \pm 0.022$	$0.00^{c} \pm 0.000$	$0.09^{ab} \pm 0.030$
6-methyl-5-hepten-2-one*	$0.03^{b} \pm 0.013$	$0.01^{b} \pm 0.009$	$0.04^{b} \pm 0.019$	$0.00^{b} \pm 0.000$	$0.13^{a} \pm 0.034$	$0.00^{b} \pm 0.000$
2,3-octanedione*	$0.26^{b} \pm 0.080$	$0.08^{b} \pm 0.044$	$0.05^{b} \pm 0.028$	$0.20^{b} \pm 0.115$	$1.56^{a} \pm 0.422$	$1.39^{a} \pm 0.340$

Table 7.7 continued

Volatile compounds	Springbok	Gemsbok	Blesbok	Impala	Red Hartebeest	Kudu
Benzene compounds						
toluene*	$0.15^{b} \pm 0.010$	$0.22^{a} \pm 0.014$	$0.19^{ab} \pm 0.016$	$0.18^{ab} \pm 0.013$	$0.08^{c} \pm 0.025$	$0.17^{ab} \pm 0.026$
benzaldehyde*	$1.48^{c} \pm 0.160$	$2.19^{b} \pm 0.110$	$1.64^{c} \pm 0.130$	$1.46^{c} \pm 0.141$	$2.74^{a} \pm 0.343$	$2.78^{a} \pm 0.173$
acetophenone**	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.03^{a} \pm 0.015$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$
4-ethylbenzaldehyde*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.04^{b} \pm 0.027$	$0.11^{a} \pm 0.031$
Furans						
2-pentylfuran*	$0.21^{bc} \pm 0.090$	$0.04^{c} \pm 0.020$	$0.01^{c} \pm 0.011$	$0.11^{c} \pm 0.069$	$0.49^{b} \pm 0.176$	$0.88^{a} \pm 0.145$
Carboxylic acids						
butanoic acid (butyric acid)*	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.15^{a} \pm 0.064$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$
Esters						
butanoic acid, ethyl ester (ethyl butanoate)*	$0.01^{b} \pm 0.003$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$	$0.16^{a} \pm 0.045$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$
2-propenoic acid, butyl ester (butyl acrylate)*	$6.44^{b} \pm 0.420$	$8.55^{a} \pm 0.430$	$5.63^{b} \pm 0.375$	$5.77^{b} \pm 0.367$	$2.68^{c} \pm 0.422$	$1.45^{d} \pm 0.260$
propanoic acid, butyl ester (butyl propanoate)*	$0.90^{bc} \pm 0.058$	$1.21^{a} \pm 0.086$	$1.10^{ab} \pm 0.096$	$0.83^{c} \pm 0.057$	$0.75^{c} \pm 0.095$	$0.43^{d} \pm 0.081$
butanoic acid, butyl ester (butyl butanoate)*	$0.74^{c} \pm 0.042$	$1.01^{a} \pm 0.037$	$0.90^{ab} \pm 0.042$	$0.90^{ab} \pm 0.060$	$0.74^{bc} \pm 0.074$	$0.35^{d} \pm 0.072$
Sulphur-containing compounds						
dimethyl sulphone*	$0.37^{b} \pm 0.056$	$0.22^{c} \pm 0.040$	$0.03^{d} \pm 0.017$	$0.11^{cd} \pm 0.043$	$0.21^{c} \pm 0.052$	$0.52^{a} \pm 0.056$
Terpenes						
limonene***	$0.00^{b} \pm 0.000$	$0.06^{ab} \pm 0.030$	$0.10^{a} \pm 0.040$	$0.08^{ab} \pm 0.057$	$0.00^{b} \pm 0.000$	$0.00^{b} \pm 0.000$

[a-d]Means within a variable with superscripts that do not have a common letter indicate significant differences *($p<0.01$), **($p<0.05$), ***($p<0.10$) between species; SE, standard error.

The percentages of 3-hexanone and butanoic acid, butyl ester differed significantly ($p<0.05$ and $p<0.10$, respectively) between genders, being higher ($p<0.05$ and $p<0.10$, respectively) in the meat derived from female game species (3-hexanone, females, 0.08 ± 0.016; butanoic acid, butyl ester, females, 0.84 ± 0.043), as compared to males (3-hexanone, males, 0.04 ± 0.010; butanoic acid, butyl ester, males, 0.71 ± 0.049).

7.4 Discussion

Lipids and water-soluble compounds are two major categories of precursors of meat flavour, as the primary reactions responsible for the formation of volatile compounds during cooking are the thermal degradation of lipids and the Maillard reaction between amino acids and reducing sugars (Mottram, 1998a). The lean portion of meat contributes to a general meat-like flavour (non-species-specific), while the IML (phospholipids and to a lesser degree triglycerides) contribute to a species-specific flavour of cooked meat (Mottram, 1998b).

Springbok and impala are classified as mixed feeding species, as they utilise grasses (grazing), as well as shrubs and leaves from bushes (browsing) (Van Zyl, 1965; Bothma *et al.*, 2010a). Additionally, these two species will utilise higher amounts of grazing in the wet season, while browsing is more preferred in the dry season (Van Zyl, 1965; Bothma *et al.*, 2010a). Gemsbok and red hartebeest are also mixed feeders, although approximately 75% of their diet consists of grazing and 25% of browsing (Bothma *et al.*, 2010a). Blesbok are selective grazers (Du Plessis, 1972; Bothma *et al.*, 2010b), while kudu are pure browsers (Bothma *et al.*, 2010a).

Although the dietary regimes of the six game species differ, the main fatty acid in the meat derived from these species (except gemsbok) have been identified as C16:0 (palmitic acid), C18:0 (stearic acid), C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) (Hoffman *et al.*, 2005, 2007, 2009, 2010; Neethling *et al.*, 2014). Although the fatty acid profile of the meat derived from the different game species is similar, the fatty acid content ($mg.g^{-1}$) of the meat derived from the six game species differed significantly between species (for both genders) (Tables 7.2 and 7.3). The similarity could be linked to the fact that all six species are ruminants where a large portion of the unsaturated fatty acids in the diet bio-hydrogenated to more SFA (Wood *et al.*, 1999), such as C16:0 (stearic acid) and C18:0 (palmitic acid), an incorporated into muscle lipids. However, a portion of the unsaturated fatty acids, such as C18:2n6c (linoleic acid) and C18:3n3 (α-linolenic acid), can pass through the rumen unchanged. Hoffman *et al.* (2009) found significant differences in the content of C18:1n9c (oleic acid), C18:2n6c (linoleic acid), C18:3n3 (α-linolenic acid), the fatty acid totals (SFA, MUFA and PUFA), as well as the fatty acid ratios (PUFA:SFA and n6:n3 PUFA) of the meat derived from kudu and impala. Although Hoffman and Wiklund (2006) compared the fatty acid profiles (percentage of total fatty acids) of various game species, the fatty acid profiles were derived from numerous studies with various methodologies for the analysis of the fatty acid profiles which makes comparisons difficult.

In this study, the content of selected fatty acids, as well as the fatty acid totals and ratios differed significantly between genders, yet these gender differences varied within the specific species (Table 7.3). This is in agreement with suggestions in Chapter 2 that the influence of gender on the fatty acid content of the meat derived from South African game species differs between species. Blesbok meat had the greatest gender

differences in the content of the majority of the fatty acids listed in Table 7.3, as compared to the other five species. Neethling *et al.* (2014) also found significant gender differences in the content of C18:1n9c (oleic acid), C18:2n6c (linoleic acid), as well as the fatty acid totals (MUFA, PUFA, n6 and n3 PUFA) and ratios (PUFA:SFA and n6:n3 PUFA) of blesbok meat. The greater gender differences in the fatty acid content of blesbok meat in this study could be attributed to the mating seasons, as this period is energetically draining for male animals, and male game species generally spend less time feeding during this period (Stevenson *et al.*, 1992). Furthermore, male blesbok are territorial during the mating season (Du Plessis, 1972) and these animals could therefore have grazed one small territory for the period of the mating season which could have resulted in overgrazing and the deterioration of grass species in the heavily utilised areas (Bothma, 2002). However, female blesbok are able to roam freely and graze greater areas which, depending on the size of the habitat (generally fenced in area in South Africa), will most likely not lead to overgrazing.

Hoffman *et al.* (2007) found gender differences in the C18:1n9c (oleic acid) and total MUFA content of springbok meat, however, no such differences were present for springbok meat in this study (Table 7.3). The C18:2n6c (linoleic acid) content was higher ($p<0.01$) in the meat derived from female impala as compared to males (Table 7.3). Similarly, Hoffman *et al.* (2005) found significant differences in the C18:2n6c (linoleic acid) percentage of impala meat (higher for females), however, these authors also found gender differences in the total SFA and total PUFA percentages, whereas no significant gender differences for the latter two fatty acid totals were found in this study (Table 7.3). Although gender had no significant influence on the fatty acid content of red hartebeest and kudu meat (Smit, 2004; Hoffman *et al.*, 2009), the C18:1n9c (oleic acid) content of red hartebeest and n6:n3 PUFA ratio of kudu meat differed ($p<0.01$) between genders in our study (Table 7.3). This is the first time the fatty acid content of gemsbok meat has been reported; gender influenced the content of C18:1n9c (oleic acid), total MUFA and PUFA:SFA ratio of the gemsbok meat (Table 7.3).

As mentioned previously, the fatty acid content influences the volatile compound profile of meat (Nuernberg *et al.*, 2005; Chapters 3 and 5). Species therefore had a notable influence on the volatile compound profile of game meat in this study (Tables 7.5 and 7.6), however, the influence of gender was minor (Table 7.6), as compared to the influence of gender on the fatty acid content. Nonetheless, the gender differences in the volatile compound profile of game meat in this study was also species-specific (Table 7.6).

A total of 36 volatile compounds were tentatively identified in the meat derived from the six game species (Table 7.5). Aldehydes, hydrocarbons, alcohols, ketones, lactones, benzene compounds, furans and carboxylic acids are products of the thermal oxidation of fatty acids from phospholipids and triglycerides (Forss, 1973; Mottram, 1998a; Song *et al.*, 2011). A number of volatile compounds in the meat derived from the six species were possibly Maillard reaction products, such as the heterocyclic sulphur-containing compounds, as well as the sulphur- and nitrogen-containing compounds (Forss, 1973; Mottram, 1998a). The extraction temperature used in this study (70°C) resembled a mild cooking temperature and method, which have been associated with the formation of primarily lipid degradation/oxidation products. More intense cooking methods (higher temperatures for longer times) have been associated with a decrease in lipid degradation/oxidation and an increase in Maillard reaction and Strecker degradation products (Mottram, 1985).

The IML content of the meat derived from the six game species can be classified as low (<3.0 g.100 g^{-1} of meat). Furthermore, irrespective of the species and gender effects, the PUFA:SFA and n6:n3 PUFA ratios were above and below the recommended values of 0.7 and 4.0, respectively (Wood *et al.*, 1999; Raes *et al.*, 2004) (Table 7.3). In meat that contains low levels of IML, the highest quantity of PUFA occur in the polar lipid fraction of the phospholipids. These PUFA are extremely reactive and therefore highly susceptible to oxidation, playing an important role in the development of rancidity in frozen and cooked meats (Igene *et al.*, 1980). The volatile compound profile of the meat derived from the six game species was therefore primarily lipid-derived.

Saturated aldehydes and alcohols are primarily derived from the oxidation of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) (Elmore *et al.*, 1999; Belitz *et al.*, 2009), while hexanal and 1-octen-3-ol can also be derived from the oxidation of C20:4n6 (arachidonic acid) (Blank *et al.*, 2001; Lorenzo, 2014; Marušić *et al.*, 2014). 2-Pentylfuran is a product of the thermal degradation of C18:2n6c (linoleic acid) (Mottram, 1985; Elmore *et al.*, 1999). Higher contents of C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) have been linked to higher levels of saturated aldehydes, alcohols and 2-pentylfuran in beef meat (Elmore *et al.*, 1999). Higher contents of the latter fatty acids have also been linked to higher percentages of aldehydes, alcohols, ketones and 2-pentylfuran in springbok meat (Chapter 3), however, no such links were established for blesbok meat (Chapter 5). No significant correlations (positive or negative) existed between the C18:1n9c (oleic acid) and C18:2n6c (linoleic acid) contents (Table 7.3) and the percentages of aldehydes, hydrocarbons, alcohols, ketones, benzene compounds, furans and carboxylic acids in game meat in this study (Tables 7.5 and 7.6). Additionally, the hexanal and 1-octen-3-ol percentages were not correlated to the C20:4n6 (arachidonic acid) content and the 2-pentylfuran percentage was not correlated to the C18:2n6c (linoleic acid) content. However, 3-hydroxy-2-butanone (acetoin) had a positive correlation with the C18:2n6c (linoleic acid) content ($r = 0.608$; $p<0.05$).

The percentages of three of the four esters (2-propenoic acid, butyl ester; propanoic acid, butyl ester; and butanoic acid, butyl ester) were negatively correlated ($p<0.05$) to the percentages of selected alcohols: 1-penten-3-ol ($r = -0.650, -0.447, -0.536$, respectively); 1-pentanol ($r = -0.678, -0.470, -0.542$, respectively); 1-hexanol ($r = -0.542, -0.448, -0.468$, respectively); 1-heptanol ($r = -0.677, -0.603, -0.674$, respectively); 1-octen-3-ol ($r = -0.703, -0.564, -0.645$, respectively); 2-octen-1-ol ($r = -0.677, -0.570, -0.641$, respectively); and 1-octanol ($r = -0.560, -0.540, -0.487$, respectively). Esters are derived from the esterification of various alcohols and carboxylic acids (Um *et al.*, 1992). Consequently, the percentages of esters increased as the percentages of selected alcohols decreased in the meat derived from the six game species (Table 7.7).

The solid-phase microextraction (SPME) technique is generally not used for the absolute quantification of volatile compounds (Lorenzo & Domínguez, 2014). The volatile compound data are therefore reported as semi-quantitative, as the percentage area of the peak for the total ion count (TIC) was used. Furthermore, the percentages at which volatile compounds are present in meat does not reflect the aroma intensity or the overall contribution of these compounds to the ultimate cooked meat flavour (Moon *et al.*, 2006). However, the significance of the contribution of volatile compounds to the aroma and flavour of cooked meat is linked to

their concentrations, in addition to their odour threshold values (Moon *et al.*, 2006; Lu *et al.*, 2008). Aldehydes have low odour threshold values and are therefore important contributors to meat aroma and/or flavour (Mottram, 1998a; Resconi *et al.*, 2012; Van Ba *et al.*, 2013). Similarly, unsaturated alcohols (Calkins & Hodgen, 2007; Song *et al.*, 2011, 2014), ketones (Mottram, 1998a; Van Ba *et al.*, 2013), 2-pentylfuran (Elmore *et al.*, 1999; Song *et al.*, 2010) and sulphur-containing compounds (Resconi *et al.*, 2012) have low odour threshold values and can contribute significantly to the aroma and/or flavour of cooked meat. Compounds containing a benzene ring are aromatic in nature (Raes *et al.*, 2003). Limited information could be sourced on the odour threshold values of carboxylic acids and esters.

As a result of the above-mentioned odour threshold values, the following compounds could contribute to the aroma and/or flavour of the meat derived from the six game species: hexanal, octanal, nonanal, 1-penten-3-ol, 1-octen-3-ol, 2-octen-1-ol, all ketones, 2-pentylfuran, dimethyl sulphone and limonene (Tables 7.5 and 7.6). Aldehydes are aroma-active lipid degradation/oxidation products that contribute to desirable fatty and meat-like aroma in moderate concentrations (Song *et al.*, 2010, 2011), however, at higher concentrations aldehydes contribute to the development of off-aroma and flavours in meat (Lorenzo & Domínguez, 2014). The meat derived from red hartebeest and kudu, had the highest ($p<0.01$) percentages of aldehydes (Tables 7.5 and 7.6), which could contribute to faster deterioration of the aroma and flavours and the increased development of off-aroma and flavours (rancidity) in the meat from these species (Song *et al.*, 2011). Furthermore, the percentages of the lipid-derived unsaturated alcohols (1-penten-3-ol, 1-octen-3-ol and 2-octen-1-ol), butyrolactone, 2,3-octanedione, benzaldehyde and 2-pentylfuran were also highest ($p<0.01$) in the meat derived from red hartebeest and kudu (Table 7.7). Faridnia *et al.* (2015) suggested that freezing and thawing could accelerate the oxidation of lipids in meat. The higher percentages of lipid oxidation compounds in the meat derived from red hartebeest and kudu meat could therefore be attributed to the freezing and thawing cycles of the meat, which occurred twice before the meat was analysed (as compared to once for the other four species). These compounds could contribute various aroma and/or flavour characteristics to red hartebeest and kudu meat, ranging from fatty, green (aldehydes), penetrating, pungent (1-penten-3-ol), mushroom, liver-like off-flavour (1-octen-3-ol), citrus (2-octen-1-ol), herbaceous (2-heptanone), warmed-over (2,3-octanedione), bitter almond, caramel (benzaldehyde) or metallic (2-pentylfuran) (Table 7.5).

Springbok meat had the highest ($p<0.05$) percentages of 2,3-butanedione (diacetyl) and 3-hydroxy-2-butanone (acetone) (Table 7.6) which could contribute to higher butter-like aroma and/or flavours (Table 7.5). The percentage toluene was higher ($p<0.01$) for gemsbok meat (Table 7.7) and could contribute a higher sweet and fruit-like aroma (Table 7.5). Blesbok meat had a higher ($p<0.10$) percentage of limonene (Table 7.7), known to contribute to pleasant, roasted meat and sometimes rancid aroma and/or flavours (Table 7.5). Impala meat had the highest ($p<0.01$) percentages of 2-ethylhexanol and butanoic acid (Table 7.7), which could contribute a variety of aroma and/or flavour attributes to impala meat (Table 7.5).

7.5 Conclusions

This is the first study quantifying the fatty acid content of gemsbok meat. The fatty acid content and volatile compound profile differed significantly as a result of species from which the meat was derived. Furthermore, the influence of gender on the fatty acid content and volatile compound profile of game meat was species-specific. The volatile compound profile of game meat in this study was primarily lipid-derived, which could be attributed to the low IML and high PUFA content of the meat.

The meat from red hartebeest and kudu contained the highest percentages of the lipid-derived compounds, such as aldehydes, alcohols, ketones and 2-pentylfuran. Various volatile compounds known to be aroma-active differed significantly between species and genders. It is therefore postulated that the differences in the volatile compound profile (as well as the differences in fatty acid profiles) between species and genders could have a significant influence on the aroma and/or flavour of game meat derived from the six species in this study. Descriptive sensory analysis is required to establish what the extent of the differences in the volatile compound profile will be on the sensory quality of game meat derived from the six species, as well as between genders. The latter will aid in establishing whether the red meat industry should take species and gender into account for the commercial production and marketing of game meat.

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Chapter 8

Species differences in the sensory quality of game meat

Abstract

Game meat in South Africa is derived from female and male animals of a variety of wild and free-living species. However, little research is available on the influence of species and gender on the sensory quality of game meat. The aim of this study was to quantify the influence of species and gender on the physical measurements, proximate composition and descriptive sensory profile (by a trained panel) of the meat derived from six regularly hunted South African game species (springbok, *Antidorcas marsupialis*; gemsbok, *Oryx gazella;* blesbok, *Damaliscus pygargus phillipsi*; impala, *Aepyceros melampus*; red hartebeest, *Alcelaphus buselaphus caama*; and kudu, *Tragelaphus strepsiceros*). The attribute overall aroma was correlated to gamey aroma ($r = 0.891$; $p<0.0001$). Overall aroma, gamey, beef-like, metallic, liver-like and herbaceous aroma and flavour, black pepper-like aroma, sour-associated aroma, sweet taste, onion-like flavour, initial and sustained juiciness, tenderness, residue and liver-like texture were significantly influenced by the species from which the game meat was derived. The sensory quality of springbok meat was very different in comparison to the other five species. Nonetheless, there is enough evidence to suggest that the sensory quality of the meat derived from the six game species is different from each other. The influence of gender on the sensory quality of game meat was also species-specific, however, the impact of gender on the sensory quality was significantly lower when compared to that of species. It is therefore recommended that the South African game meat industry take species from which the meat is derived into account with the marketing of game meat.

Keywords: Game meat; Descriptive sensory analysis; Meat aroma; Meat flavour; Meat tenderness

8.1 Introduction

In South Africa, the meat derived from wild and free-living, non-domesticated species is referred to as game meat. Even though game meat is derived from a variety of game species, the meat is often marketed under a generic name: 'game meat' or 'venison'. However, Hoffman *et al.* (2009b) found significant differences in the overall aroma, flavour and texture attributes of game meat derived from impala (*Aepyceros melampus*) and kudu (*Tragelaphus strepsiceros*). Furthermore, Van Schalkwyk *et al.* (2011) found significant differences in the sensory quality of salami produced from springbok (*Antidorcas marsupialis*), gemsbok (*Oryx gazella*), kudu and zebra (*Equus burchelli*) meat. Unfortunately, no other research is available that compares the overall sensory quality, i.e. aroma and flavour, as well as texture attributes of the meat derived from numerous South African game species when evaluated under similar conditions by the same trained sensory panel; it is known that variation in the sensory attributes tested and panellists used for descriptive sensory analysis of meat products could easily result in incomparable results between studies (Murray *et al.*, 2001).

In 2014, springbok, blesbok (*Damaliscus pygargus phillipsi*), impala, warthog (*Phacochoerus africanus*) and kudu were identified as the top five game species targeted by local hunters in South Africa (Maqutu, 2014). In addition, gemsbok and red hartebeest are also popular South African game species harvested for game meat

production. Giesecke and Van Gylswyk (1975) established that gemsbok primarily consume grasses. The diets of springbok and impala comprise of a lower percentage of grasses as compared to blesbok, gemsbok and red hartebeest, while for kudu the percentage grasses in their diet is very low to zero (Giesecke & Van Gylswyk, 1975; Bothma, 2002). In addition, the latter three species have preferences towards selected plant species (Giesecke & Van Gylswyk, 1975). Blesbok feed selectively on short grass species (Du Plessis, 1972; Bothma, 2002), while red hartebeest feed on grass and occasionally leaves and fruits (Bothma, 2002). However, habitat differences can have a significant influence on the dietary regime of wild game species (Giesecke & Van Gylswyk, 1975). Nonetheless, springbok, gemsbok, impala and red hartebeest are classified as mixed feeders, as these species tend to utilise grazing (grass) and browsing (leaves, shrubs and/or fruits), while blesbok are classified as strict grazers and kudu as strict browsers (Bothma, 2002).

The sensory quality of meat consist of all factors that contribute to or influence consumer perception, which includes the appearance, orthonasal and retronasal aroma, taste, juiciness and textural attributes. These attributes can be influenced by the animal species, as well as the dietary regime (type of diet) and gender (Sink, 1979; Melton, 1990; Wood *et al.*, 1999; Priolo *et al.*, 2001; Calkins & Hodgen, 2007). A lack of research on the factors influencing the sensory quality of South African game meat can negatively influence the marketing and consumer perception thereof. It is therefore important to establish to what extent species and gender influence the sensory quality of the meat derived from South African game species, and whether the respective game species could be associated with species-specific sensory attributes.

The aim of the present study was therefore to investigate the influence of species and gender on the physical measurements, proximate composition and sensory profile (evaluated by the same panel of judges), which was combined to establish the sensory quality, of the meat derived from six South African game species: springbok (*Antidorcas marsupialis*); gemsbok (*Oryx gazella*); blesbok (*Damaliscus pygargus phillipsi*); impala (*Aepyceros melampus*); red hartebeest (*Alcelaphus caama*); and kudu (*Tragelaphus strepsiceros*).

8.2 Materials and methods

8.2.1 Experimental layout and harvesting

The experimental layout and harvesting information is as described in Chapter 7 (Section 7.3.1).

8.2.2 Sampling

The *longissimus thoracis et lumborum* (LTL) muscle was sampled from the left and right side of the cooled springbok, gemsbok, blesbok and impala carcasses. Only one of the LTL muscles of red hartebeest and kudu was sampled, as these are much larger muscles. All visible connective tissue was removed from the LTL muscles. The *longissimus thoracis* (LT) and *longissimus lumborum* (LL) sections were sub-sampled from the left LTL muscle, vacuum-packed and frozen at -20°C until the training and testing phases of descriptive sensory analysis (DSA), respectively. The LL section was sub-sampled from the right LTL muscle, homogenised, vacuum-packed and frozen at -20°C for the analysis of the proximate composition. For red hartebeest and kudu samples, the one LTL muscle was divided as follows, so as to accommodate all sampling:

the LL section was sub-sampled and divided into two sections, for the testing phase of DSA (section closest to the posterior end) and for the analysis of the proximate composition; while the LT section was sub-sampled for the training phase of DSA. Physical measurements (cooking loss percentage, ultimate pH and Warner-Bratzler shear force) were conducted on the sensory testing samples (left LL section).

8.2.3 Physical measurements

8.2.3.1 Ultimate pH (pHu)

The pHu measurement was measured as described in Chapter 4.

8.2.3.2 Cooking loss percentage

The cooking loss percentage was measured and calculated as described in Chapter 4.

8.2.3.3 Warner-Bratzler shear force (WBSF)

The Warner-Bratzler shear force (WBSF) measurement was conducted as described in Chapter 4.

8.2.4 Proximate composition

The proximate composition was determined as described in Chapter 4.

8.2.5 Sample preparation for descriptive sensory analysis

The sample preparation was processed as described in Chapter 4, with the exception of cooking the meat to an internal temperature of 73°C. The internal temperature (76°C) used for DSA in the two previous studies (Chapters 4 and 6) was found to have a slightly negative effect on the texture attributes (specifically juiciness and therefore the perception of sensory tenderness). As a result, we experimented with lower temperatures (72°C, 73°C, 74°C and 75°C), but not lower than 72°C which is the recommended internal temperature for beef and lamb (AMSA, 1995) and chose 73°C, i.e. an internal temperature that was most appropriate (not too raw or over cooked) for the range of species tested in this research chapter.

8.2.6 Description sensory analysis (DSA)

Descriptive sensory analysis of the meat derived from the six game species (randomly grouped for gender) was conducted by a panel of 10 judges, trained as described by Geldenhuys *et al.* (2014). The panel also had previous experience in the sensory analysis of other meat products.

The panel was trained over eight sessions, during which each panellist received four 1 cm x 1 cm x 1 cm meat cubes from each of the six treatments (species). Reference standards (Table 8.1) were selected to clarify aroma, flavour and texture attributes relevant to game meat in general. The panel decided on 29 sensory attributes: overall aroma; gamey, beef-like, metallic, liver-like, herbaceous and lamb-like aroma and flavour; sweet-associated aroma; black pepper-like aroma; sour-associated aroma; lamb-like fatty aroma; sour, sweet and salty taste; onion-like flavour; buttery flavour; fish-like flavour; initial and sustained juiciness; tenderness;

residue; mealiness; and liver-like texture. The definitions and scales used for the sensory attributes are listed in Table 8.2.

The panel used the test re-test method for DSA with 12 replications per treatment. The sensory analysis room was light- (artificial daylight) and temperature-controlled (21°C) (AMSA, 1995). Each panellist was seated at individual tasting booths at a computer equipped with the Compusense® *five* software programme (Compusense, Guelph, Canada). The panellists received the meat samples for the six treatments in a complete randomised order and analysed each sample for the intensity of the respective sensory attributes (Table 8.2). An unstructured line scale was used for scoring, where zero indicated "low intensity" and 100 indicated "high intensity" (AMSA, 1995). Still mineral water (aQuellé), apple segments (Fuji) and water biscuits (Carr, UK) were available to panellists to refresh their palate between samples.

8.2.7 Statistical analysis

The study consisted of a completely randomised factorial design with ± six animals harvested at random from each of six species (within specific areas) and two genders. Univariate analysis of variance was performed, according to the model for the experimental design, on all variables accessed, using General Linear Models (GLM) Procedure of SAS® software (Version 9.2; SAS Institute Inc, Cary, USA). The model for the statistical design is indicated by the following equation:

Model: $y_{ijk} = \mu + s_i + g_j + sg_{ij} + \varepsilon_{ijk}$

where terms within the model are defined as: the response (y_{ijk}) obtained for the k^{th} observation from the i^{th} species and the j^{th} gender, the overall mean (μ), the species main effect (s_i), the gender main effect (g_j), the species by gender interaction effect (sg_{ij}) and the random error (ε_{ijk}) associated with response on the k^{th} observation in the i^{th} species and the j^{th} gender.

Sensory data was pre-processed by subjecting it to a test-retest analysis of variance (ANOVA), using SAS® (Version 9.2; SAS Institute Inc, Cary, USA), to test for panel reliability. Judge*Replication and Judge*Sample interactions were used, respectively, as measures of temporal stability (precision) and internal consistency (homogeneity) of the panel (Næs *et al.*, 2010). A Shapiro-Wilk test was performed on the standardised residuals from the model to test for normality (Shapiro & Wilk, 1965). In cases where there were significant deviations from normality outliers were removed when the standardised residual for an observation deviated with more than three standard deviations from the model value. Fisher's t-least significant difference was calculated at the 5% level to compare means (Ott, 1998). A probability level of 5% was considered significant for all significance tests, while 10% was considered significant where biologically relevant.

In addition to the univariate ANOVAs, the data were also subjected to Multivariate methods such as Principal Component Analysis (PCA) and Discriminant Analysis (DA) (XLStat, Version 2014, Addinsoft, New York, USA) to visualise and elucidate the relationships between the samples and their attributes (Næs *et al.*, 2010). Where applicable, correlation coefficients were calculated for the physical, proximate and sensory data by means of the Pearson's correlation coefficient (r) (Snedecor & Cochran, 1980).

Table 8.1 Reference standards used during training for descriptive sensory analysis of the meat derived from six game species

Reference standard	Description	Internal temperature	Scale
Blesbok[a]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Ostrich[b]	Aroma and flavour associated with cooked game meat	76°C	0 = low intensity; 100 = high intensity
Beef[c]	Aroma and flavour associated with cooked beef loin	72°C	0 = low intensity; 100 = high intensity
Beef ox liver	Aroma, flavour and texture associated with cooked beef liver	Pan-fried over high heat	0 = low intensity; 100 = high intensity
Ostrich[b]	Aroma and flavour associated with raw meat/blood-like	76°C	0 = low intensity; 100 = high intensity
Blesbok with herbs[d]	Aroma and flavour associated with a combination of herbs (sage, thyme, parsley and oregano)	76°C	0 = low intensity; 100 = high intensity
Lamb[e]	Aroma and flavour associated with cooked lamb loin	72°C	0 = low intensity; 100 = high intensity
Lamb[f]	Fatty aroma associated with cooked lamb fat	Melted at 160°C	0 = low intensity; 100 = high intensity
Beef[c]	Sour taste	72°C	0 = low intensity; 100 = high intensity
Sour solution[g]	Sour taste	-	0 = low intensity; 100 = high intensity
Blesbok[h]	Sweet-associated aroma and sweet taste	76°C	0 = low intensity; 100 = high intensity
Sweet solution[i]	Sweet taste	-	0 = low intensity; 100 = high intensity
Salty solution[j]	Salty taste	-	0 = low intensity; 100 = high intensity
Blesbok[k]	Initial juiciness; texture associated with very tender game meat	76°C	0 = extremely tough; 100 = extremely tender
Blesbok[l]	Tenderness; mealiness	76°C	0 = extremely tough; 100 = extremely tender
Springbok[m]	Tenderness; mealiness	76°C	0 = extremely tough; 100 = extremely tender
Beef[c]	Texture associated with over-matured meat (mealiness)	72°C	0 = none; 100 = prominent

[a]blesbok (*Damaliscus pygargus phillipsi*) *longissimus lumborum* muscle; [b]ostrich (*Struthio camelus*) moon steak; [c]beef *longissimus lumborum* muscle aged for 28 days (fat removed); [d]blesbok *longissimus lumborum* muscle prepared with a combination of herbs (sage, thyme, parsley and oregano); [e]lamb *longissimus lumborum* muscle; [f]subcutaneous fat removed from lamb *longissimus lumborum* muscle; [g]0.07% citric acid solution; [h]browned outside layer of cooked blesbok (*Damaliscus pygargus phillipsi*) *longissimus lumborum*; [i]2.0% sucrose solution; [j]0.2% sodium chloride solution; [k]blesbok *psoas major* muscle; [l]blesbok *longissimus lumborum* aged for 21 days; [m]springbok (*Antidorcas marsupialis*) *longissimus lumborum* aged for 21 days.

Table 8.2 Definition and scale of descriptive sensory analysis attributes (aroma, flavour, taste and texture) for six game species

Sensory attribute	Description	Scale
Overall aroma	Intensity of the overall aroma in the first few sniffs	0 = low intensity; 100 = high intensity
Gamey aroma	Aroma associated with meat from wild animal species – sometimes a combination of liver-like and metallic aromas	0 = low intensity; 100 = high intensity
Beef-like aroma	Aroma associated with cooked beef loin*	0 = low intensity; 100 = high intensity
Metallic aroma	Aroma associated with raw meat/blood-like	0 = low intensity; 100 = high intensity
Liver-like aroma	Aroma associated with pan-fried beef ox liver	0 = low intensity; 100 = high intensity
Sweet-associated aroma	Aroma associated with the browning of a cooked meat surface (Maillard reaction)	0 = low intensity; 100 = high intensity
Herbaceous aroma	Aroma associated with the vegetation of the farms	0 = low intensity; 100 = high intensity
Black pepper-like aroma	Aroma associated with ground black pepper	0 = low intensity; 100 = high intensity
Sour-associated aroma	Aroma associated with over-matured red meat (similar to lactic acid)	0 = low intensity; 100 = high intensity
Lamb-like aroma	Aroma associated with cooked lamb loin*	0 = low intensity; 100 = high intensity
Lamb-like fatty aroma	Aroma associated with melted fat of the lamb loin*	0 = low intensity; 100 = high intensity
Gamey flavour	Flavour associated with meat from wild animal species – sometimes a combination of liver-like and metallic flavours	0 = low intensity; 100 = high intensity
Beef flavour	Flavour associated with cooked beef loin*	0 = low intensity; 100 = high intensity
Metallic flavour	Associated with raw meat or a blood-like taste	0 = low intensity; 100 = high intensity
Liver-like flavour	Flavour associated with pan-fried beef ox liver	0 = low intensity; 100 = high intensity
Lamb flavour	Flavour associated with cooked lamb loin*	0 = low intensity; 100 = high intensity
Herbaceous flavour	Flavour associated with the vegetation of the farms	0 = low intensity; 100 = high intensity
Onion-like flavour	Flavour associated with steamed onions (sometimes garlic-like)	0 = low intensity; 100 = high intensity
Buttery flavour	Flavour associated with melted butter	0 = low intensity; 100 = high intensity

Table 8.2 continued

Sensory attribute	Description	Scale
Fish-like flavour	Flavour associated with raw, fresh fish	0 = low intensity; 100 = high intensity
Sour taste	Taste associated with a citric acid solution	0 = low intensity; 100 = high intensity
Sweet taste	Taste associated with a sucrose solution	0 = low intensity; 100 = high intensity
Salty taste	Taste associated with sodium ions	0 = low intensity; 100 = high intensity
Initial juiciness	Amount of fluid extruded on surface of meat when pressed between thumb and forefinger (perpendicular to fibres)	0 = extremely dry; 100 = extremely juicy
Sustained juiciness	Amount of moisture perceived during mastication	0 = extremely dry; 100 = extremely juicy
Tenderness	Impression of tenderness after mastication	0 = extremely tough; 100 = extremely tender
Residue	Residual tissue remaining after mastication (difficult to chew through)	0 = none; 100 = prominent
Mealiness	Disintegration of muscle fibres into very small particles (perception within the first few chews)	0 = none; 100 = prominent
Liver-like texture	Texture similar to that of pan-fried beef ox liver (spongy/pasty)	0 = none; 100 = prominent

**longissimus lumborum* muscle.

8.3 Results

8.3.1 Sensory quality

Table 8.3 depicts the level of statistical significance (p-values) for the influence of the main effects of species (S) and gender (G) and their interaction (SxG) on the physical measurements (cooking loss percentage, pHu and WBSF), proximate composition (moisture, protein, intramuscular lipid and ash content) and sensory attributes (Table 8.2) of the meat derived from the six game species (springbok, gemsbok, blesbok, impala, red hartebeest and kudu). Table 8.4 depicts the correlation matrix and p-values of the Pearson correlation coefficients (r) for selected attributes: overall aroma; gamey, beef-like, metallic, liver-like and herbaceous aroma and flavour; onion-like flavour; initial and sustained juiciness; tenderness; residue; WBSF; cooking loss %; moisture content; and intramuscular lipid (IML) content.

A significant interaction existed between the main effects (S and G) for the pHu, moisture, protein and IML content, as well as the sweet-associated aroma, sour and salty taste, buttery and fish-like flavour, and mealiness of the meat derived from the six game species (Table 8.5). Although there was an interaction between the main effects for the pHu, the values for pHu differed between 5.5 and 5.7; the pHu differed ($p<0.05$) between genders for springbok meat (with that of the females being 0.2 units higher than that of the males) but did not differ between genders for any of the other species. Similarly, the differences between the means for the moisture, protein and lipids were small and again no trends were noticeable (Table 8.5). The following differences were present between genders (within species) and are worth reporting: the moisture and protein content differed ($p<0.05$) between genders for blesbok meat (Table 8.5). The IML content ($p<0.10$), sour taste ($p<0.10$), fish-like flavour ($p<0.01$) and mealiness ($p<0.01$) differed between genders for impala meat (Table 8.5). The sweet-associated aroma and mealiness differed ($p<0.01$) between genders for red hartebeest meat, while the sweet-associated aroma ($p<0.01$), salty taste ($p<0.05$) and buttery flavour ($p<0.01$) differed between genders for kudu meat (Table 8.5).

Table 8.6 depicts the influence of species on the cooking loss percentage, WBSF and selected sensory attributes of the meat derived from the six game species. The cooking loss percentage was highest ($p<0.10$) for the meat derived from gemsbok, impala and kudu (Table 8.6). The WBSF was highest ($p<0.01$) for the meat derived from impala, while lowest ($p<0.01$) for springbok and red hartebeest meat (Table 8.6). The overall and gamey aroma was highest ($p<0.01$) for the meat derived from springbok and lowest ($p<0.01$) for gemsbok meat, while the opposite was true for the beef-like aroma of springbok and gemsbok meat (Table 8.6). The metallic aroma was highest ($p<0.01$) for the meat derived from springbok and blesbok (Table 8.6). In addition, the liver-like aroma was highest ($p<0.01$) for blesbok meat, while herbaceous aroma was highest ($p<0.05$) for springbok meat (Table 8.6). The black pepper-like aroma was highest ($p<0.05$) for the meat derived from blesbok, while the sour-associated aroma was highest ($p<0.05$) for blesbok and impala meat (Table 8.6). The gamey flavour was again highest ($p<0.01$) for springbok meat, while beef flavour was lowest ($p<0.01$) for springbok meat and highest ($p<0.01$) for gemsbok meat (Table 8.6). Springbok and blesbok meat had the highest ($p<0.01$) metallic flavour (Table 8.6). The liver-like flavour was highest ($p<0.01$) for the meat

derived from springbok, blesbok and red hartebeest (Table 8.6). Springbok meat also had the highest sweet taste ($p<0.10$), herbaceous flavour ($p<0.01$) and onion-like flavour ($p<0.01$) (Table 8.6). Initial and sustained juiciness was highest ($p<0.05$) for kudu and springbok meat, respectively (Table 8.6).

The sensory tenderness was highest ($p<0.01$) for springbok and lowest for impala meat (Table 8.6). Residue was negatively correlated to sensory tenderness ($r = -0.893$; $p<0.0001$) and thus lowest and highest in springbok and impala meat, respectively (Table 8.6). The liver-like texture was highest ($p<0.01$) for springbok and blesbok meat (Table 8.6).

The herbaceous aroma and sweet taste of the meat derived from the six game species differed significantly between genders. Herbaceous aroma ($p<0.01$) and sweet taste ($p<0.05$) were more intense for the meat derived from female animals (4.6 ± 0.73 and 1.8 ± 0.18, respectively) as compared to the meat from male animals (3.1 ± 0.52 and 1.3 ± 0.15, respectively).

The principal component analysis (PCA) bi-plot (Fig. 8.1), using the correlation matrix, demonstrates the extent to which the treatments (species and gender) differ in terms of the attributes selected in Table 8.4. The PCA bi-plot describes 66.16% of the variation between treatments, with principal component one (PC1) or factor one (F1) and PC2/F2 describing 50.20% and 15.96% of the variation between treatments, respectively (Fig. 8.1). According to the PCA bi-plot (Fig. 8.1) there is a clear separation of species along PC1 with springbok (male and female) and blesbok being on the right and the four other game species on the left.

The discriminant analysis (DA) plot (Fig. 8.2) is a classification method that illustrates the differences between treatments (species and gender). The DA plot describes 64.81% of the variation between treatments, with PC1 and PC2 describing 47.00% and 17.81% of the variation between treatments, respectively (Fig. 8.2). Fig. 8.2a illustrates the classification of the observations (gender per species), while Fig. 8.2b indicates all variables used for the classification of the observations (A). According to this DA plot springbok (both genders) are clearly separated from all the other game species on the far right of PC1 (Fig. 8.2a). However, the classification of blesbok (both genders) seem to be less specific (Fig. 8.2a), i.e. it associates reasonably strongly with the attributes on the right side of PC1 and less strongly with the attributes on the left side of PC1 (Fig. 8.2b).

8.3.2 Game meat aroma and flavour

Table 8.7 depicts the Pearson correlation coefficients (r) for specific sensory attributes, proximate measurements, fatty acids and selected volatile compounds, primarily to determine correlations, but also potential drivers of sensory quality, especially the aroma and flavour attributes of the six game species. The sensory aroma and flavour attributes (as tested by DSA in this study) included were the overall aroma; gamey, beef-like, metallic, liver-like, sweet-associated, herbaceous, black pepper-like, sour-associated, lamb-like fatty aroma; gamey, beef, metallic, liver-like, herbaceous, onion-like, buttery and fish-like flavour, whereas the chemical attributes included were the IML content; C18:1n9c (oleic acid); C18:2n6c (linoleic acid); C18:3n3 (α-linolenic acid); hexanal, octanal, nonanal (aldehydes); 1-penten-3-ol, 1-octen-3-ol, 2-octen-1-ol (unsaturated alcohols); 2,3-butanedione, 3-hydroxy-2-butanone, 2-heptanone, 2,3-octanedione, 3-octanone

(ketones); toluene, benzaldehyde (benzene compounds); 2-pentylfuran (furans); acetic acid, butanoic acid (carboxylic acids); dimethyl sulphone (sulphur-containing compounds); and limonene (terpenes) (Chapter 7).

Table 8.3 Level of statistical significance (p-values) for the main effects of species (S) and gender (G) and their interaction (SxG) on the physical measurements, proximate composition (g.100 g^{-1}) and sensory attributes of the meat derived from six game species

	SxG	Species	Gender
Physical measurements			
Cooking loss %	0.535	0.073	0.510
pHu	0.036	0.053	0.561
WBSF (N)	0.090	<0.0001	0.781
Proximate composition			
Moisture content	0.047	<0.0001	0.457
Protein content	0.035	<0.0001	0.909
IML content	0.072	<0.0001	0.010
Ash content	0.765	0.258	0.550
Sensory attributes			
Overall aroma	0.841	<0.0001	0.899
Gamey aroma	0.886	<0.0001	0.796
Beef-like aroma	0.222	<0.0001	0.725
Metallic aroma	0.829	<0.0001	0.328
Liver-like aroma	0.807	<0.0001	0.165
Sweet-associated aroma	0.002	0.008	0.595
Herbaceous aroma	0.178	<0.0001	0.001
Black pepper-like aroma	0.450	0.027	0.725
Sour-associated aroma	0.940	0.023	0.541
Lamb-like aroma	nd	nd	nd
Fatty (lamb-like) aroma	0.208	0.351	0.908
Gamey flavour	0.750	<0.0001	0.466
Beef flavour	0.250	<0.0001	0.490
Metallic flavour	0.418	<0.0001	0.151
Liver-like flavour	0.399	<0.0001	0.433
Lamb-like flavour	nd	nd	nd
Herbaceous flavour	0.349	<0.0001	0.085
Onion-like flavour	0.840	<0.0001	0.207
Buttery flavour	<0.0001	<0.0001	<0.0001
Fish-like flavour	0.001	0.001	0.041
Sour taste	0.072	0.001	0.099
Sweet taste	0.585	0.075	0.023
Salty taste	0.043	0.013	0.471
Initial juiciness	0.348	0.038	0.140
Sustained juiciness	0.393	0.019	0.621
Tenderness	0.291	<0.0001	0.949
Residue	0.284	0.006	0.914
Mealiness	0.001	0.001	0.596
Liver-like texture	0.404	0.003	0.833

SxG, species and gender interactions; nd, not detected in the meat derived from springbok, gemsbok, blesbok, impala, red hartebeest or kudu; pHu, ultimate pH; WBSF, Warner-Bratzler shear force; IML, intramuscular lipid.

Table 8.4 Correlation matrix for the Pearson correlation coefficients (r) and p-values* for the physical measurements, proximate composition and sensory attributes of the meat derived from six game species

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Overall A	**1**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.006**	**0.000**	**0.000**	0.958	**0.020**	**0.001**	0.052	0.108	**0.001**	**0.000**	**0.000**
2. Gamey A	**0.891**	**1**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	0.279	**< 0.0001**	**< 0.0001**	**0.003**	**0.010**	**< 0.0001**	**< 0.0001**	**< 0.0001**
3. Beef-like A	**-0.561**	**-0.767**	**1**	**< 0.0001**	**< 0.0001**	**0.000**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.000**	**< 0.0001**	**0.010**	**0.011**	**< 0.0001**	**< 0.0001**	**0.000**	**0.001**	**< 0.0001**	**0.000**	**< 0.0001**
4. Metallic A	**0.497**	**0.674**	**-0.666**	**1**	**< 0.0001**	0.212	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.024**	0.256	**0.009**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.000**	**0.000**
5. Liver-like A	**0.452**	**0.590**	**-0.471**	**0.678**	**1**	0.794	**< 0.0001**	**0.000**	**< 0.0001**	**< 0.0001**	0.445	0.497	0.058	**0.001**	**< 0.0001**	**0.005**	**0.017**	**< 0.0001**	**0.002**	**0.012**
6. Herbaceous A	**0.615**	**0.536**	**-0.406**	0.150	-0.031	**1**	**< 0.0001**	**0.000**	0.204	0.936	**< 0.0001**	**< 0.0001**	0.244	0.112	**0.010**	0.051	0.167	0.199	**< 0.0001**	**< 0.0001**
7. Gamey F	**0.648**	**0.812**	**-0.777**	**0.728**	**0.512**	**0.474**	**1**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.018**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**
8. Beef F	**-0.560**	**-0.745**	**0.752**	**-0.672**	**-0.434**	**-0.435**	**-0.926**	**1**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.001**	**0.019**	**< 0.0001**	**< 0.0001**	**0.000**	**0.000**	**< 0.0001**	**0.001**	**< 0.0001**
9. Metallic F	**0.449**	**0.637**	**-0.714**	**0.804**	**0.527**	0.152	**0.834**	**-0.809**	**1**	**< 0.0001**	**0.003**	0.102	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.006**	**0.000**
10. Liver-like F	**0.325**	**0.489**	**-0.412**	**0.681**	**0.590**	0.010	**0.608**	**-0.554**	**0.643**	**1**	0.265	0.464	0.070	**0.000**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.004**	**0.029**
11. Herbaceous F	**0.626**	**0.590**	**-0.483**	**0.267**	0.092	**0.828**	**0.625**	**-0.575**	**0.353**	0.134	**1**	**< 0.0001**	0.756	**0.007**	**0.000**	**0.002**	**0.015**	**0.036**	**< 0.0001**	**< 0.0001**
12. Onion-like F	**0.564**	**0.504**	**-0.302**	0.137	0.082	**0.660**	**0.514**	**-0.371**	0.196	0.088	**0.662**	**1**	0.740	0.082	**0.004**	**0.026**	0.381	0.196	**0.001**	**< 0.0001**
13. Initial J	0.006	0.130	**-0.302**	**0.307**	0.226	-0.140	**0.280**	**-0.277**	**0.462**	0.216	-0.037	-0.040	**1**	**< 0.0001**	**0.000**	**0.002**	**0.006**	**< 0.0001**	0.406	0.172
14. Sustained J	**0.275**	**0.461**	**-0.628**	**0.609**	**0.387**	0.190	**0.662**	**-0.641**	**0.730**	**0.421**	**0.317**	0.208	**0.726**	**1**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	0.441	**0.023**
15. Tenderness	**0.389**	**0.518**	**-0.554**	**0.698**	**0.465**	**0.302**	**0.676**	**-0.592**	**0.635**	**0.656**	**0.435**	**0.337**	**0.438**	**0.744**	**1**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.005**	**0.000**
16. Residue	-0.232	**-0.348**	**0.424**	**-0.574**	**-0.333**	-0.232	**-0.496**	**0.409**	**-0.470**	**-0.478**	**-0.357**	**-0.265**	**-0.362**	**-0.596**	**-0.893**	**1**	**< 0.0001**	**< 0.0001**	**0.048**	**0.021**
17. WBSF	-0.192	**-0.303**	**0.378**	**-0.554**	**-0.282**	-0.166	**-0.466**	**0.408**	**-0.458**	**-0.598**	**-0.289**	-0.105	**-0.325**	**-0.519**	**-0.791**	**0.746**	**1**	**< 0.0001**	**0.016**	0.075
18. Cooking loss	**-0.400**	**-0.552**	**0.662**	**-0.700**	**-0.489**	-0.154	**-0.658**	**0.632**	**-0.745**	**-0.527**	**-0.250**	-0.155	**-0.660**	**-0.837**	**-0.730**	**0.521**	**0.509**	**1**	0.067	**0.009**
19. Moisture	**-0.498**	**-0.531**	**0.407**	**-0.406**	**-0.366**	**-0.457**	**-0.478**	**0.399**	**-0.326**	**-0.338**	**-0.455**	**-0.376**	0.100	-0.093	**-0.329**	**0.236**	**0.285**	0.219	**1**	**< 0.0001**
20. IML	**0.562**	**0.637**	**-0.525**	**0.443**	**0.298**	**0.579**	**0.645**	**-0.603**	**0.433**	**0.260**	**0.610**	**0.484**	-0.164	**0.269**	**0.422**	**-0.273**	-0.213	**-0.309**	**-0.628**	**1**

Numbers in the first column corresponds to numbers in the first row; A, aroma; F, flavour; J, juiciness; non-shaded area indicates Pearson correlation coefficients (r), grey shaded area indicates corresponding p-values for Pearson correlation coefficients (r); *all values in bold are significant at a level of $p<0.05$; WBSF, Warner-Bratzler shear force; IML, intramuscular lipid.

Table 8.5 Influence of the interaction between the main effects (species and gender) on the ultimate pH, proximate composition (g.100 g^{-1}) and selected sensory attributes of the meat derived from six game species (Means ± SE)

	Springbok		Gemsbok		Blesbok		Impala		Red Hartebeest		Kudu	
	Female	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
Physical measurements												
pHu**	$5.7^{a} \pm 0.04$	$5.5^{cd} \pm 0.04$	$5.6^{bcd} \pm 0.02$	$5.6^{bcd} \pm 0.02$	$5.6^{abcd} \pm 0.02$	$5.7^{ab} \pm 0.03$	$5.6^{abc} \pm 0.03$	$5.6^{bcd} \pm 0.01$	$5.5^{d} \pm 0.06$	$5.6^{cd} \pm 0.05$	$5.6^{abc} \pm 0.02$	$5.7^{ab} \pm 0.03$
Proximate composition												
Moisture content**	$72.9^{e} \pm 0.37$	$73.6^{de} \pm 0.12$	$76.5^{a} \pm 0.31$	$76.2^{a} \pm 0.29$	$74.1^{cd} \pm 0.34$	$74.9^{b} \pm 0.13$	$74.6^{bc} \pm 0.22$	$75.0^{b} \pm 0.15$	$74.1^{cd} \pm 0.38$	$73.5^{de} \pm 0.28$	$74.5^{bc} \pm 0.10$	$74.1^{cd} \pm 0.27$
Protein content**	$22.8^{def} \pm 0.32$	$22.3^{efg} \pm 0.31$	$21.6^{g} \pm 0.31$	$22.3^{efg} \pm 0.33$	$23.1^{bcde} \pm 0.23$	$22.1^{fg} \pm 0.35$	$22.7^{def} \pm 0.15$	$23.0^{cde} \pm 0.28$	$23.7^{abc} \pm 0.39$	$23.9^{ab} \pm 0.30$	$23.5^{abcd} \pm 0.15$	$24.0^{a} \pm 0.31$
IML content***	$3.0^{a} \pm 0.21$	$3.0^{a} \pm 0.06$	$1.4^{cde} \pm 0.09$	$1.2^{e} \pm 0.09$	$2.3^{b} \pm 0.13$	$2.1^{b} \pm 0.12$	$2.2^{b} \pm 0.08$	$1.7^{c} \pm 0.13$	$1.6^{cd} \pm 0.08$	$1.7^{c} \pm 0.08$	$1.4^{cde} \pm 0.06$	$1.3^{de} \pm 0.03$
Sensory attributes												
Sweet-associated aroma*	$4.1^{ab} \pm 0.59$	$3.8^{ab} \pm 0.51$	$1.6^{d} \pm 0.38$	$3.0^{bcd} \pm 0.68$	$2.6^{bcd} \pm 0.72$	$4.0^{ab} \pm 0.79$	$2.0^{cd} \pm 0.46$	$1.8^{cd} \pm 0.34$	$1.7^{d} \pm 0.41$	$3.3^{bc} \pm 0.91$	$5.0^{a} \pm 0.60$	$2.0^{cd} \pm 0.26$
Buttery flavour*	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$5.3^{a} \pm 0.66$	$0.5^{b} \pm 0.26$
Fish-like flavour*	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.1^{b} \pm 0.13$	$2.3^{a} \pm 1.01$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$	$0.0^{b} \pm 0.00$
Sour taste***	$6.7^{abc} \pm 0.84$	$6.9^{a} \pm 0.49$	$5.1^{abcd} \pm 0.63$	$4.3^{d} \pm 0.81$	$3.6^{d} \pm 0.28$	$5.0^{cd} \pm 0.78$	$3.9^{d} \pm 0.78$	$6.9^{ab} \pm 0.79$	$3.9^{d} \pm 0.59$	$4.0^{d} \pm 0.46$	$5.0^{bcd} \pm 0.92$	$4.8^{d} \pm 0.39$
Salty taste**	$0.8^{a} \pm 0.21$	$0.5^{abc} \pm 0.26$	$0.4^{abc} \pm 0.20$	$0.5^{abc} \pm 0.22$	$0.3^{bc} \pm 0.17$	$0.0^{c} \pm 0.00$	$0.7^{ab} \pm 0.21$	$0.2^{bc} \pm 0.11$	$0.1^{c} \pm 0.10$	$0.0^{c} \pm 0.00$	$0.0^{c} \pm 0.00$	$0.7^{ab} \pm 0.21$
Mealiness*	$3.3^{def} \pm 0.99$	$2.9^{def} \pm 0.91$	$4.7^{bcdef} \pm 1.28$	$5.7^{bcd} \pm 0.92$	$2.6^{ef} \pm 0.75$	$2.1^{f} \pm 0.88$	$7.1^{ab} \pm 0.99$	$2.3^{f} \pm 0.27$	$3.8^{cdef} \pm 0.46$	$8.5^{a} \pm 1.82$	$6.3^{abc} \pm 0.92$	$5.3^{bcde} \pm 0.73$

[a-g]Means within a variable with superscripts that do not have a common letter indicate significant differences *(p<0.01), **(p<0.05), ***(p<0.10) between species and/or genders; SE, standard error; pHu, ultimate pH value; IML, intramuscular lipid.

Table 8.6 Influence of species on the cooking loss percentage, Warner-Bratzler shear force value and selected sensory attributes of the meat derived from six game species (Means ± SE)

	Springbok	Gemsbok	Blesbok	Impala	Red Hartebeest	Kudu
Physical measurements						
Cooking loss %***	$25.9^{b} \pm 1.15$	$31.9^{a} \pm 1.159$	$28.3^{ab} \pm 1.81$	$31.6^{a} \pm 1.08$	$28.7^{ab} \pm 2.34$	$30.5^{a} \pm 1.41$
WBSF (N)*	$35.0^{c} \pm 3.06$	$47.2^{b} \pm 2.72$	$40.3^{bc} \pm 3.74$	$62.5^{a} \pm 2.91$	$37.2^{c} \pm 4.81$	$38.8^{bc} \pm 2.53$
Sensory attributes						
Overall aroma*	$72.1^{a} \pm 0.94$	$59.4^{d} \pm 0.89$	$65.4^{b} \pm 0.88$	$65.7^{b} \pm 0.99$	$61.6^{cd} \pm 1.05$	$63.5^{bc} \pm 0.96$
Gamey aroma*	$71.1^{a} \pm 0.78$	$56.6^{d} \pm 0.99$	$65.7^{b} \pm 1.08$	$63.4^{b} \pm 0.92$	$60.0^{c} \pm 1.30$	$59.8^{c} \pm 0.85$
Beef-like aroma*	$26.1^{d} \pm 0.43$	$34.2^{a} \pm 1.39$	$29.4^{c} \pm 0.84$	$31.2^{bc} \pm 0.77$	$33.3^{ab} \pm 1.39$	$32.7^{ab} \pm 0.92$
Metallic aroma*	$14.9^{a} \pm 1.15$	$7.1^{c} \pm 0.85$	$14.1^{a} \pm 1.08$	$9.5^{bc} \pm 0.95$	$10.8^{b} \pm 1.51$	$8.6^{bc} \pm 0.81$
Liver-like aroma*	$3.4^{ab} \pm 0.62$	$1.2^{c} \pm 0.30$	$4.4^{a} \pm 0.55$	$2.9^{b} \pm 0.45$	$3.1^{ab} \pm 0.39$	$1.4^{c} \pm 0.34$
Herbaceous aroma*	$10.6^{a} \pm 0.90$	$1.3^{c} \pm 0.32$	$2.0^{c} \pm 0.43$	$2.6^{bc} \pm 0.53$	$2.2^{c} \pm 0.43$	$3.8^{b} \pm 0.66$
Black pepper-like aroma**	$0.2^{ab} \pm 0.11$	$0.1^{b} \pm 0.07$	$0.4^{a} \pm 0.15$	$0.1^{b} \pm 0.05$	$0.1^{b} \pm 0.07$	$0.0^{b} \pm 0.00$
Sour-associated aroma**	$1.4^{ab} \pm 0.19$	$1.0^{b} \pm 0.28$	$2.0^{a} \pm 0.23$	$1.9^{a} \pm 0.23$	$1.5^{ab} \pm 0.31$	$1.1^{b} \pm 0.26$
Gamey flavour*	$76.5^{a} \pm 1.26$	$60.4^{c} \pm 1.31$	$70.7^{b} \pm 1.09$	$62.6^{c} \pm 1.25$	$61.7^{c} \pm 1.27$	$62.1^{c} \pm 1.10$
Beef flavour*	$27.1^{d} \pm 0.68$	$38.5^{a} \pm 1.28$	$30.4^{c} \pm 0.78$	$35.3^{b} \pm 1.00$	$38.1^{ab} \pm 1.43$	$36.9^{ab} \pm 1.25$
Metallic flavour*	$14.8^{a} \pm 1.14$	$7.8^{b} \pm 1.30$	$14.8^{a} \pm 1.07$	$8.3^{b} \pm 1.22$	$7.4^{b} \pm 1.30$	$8.6^{b} \pm 1.12$
Liver-like flavour*	$4.5^{a} \pm 0.62$	$2.1^{b} \pm 0.48$	$5.6^{a} \pm 0.99$	$1.1^{b} \pm 0.42$	$4.5^{a} \pm 1.13$	$1.3^{b} \pm 0.46$
Herbaceous flavour*	$6.1^{a} \pm 0.44$	$0.7^{c} \pm 0.18$	$1.2^{c} \pm 0.25$	$0.8^{c} \pm 0.25$	$0.5^{c} \pm 0.16$	$2.1^{b} \pm 0.43$
Onion-like flavour*	$4.6^{a} \pm 0.55$	$1.4^{b} \pm 0.26$	$1.9^{b} \pm 0.45$	$1.6^{b} \pm 0.36$	$1.3^{b} \pm 0.36$	$2.4^{b} \pm 0.32$
Sweet taste***	$2.0^{a} \pm 0.37$	$1.1^{b} \pm 0.33$	$1.7^{ab} \pm 0.29$	$1.0^{b} \pm 0.26$	$1.5^{ab} \pm 0.23$	$1.8^{ab} \pm 0.11$
Initial juiciness**	$63.8^{b} \pm 1.72$	$66.8^{ab} \pm 3.03$	$63.6^{b} \pm 1.72$	$61.2^{b} \pm 1.96$	$62.3^{b} \pm 2.31$	$70.6^{a} \pm 2.18$
Sustained juiciness**	$64.5^{a} \pm 1.83$	$57.6^{bc} \pm 2.99$	$62.8^{ab} \pm 1.69$	$53.6^{c} \pm 2.05$	$56.8^{bc} \pm 3.05$	$60.0^{abc} \pm 2.42$
Tenderness*	$77.7^{a} \pm 1.80$	$63.2^{cd} \pm 2.72$	$70.8^{ab} \pm 2.80$	$57.5^{d} \pm 1.80$	$66.6^{bc} \pm 3.94$	$66.8^{bc} \pm 2.55$
Residue*	$1.6^{c} \pm 0.50$	$6.1^{ab} \pm 1.69$	$3.9^{bc} \pm 1.61$	$9.0^{a} \pm 1.35$	$7.0^{ab} \pm 1.75$	$4.1^{bc} \pm 1.14$
Liver-like texture*	$0.7^{a} \pm 0.20$	$0.1^{bc} \pm 0.10$	$0.9^{a} \pm 0.24$	$0.0^{c} \pm 0.00$	$0.7^{ab} \pm 0.38$	$0.1^{c} \pm 0.06$

[a-d]Means within a variable with superscripts that do not have a common letter indicate significant differences *(p<0.01), **(p<0.05), ***(p<0.10) between species; SE, standard error; WBSF, Warner-Bratzler shear force.

Table 8.7 Correlation matrix for the Pearson correlation coefficients (r) and p-values* for the intramuscular fat content, selected sensory attributes, fatty acids and volatile compounds of the meat derived from six game species

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**1**	**0.000**	**0.000**	**0.004**	0.051	0.066	**0.001**	0.603	0.144	0.435	**0.001**	**0.001**	**0.018**	0.451
2	**0.967**	**1**	**< 0.0001**	**0.001**	**0.017**	0.089	**0.005**	0.582	0.053	0.317	**< 0.0001**	**< 0.0001**	**0.005**	0.202
3	**-0.891**	**-0.936**	**1**	**0.003**	**0.048**	**0.029**	**0.007**	0.506	0.096	0.591	**0.000**	**0.000**	**0.003**	0.311
4	**0.756**	**0.845**	**-0.774**	**1**	**< 0.0001**	0.084	0.149	0.983	**0.047**	0.267	**0.000**	**0.002**	**0.001**	**0.004**
5	0.574	**0.670**	**-0.581**	**0.902**	**1**	0.345	0.717	0.861	**0.016**	0.142	**0.041**	0.072	**0.018**	**0.005**
6	0.546	0.512	**-0.626**	0.519	0.299	**1**	0.051	0.777	0.943	0.493	0.084	0.183	0.171	0.458
7	**0.812**	**0.746**	**-0.731**	0.443	0.117	0.573	**1**	0.208	0.998	0.921	**0.008**	**0.012**	0.137	0.835
8	-0.167	-0.177	0.213	0.007	0.057	0.091	-0.391	**1**	0.892	0.566	0.568	0.532	0.920	0.744
9	0.449	0.571	-0.502	**0.583**	**0.675**	0.023	-0.001	-0.044	**1**	0.093	0.176	0.119	0.165	0.299
10	-0.249	-0.316	0.173	-0.349	-0.450	0.220	-0.032	-0.185	-0.506	**1**	0.604	0.590	0.576	0.127
11	**0.845**	**0.913**	**-0.878**	**0.852**	**0.597**	0.519	**0.725**	-0.184	0.418	-0.167	**1**	**< 0.0001**	**< 0.0001**	0.077
12	**-0.820**	**-0.903**	**0.866**	**-0.799**	-0.537	-0.412	**-0.693**	0.200	-0.475	0.173	**-0.977**	**1**	**0.000**	0.138
13	**0.664**	**0.755**	**-0.776**	**0.845**	**0.665**	0.422	0.456	-0.032	0.428	-0.180	**0.902**	**-0.879**	**1**	**0.033**
14	0.241	0.396	-0.320	**0.768**	**0.752**	0.237	0.067	0.106	0.328	-0.466	0.530	-0.455	**0.616**	**1**
15	**0.826**	**0.762**	**-0.761**	0.489	0.155	**0.652**	**0.976**	-0.269	-0.028	0.038	**0.781**	**-0.733**	0.547	0.102
16	**0.798**	**0.723**	**-0.656**	0.489	0.167	**0.576**	**0.900**	-0.237	0.012	0.088	**0.782**	**-0.721**	0.547	0.100
17	-0.062	-0.182	0.032	-0.243	-0.370	0.490	0.133	0.037	-0.301	0.547	-0.229	0.272	-0.315	-0.458
18	0.057	0.017	0.178	-0.179	-0.115	-0.233	-0.055	0.079	0.380	-0.312	-0.227	0.127	-0.409	-0.300
19	**0.915**	**0.933**	**-0.819**	**0.761**	0.559	0.443	**0.747**	-0.212	0.525	-0.271	**0.909**	**-0.898**	**0.741**	0.356
20	**0.595**	0.537	-0.383	0.395	0.192	0.312	**0.738**	-0.358	-0.067	-0.102	**0.616**	-0.514	0.380	0.266
21	**0.801**	**0.850**	**-0.781**	**0.793**	**0.649**	0.498	0.473	0.120	**0.608**	-0.176	**0.813**	**-0.835**	**0.764**	0.379
22	0.506	**0.640**	**-0.610**	**0.795**	**0.753**	0.413	0.096	0.239	**0.747**	-0.225	**0.659**	**-0.672**	**0.732**	**0.581**
23	-0.078	-0.218	0.229	-0.241	-0.321	0.076	0.025	0.552	-0.522	0.058	-0.274	0.299	-0.287	-0.275
24	**-0.789**	**-0.807**	**0.744**	**-0.603**	-0.444	-0.286	**-0.627**	0.358	-0.540	0.164	**-0.750**	**0.810**	**-0.658**	-0.172
25	-0.150	-0.204	0.140	-0.139	-0.063	0.159	0.045	0.028	-0.531	-0.038	-0.301	0.400	-0.369	0.074
26	-0.278	-0.325	0.303	-0.175	-0.153	0.085	-0.124	0.217	-0.419	0.032	-0.393	0.453	-0.451	0.009
27	-0.238	-0.313	0.297	-0.231	-0.251	0.065	-0.095	0.385	-0.463	0.035	-0.384	0.420	-0.434	-0.117
28	-0.292	-0.357	0.333	-0.301	-0.331	-0.004	-0.114	0.346	-0.486	0.068	-0.416	0.433	-0.474	-0.169
29	**0.730**	**0.716**	**-0.648**	0.440	0.217	0.352	**0.695**	-0.306	0.489	-0.210	**0.684**	**-0.709**	0.516	0.049
30	**0.778**	**0.781**	**-0.720**	0.545	0.376	0.267	**0.604**	-0.247	**0.618**	-0.272	**0.742**	**-0.777**	**0.659**	0.102
31	-0.481	-0.511	0.536	-0.458	-0.541	-0.241	-0.160	0.205	**-0.822**	0.413	-0.324	0.327	-0.361	-0.140
32	-0.123	-0.218	0.305	-0.048	0.025	0.028	-0.098	0.434	-0.374	-0.271	-0.328	0.414	-0.336	0.129
33	-0.326	-0.253	0.203	-0.249	-0.216	-0.039	-0.096	-0.136	-0.359	0.186	-0.095	0.154	-0.153	0.110
34	-0.275	-0.279	0.192	-0.432	-0.491	-0.347	-0.211	-0.036	-0.068	0.395	-0.105	0.009	0.037	-0.500
35	-0.520	**-0.604**	**0.604**	-0.332	-0.254	0.017	-0.346	0.348	**-0.628**	0.169	-0.568	**0.674**	-0.515	0.004
36	-0.021	-0.173	0.177	-0.145	-0.196	0.304	0.089	0.371	-0.477	0.164	-0.285	0.356	-0.368	-0.213
37	0.140	0.132	0.085	0.128	0.289	-0.220	-0.105	-0.011	0.573	**-0.582**	-0.065	0.037	-0.108	0.109
38	0.090	0.033	0.122	-0.212	-0.094	-0.332	-0.069	-0.073	0.443	-0.304	-0.253	0.138	-0.379	-0.421
39	0.149	-0.030	-0.024	-0.198	-0.425	0.500	0.488	0.061	**-0.690**	0.456	-0.045	0.112	-0.225	-0.371
40	-0.116	-0.033	0.012	-0.060	0.099	-0.079	-0.406	0.341	0.556	-0.222	-0.117	0.066	-0.028	-0.075

Table 8.7 continued

Variables	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	**0.001**	**0.002**	0.849	0.861	**0.000**	**0.041**	**0.002**	0.094	0.810	**0.002**	0.641	0.382	0.456	0.356
2	**0.004**	**0.008**	0.572	0.958	**< 0.0001**	0.072	**0.000**	**0.025**	0.495	**0.002**	0.525	0.302	0.322	0.254
3	**0.004**	**0.020**	0.923	0.580	**0.001**	0.219	**0.003**	**0.035**	0.474	**0.005**	0.665	0.339	0.349	0.290
4	0.106	0.107	0.446	0.578	**0.004**	0.204	**0.002**	**0.002**	0.450	**0.038**	0.666	0.587	0.470	0.342
5	0.630	0.603	0.236	0.721	0.059	0.551	**0.022**	**0.005**	0.310	0.148	0.845	0.636	0.431	0.294
6	**0.022**	**0.050**	0.106	0.466	0.149	0.324	0.099	0.182	0.814	0.368	0.622	0.792	0.840	0.991
7	**< 0.0001**	**< 0.0001**	0.681	0.865	**0.005**	**0.006**	0.121	0.767	0.938	**0.029**	0.890	0.702	0.768	0.723
8	0.398	0.458	0.908	0.807	0.508	0.253	0.710	0.454	0.063	0.253	0.932	0.498	0.217	0.271
9	0.932	0.971	0.341	0.223	0.079	0.837	**0.036**	**0.005**	0.082	0.070	0.076	0.175	0.130	0.109
10	0.906	0.785	0.065	0.323	0.395	0.752	0.583	0.481	0.858	0.610	0.907	0.922	0.914	0.834
11	**0.003**	**0.003**	0.474	0.478	**< 0.0001**	**0.033**	**0.001**	**0.020**	0.388	**0.005**	0.341	0.206	0.218	0.179
12	**0.007**	**0.008**	0.392	0.694	**< 0.0001**	0.087	**0.001**	**0.017**	0.346	**0.001**	0.197	0.139	0.174	0.159
13	0.065	0.066	0.318	0.187	**0.006**	0.223	**0.004**	**0.007**	0.366	**0.020**	0.238	0.142	0.159	0.119
14	0.752	0.757	0.135	0.344	0.256	0.403	0.225	**0.048**	0.386	0.593	0.818	0.978	0.717	0.599
15	**1**	**< 0.0001**	0.710	0.642	**0.003**	**0.005**	0.061	0.558	0.898	**0.030**	0.994	0.564	0.680	0.618
16	**0.941**	**1**	0.734	0.757	**0.001**	**0.000**	0.060	0.494	0.975	**0.043**	0.576	0.421	0.532	0.468
17	0.120	0.110	**1**	0.809	0.372	0.579	0.425	0.372	0.109	0.306	0.462	0.068	0.060	0.067
18	-0.150	-0.100	-0.078	**1**	0.683	0.824	0.640	0.830	0.763	0.457	0.294	0.568	0.680	0.705
19	**0.775**	**0.809**	-0.284	0.132	**1**	**0.012**	**0.000**	**0.028**	0.265	**0.000**	0.181	0.067	0.082	0.058
20	**0.746**	**0.850**	-0.179	-0.072	**0.694**	**1**	0.325	0.899	0.622	0.167	0.889	0.443	0.384	0.326
21	0.555	0.557	-0.255	0.151	**0.863**	0.311	**1**	**0.000**	0.370	**0.001**	0.121	0.070	0.119	0.083
22	0.188	0.219	-0.284	0.070	**0.632**	0.041	**0.870**	**1**	0.162	**0.044**	0.089	0.123	0.120	0.084
23	0.042	0.010	0.487	-0.098	-0.350	-0.159	-0.285	-0.431	**1**	0.115	0.126	**0.011**	**0.000**	**0.000**
24	**-0.624**	**-0.590**	0.323	-0.237	**-0.875**	-0.426	**-0.829**	**-0.589**	0.479	**1**	0.089	**0.013**	**0.019**	**0.015**
25	0.002	-0.180	0.235	-0.331	-0.414	-0.045	-0.473	-0.512	0.467	0.512	**1**	**0.003**	**0.014**	**0.019**
26	-0.186	-0.257	0.543	-0.184	-0.545	-0.245	-0.540	-0.470	**0.704**	**0.688**	**0.770**	**1**	**< 0.0001**	**< 0.0001**
27	-0.133	-0.200	0.558	-0.133	-0.522	-0.277	-0.475	-0.474	**0.870**	**0.663**	**0.684**	**0.956**	**1**	**< 0.0001**
28	-0.160	-0.232	0.546	-0.122	-0.561	-0.311	-0.520	-0.519	**0.854**	**0.680**	**0.661**	**0.944**	**0.992**	**1**
29	**0.684**	**0.723**	-0.134	0.354	**0.870**	**0.593**	**0.685**	0.458	-0.418	**-0.847**	**-0.590**	**-0.660**	**-0.617**	**-0.634**
30	**0.613**	**0.661**	-0.237	0.250	**0.891**	0.496	**0.764**	0.567	-0.420	**-0.887**	**-0.662**	**-0.720**	**-0.659**	**-0.682**
31	-0.120	-0.107	0.057	-0.297	-0.488	-0.024	-0.479	-0.542	0.503	0.560	0.391	0.426	0.493	0.544
32	-0.133	-0.171	0.264	-0.063	-0.375	-0.070	-0.378	-0.389	**0.781**	0.557	**0.726**	**0.850**	**0.862**	**0.811**
33	-0.037	-0.058	-0.340	-0.236	-0.131	0.217	-0.216	-0.150	-0.395	0.219	0.202	-0.210	-0.298	-0.266
34	-0.143	-0.033	-0.080	-0.015	-0.084	-0.165	-0.039	-0.047	-0.209	-0.092	**-0.704**	**-0.618**	-0.482	-0.417
35	-0.350	-0.327	0.461	-0.245	**-0.683**	-0.188	**-0.658**	-0.533	**0.652**	**0.829**	**0.668**	**0.849**	**0.807**	**0.778**
36	0.077	0.042	**0.697**	-0.068	-0.335	-0.093	-0.299	-0.411	**0.889**	0.480	**0.622**	**0.847**	**0.908**	**0.868**
37	-0.186	-0.096	-0.359	**0.792**	0.278	0.111	0.227	0.259	-0.373	-0.338	-0.364	-0.345	-0.388	-0.424
38	-0.180	-0.153	-0.098	**0.941**	0.118	-0.148	0.122	0.014	-0.161	-0.319	-0.367	-0.274	-0.227	-0.214
39	0.499	0.431	**0.694**	-0.165	-0.083	0.240	-0.165	-0.465	**0.694**	0.180	0.503	0.518	**0.599**	**0.582**
40	-0.347	-0.305	-0.256	0.451	0.061	-0.334	0.278	0.479	-0.446	-0.115	-0.523	-0.549	-0.508	-0.507

Table 8.7 continued

Variables	29	30	31	32	33	34	35	36	37	38	39	40
1	**0.007**	**0.003**	0.113	0.703	0.301	0.387	0.083	0.947	0.663	0.782	0.643	0.719
2	**0.009**	**0.003**	0.089	0.496	0.428	0.380	**0.038**	0.590	0.682	0.920	0.925	0.919
3	**0.023**	**0.008**	0.073	0.335	0.527	0.550	**0.037**	0.582	0.793	0.706	0.940	0.971
4	0.152	0.067	0.135	0.881	0.435	0.161	0.291	0.652	0.691	0.508	0.536	0.853
5	0.497	0.229	0.069	0.939	0.501	0.105	0.426	0.542	0.362	0.770	0.169	0.760
6	0.261	0.401	0.450	0.931	0.905	0.269	0.958	0.337	0.492	0.292	0.097	0.806
7	**0.012**	**0.038**	0.620	0.762	0.766	0.511	0.271	0.782	0.746	0.831	0.107	0.190
8	0.333	0.440	0.523	0.159	0.674	0.911	0.268	0.235	0.974	0.820	0.850	0.278
9	0.106	**0.032**	**0.001**	0.231	0.252	0.834	**0.029**	0.117	0.052	0.149	**0.013**	0.061
10	0.512	0.393	0.182	0.394	0.563	0.203	0.599	0.611	**0.047**	0.336	0.136	0.488
11	**0.014**	**0.006**	0.304	0.297	0.770	0.746	0.054	0.370	0.842	0.427	0.888	0.718
12	**0.010**	**0.003**	0.299	0.181	0.633	0.978	**0.016**	0.257	0.910	0.669	0.729	0.838
13	0.086	**0.020**	0.250	0.286	0.635	0.909	0.086	0.239	0.737	0.224	0.481	0.931
14	0.879	0.753	0.665	0.689	0.735	0.098	0.991	0.505	0.736	0.172	0.236	0.816
15	**0.014**	**0.034**	0.710	0.680	0.910	0.657	0.264	0.812	0.563	0.575	0.099	0.269
16	**0.008**	**0.019**	0.741	0.595	0.859	0.918	0.299	0.896	0.767	0.635	0.162	0.335
17	0.679	0.458	0.860	0.406	0.279	0.805	0.131	**0.012**	0.252	0.763	**0.012**	0.423
18	0.259	0.433	0.348	0.845	0.460	0.963	0.443	0.834	**0.002**	**< 0.0001**	0.609	0.141
19	**0.000**	**0.000**	0.107	0.229	0.685	0.796	**0.014**	0.287	0.382	0.715	0.798	0.849
20	**0.042**	0.101	0.941	0.828	0.497	0.609	0.558	0.774	0.732	0.647	0.453	0.289
21	**0.014**	**0.004**	0.115	0.225	0.499	0.905	**0.020**	0.346	0.477	0.707	0.608	0.382
22	0.134	0.055	0.069	0.211	0.641	0.885	0.074	0.185	0.416	0.965	0.128	0.115
23	0.176	0.174	0.096	**0.003**	0.203	0.514	**0.022**	**0.000**	0.232	0.617	**0.012**	0.146
24	**0.001**	**0.000**	0.058	0.060	0.494	0.777	**0.001**	0.114	0.283	0.312	0.576	0.721
25	**0.043**	**0.019**	0.209	**0.008**	0.528	**0.011**	**0.018**	**0.031**	0.245	0.241	0.096	0.081
26	**0.020**	**0.008**	0.167	**0.000**	0.512	**0.032**	**0.000**	**0.001**	0.272	0.389	0.085	0.065
27	**0.032**	**0.020**	0.104	**0.000**	0.346	0.113	**0.002**	**< 0.0001**	0.212	0.479	**0.040**	0.092
28	**0.027**	**0.015**	0.068	**0.001**	0.404	0.177	**0.003**	**0.000**	0.170	0.504	**0.047**	0.092
29	**1**	**< 0.0001**	**0.040**	0.070	0.636	0.572	**0.006**	0.179	0.167	0.242	0.807	0.461
30	**0.950**	**1**	**0.016**	0.059	0.388	0.454	**0.001**	0.117	0.205	0.301	0.478	0.400
31	**-0.597**	**-0.674**	**1**	0.271	0.227	0.844	0.067	0.243	**0.044**	0.151	0.145	0.111
32	-0.540	-0.559	0.346	**1**	0.377	**0.017**	**0.001**	**0.001**	0.839	0.642	0.136	0.114
33	-0.152	-0.275	0.377	-0.281	**1**	0.771	0.968	0.213	0.512	0.264	0.769	0.583
34	0.182	0.239	0.064	**-0.672**	0.094	**1**	0.179	0.112	0.678	0.792	0.493	0.256
35	**-0.743**	**-0.819**	0.545	**0.823**	-0.013	-0.415	**1**	**0.003**	0.393	0.254	0.112	0.140
36	-0.416	-0.477	0.365	**0.837**	-0.388	-0.483	**0.772**	**1**	0.350	0.651	**0.002**	0.083
37	0.426	0.394	**-0.589**	-0.066	-0.210	-0.134	-0.272	-0.296	**1**	**0.002**	0.120	0.120
38	0.366	0.326	-0.441	-0.150	-0.350	0.085	-0.357	-0.146	**0.790**	**1**	0.454	0.157
39	-0.079	-0.227	0.447	0.456	-0.095	-0.219	0.483	**0.788**	-0.473	-0.239	**1**	**0.040**
40	0.236	0.268	-0.484	-0.481	0.177	0.356	-0.452	-0.520	0.474	0.436	**-0.597**	**1**

Numbers in the first column corresponds to numbers in the first row; 1, overall aroma; 2, gamey aroma; 3, beef-like aroma; 4, metallic aroma; 5, liver-like aroma; 6, sweet-associated aroma; 7, herbaceous aroma; 8, black pepper-like aroma; 9, sour-associated aroma; 10, lamb-like fatty aroma; 11, gamey flavour; 12, beef flavour; 13, metallic flavour; 14, liver-like flavour; 15, herbaceous flavour; 16, onion-like flavour; 17, buttery flavour; 18, fish-like flavour; 19, intramuscular fat; 20, C18:1n9c (oleic acid); 21, C18:2n6c (linoleic acid); 22, C18:3n3 (α-linolenic acid); 23, hexanal; 24, octanal; 25, nonanal; 26, 1-penten-3-ol; 27, 1-octen-3-ol; 28, 2-octen-1-ol; 29, 2,3-butanedione (diacetyl); 30, 3-hydroxy-2-butanone (acetoin); 31, 2-heptanone; 32, 2,3-octanedione; 33, 3-octanone; 34, toluene; 35, benzaldehyde; 36, 2-pentylfuran; 37, acetic acid (ethanoic acid); 38, butanoic acid (butyric acid); 39, dimethyl sulphone; 40, limonene; non-shaded area indicates Pearson correlation coefficients (r), grey shaded area indicates corresponding p-values for Pearson correlation coefficients (r); *all values in bold are significant at a level of $p<0.05$.

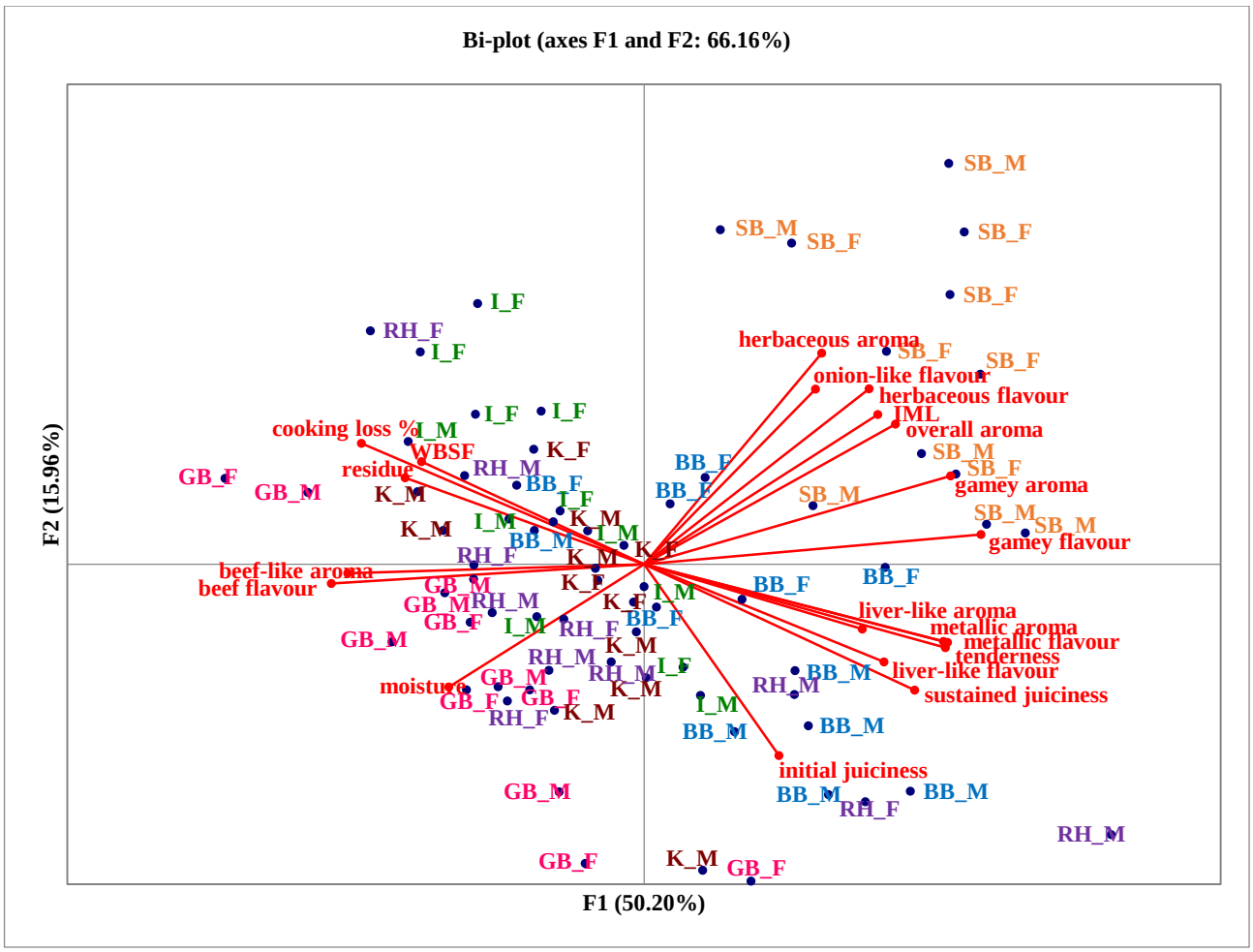

Figure 8.1 PCA bi-plot of selected physical measurements (WBSF, Warner-Bratzler shear force; and cooking loss %), proximate composition (moisture and IML, intramuscular lipid) and sensory attributes of the meat derived from female (F) and male (M) animals of six game species; SB, springbok; GB, gemsbok; BB, blesbok; I, impala; RH, red hartebeest; K, kudu. See Table 8.4 for listed attributes.

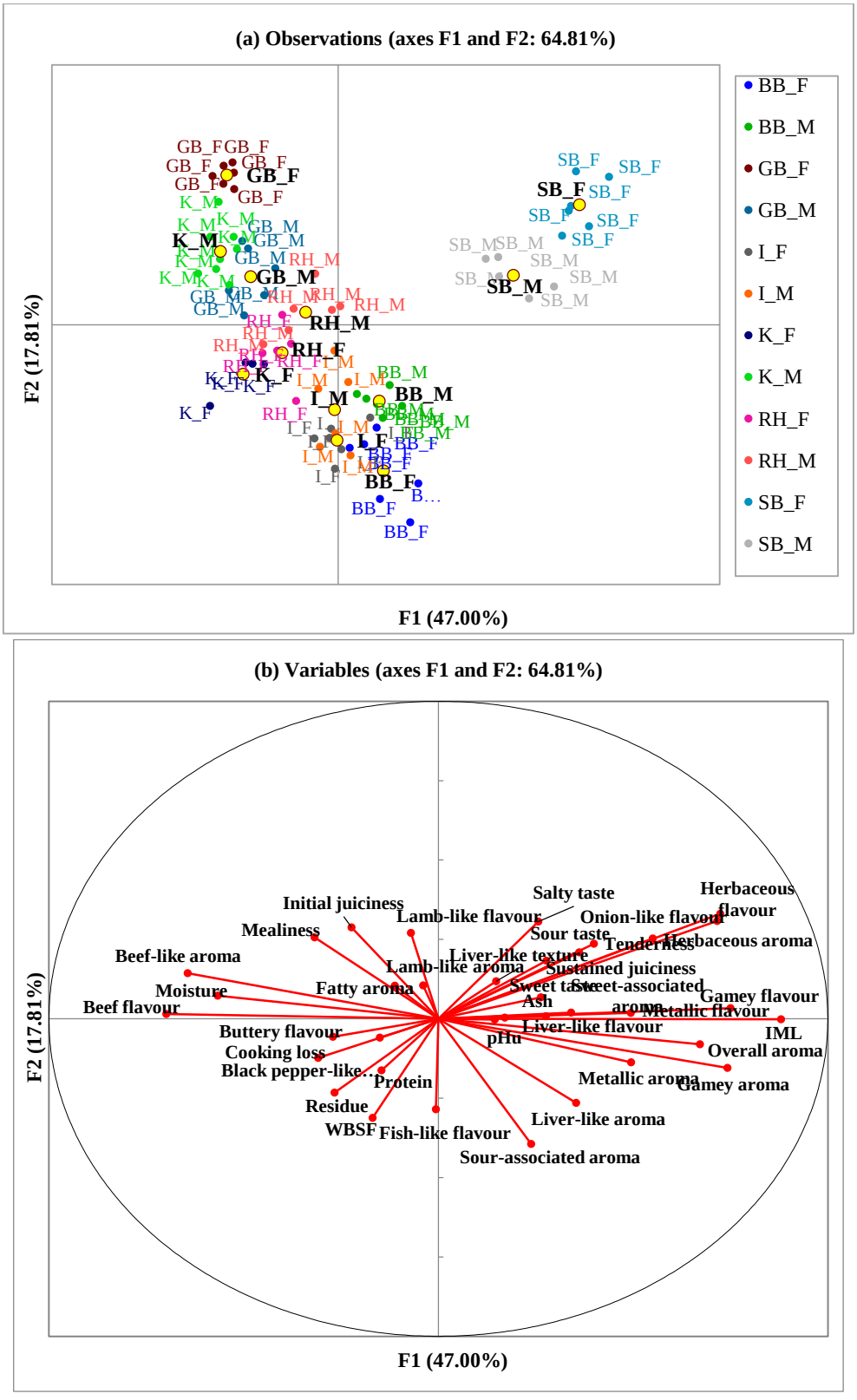

Figure 8.2 DA plot of the (a) mean observations (gender per species) of the meat derived from six game species (BB_F, blesbok female; BB_M, blesbok male; GB_F, gemsbok female; GB_M, gemsbok male; I_F, impala female; I_M, impala male; K_F, kudu female; K_M, kudu male; RH_F, red hartebeest female; RH_M, red hartebeest male; SB_F, springbok female; SB_M, springbok male), with regard to all variables (b) used for the classification of the observations. See Table 8.3 for listed attributes (variables).

A further PCA bi-plot (Fig. 8.3a) was compiled using the average values for the selected attributes, as listed in Table 8.7, of the meat derived from the six game species. The PCA bi-plot describes 61.25% of the variation between treatments, with PC1 and PC2 describing 41.20% and 20.05% of the variation between treatments, respectively (Fig. 8.3a). Fig. 8.3b illustrates the classification of the observations (gender per species) for the selected attributes (Table 8.7). The dietary preferences (Table 7.1) of the six species are indicated on Fig. 8.3b (Van Zyl, 1965; Bothma, 2002).

8.4 Discussion

8.4.1 Sensory quality

A PCA bi-plot (Fig. 8.1) provides an overview of the association between treatments (species and gender) and attributes. In this study the PCA bi-plot described 66.16% of the variation between treatments (species and gender) (Fig. 8.1), which is not classified as high, however, this is considered quite high for meat (especially game meat) which generally has a large amount of variability in its composition (Hoffman & Wiklund, 2006). The division along PC1 is largely attributed to the association of treatments with beef-like aroma and flavour, moisture content (including cooking loss %) and texture attributes (WBSF and residue) on the left, while the attributes gamey, metallic, liver-like and herbaceous aroma and flavour, as well as texture attributes (initial and sustained juiciness and tenderness) associate with treatments on the right (Fig. 8.1).

The meat derived from female and male gemsbok were grouped together in the bottom left quadrant of the PCA bi-plot and associated with beef-like aroma and flavour, cooking loss %, moisture content, WBSF and residue (Fig. 8.1). The latter was supported by the higher ($p<0.05$) moisture content for gemsbok meat derived from female and male animals (Table 8.5), as well as the higher ($p<0.01$) beef-like aroma and flavour and cooking loss % ($p<0.10$) for gemsbok meat when compared to the other species (Table 8.6). The meat derived from female and male impala, red hartebeest and kudu were more or less grouped on the left side of the PCA bi-plot and therefore also associated with the attributes on the left (Fig. 8.1).

Conversely, the meat derived from female and male springbok were grouped together in the top right quadrant of the PCA bi-plot and therefore associated with the attributes on the right side of the PCA bi-plot, such as gamey, overall aroma, metallic, liver-like, herbaceous aroma and flavour, onion-like flavour, sustained juiciness, tenderness and IML content (Fig. 8.1). The latter associations were confirmed by the significantly higher IML content of the meat derived from female and male springbok (Table 8.5), in addition to significantly higher mean values for overall aroma, gamey, metallic, liver-like, herbaceous aroma and flavour, onion-like flavour, sustained juiciness and tenderness of springbok meat as compared to the other species (Table 8.6). The meat derived from female and male blesbok were grouped in the bottom right quadrant of the PCA bi-plot and therefore associated with metallic and liver-like aroma and flavour attributes, in addition to sustained juiciness and tenderness (Fig. 8.1). The mean values of these sensory attributes were all significantly higher for blesbok meat, as compared to the meat derived from gemsbok, impala, red hartebeest and kudu (Table 8.6).

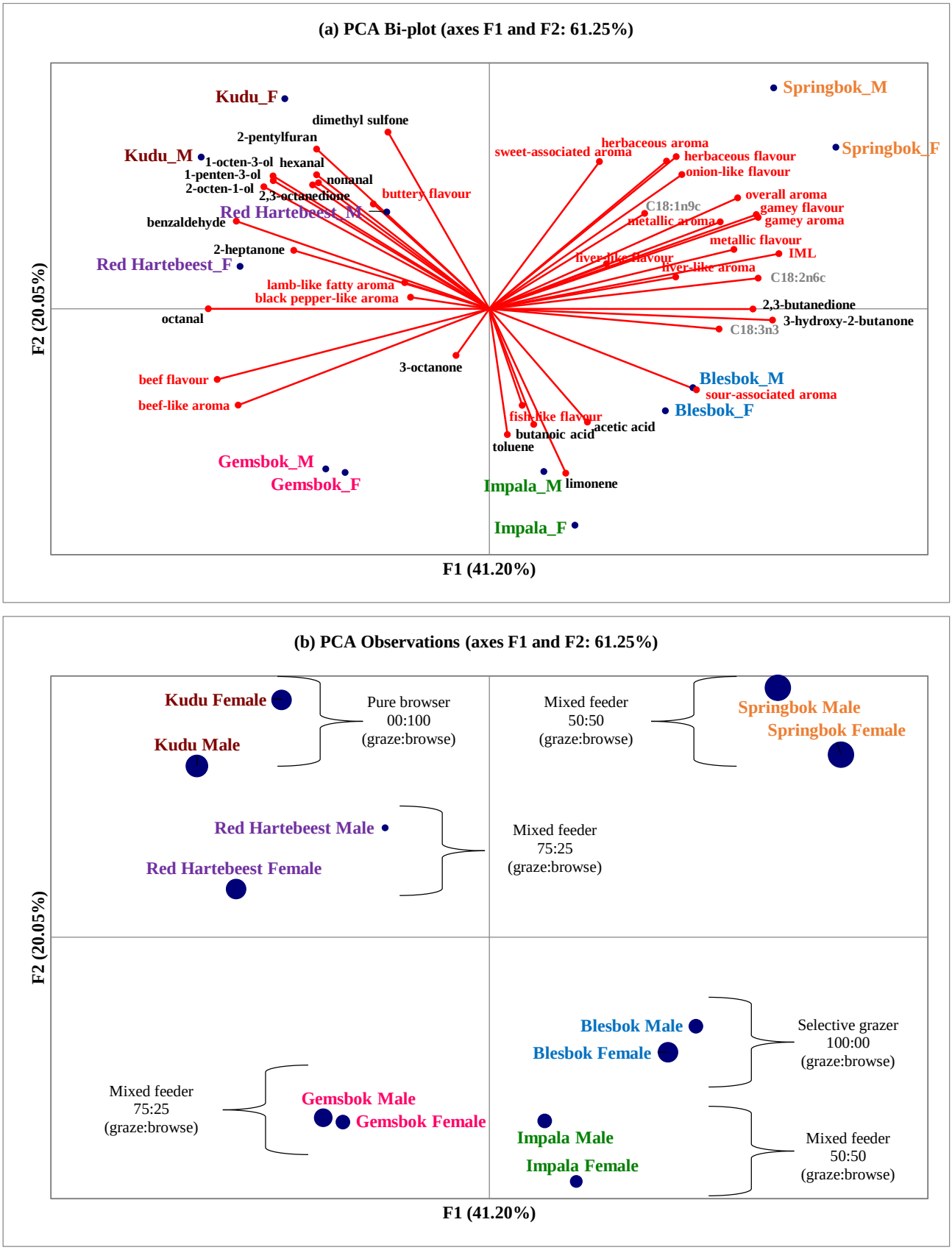

Figure 8.3 (a) PCA bi-plot of the intramuscular lipid content and selected sensory attributes, fatty acids and volatile compounds of the meat derived from female and male animals of six game species: Springbok; Gemsbok; Blesbok; Impala; Red hartebeest; Kudu; and (b) the mean observations (gender per species). See Table 8.7 for listed attributes.

Springbok meat was therefore very different from the other species, although blesbok meat was also associated with a number of attributes of the right side of the PCA bi-plot (Fig. 8.1). This can also be noted on the DA plot (Fig. 8.2a), where the meat derived from female and male springbok were present on the right side of the DA plot. The blesbok meat (female and male) was situated closest to springbok, but also in close proximity to meat derived from female and male animals of the other four game species which were grouped together on the left side of the DA plot. It is therefore clear from the DA plot that springbok meat was classified very differently when compared to game meat derived from the other five species (Fig. 8.2a and b). Furthermore, it can be noted that the influence of gender on the physical measurements, proximate composition and sensory profile of game meat was species-specific (Table 8.5, Fig. 8.2a). Gender also seemed to have an influence on the above-mentioned attributes for the meat derived from springbok, gemsbok, blesbok and kudu as the observations for these species were grouped together on the DA plot (Fig. 8.2a).

Although the pHu of the meat derived from female and male springbok differed ($p<0.05$), the differences are not of biological relevance, as both genders' pHu values (5.7 and 5.5, respectively) are considered within the 'normal' range of 5.3 to 5.8 (Honikel, 2004). Blesbok meat derived from male animals had a higher ($p<0.05$) moisture content, but lower ($p<0.05$) protein content as compared to the meat derived from female blesbok (Table 8.5). Neethling *et al.* (2014) found a strong negative correlation between the moisture and protein content of blesbok meat ($r = -0.820$; $p<0.05$), however, no gender differences were present in the latter study. Nonetheless, the inverse moisture and protein content in the meat derived from female and male blesbok (Table 8.5) could be attributed to the negative correlation between these attributes as found by Neethling *et al.* (2014). In this study, the moisture and protein content were moderately correlated ($r = -0.576$; $p<0.0001$), however, a slightly stronger correlation existed between the moisture and IML content ($r = -0.628$; $p<0.0001$) (Table 8.4). The latter was also visible on the PCA bi-plot, as IML content was situated on the right and was therefore negatively associated with moisture content on the left (Fig. 8.1). The IML content is generally negatively correlated to the moisture content in the meat derived from domesticated species (Keeton & Eddy, 2004; Legako *et al.*, 2015), however, as game meat generally contains low levels of IML (Table 8.5; Hoffman & Wiklund, 2006) this negative correlation is often not as prevalent. Consequently, negative correlations between the moisture and protein content of game meat are often more prevalent.

The IML content of the meat derived from female impala was higher ($p<0.10$) than the meat from male impala (Table 8.5). Hoffman *et al.* (2009a) also found a higher IML content for impala meat derived from females (2.40 g.100 g^{-1}) as compared to males (2.06 g.100 g^{-1}). The meat derived from female wild species often contain higher levels of IML as compared to males (Hoffman *et al.*, 2005; Renecker *et al.*, 2005; Sampels *et al.*, 2005; Hoffman *et al.*, 2007a, 2009c), however, this was only evident for impala meat in this study. Nonetheless, the IML content of the meat derived from female and male animals from all game species in this study can be classified as low (<3.0 g.100 g^{-1}), according to South African regulations (Anon., 2010).

Selected sensory attributes differed significantly between genders (specific to species), such as sweet-associated aroma (red hartebeest and kudu), sour taste (impala), salty taste (kudu), buttery flavour (kudu), fish-like flavour (impala) and mealiness (impala and red hartebeest) (Table 8.5), in addition to herbaceous aroma

and sweet taste. However, the mean ratings of these attributes were extremely low (<10.0) on the unstructured line scale (zero to 100) used for DSA (Table 8.5) and it can therefore be postulated that the presence of these attributes could possibly be regarded as being negligible, especially regarding consumer perception.

The cooking loss % of game meat in this study was negatively correlated to the sustained juiciness ($r = -0.837$; $p<0.0001$), which means that higher quantities of moisture lost during cooking resulted in a reduced perception of juiciness of the meat during mastication. However, Hoffman *et al.* (2010) found no significant correlation between the cooking loss % and sustained juiciness of blesbok meat ($r = -0.120$; $p>0.05$). Cooking causes changes in the structure of meat, thereby decreasing the water-holding capacity (WHC) (Tornberg, 2005). Yet the inherent WHC of the meat derived from the various game species could have been different (Hughes *et al.,* 2014), which could possibly have resulted in the differences in the cooking loss % and consequently the sustained juiciness between species (Table 8.6). Unfortunately, the WHC of the species meat was not determined in this study.

Rødbotten *et al.* (2004) found significant differences in the sensory tenderness of the meat derived from 15 species in Norway. The sensory tenderness of game meat in this study also differed ($p<0.01$) between species. Springbok and blesbok meat were associated with higher sensory tenderness, whereas the meat from the four other game species (gemsbok, impala, red hartebeest and kudu) where negatively associated with sensory tenderness, but positively associated with WBSF (higher value indicating less tender meat) (Fig. 8.1). The latter was confirmed by the significant differences in the mean values for sensory tenderness and WBSF between species (Table 8.6). The sensory tenderness, as measured by a trained panel during DSA, is often best correlated with WBSF (Tornberg, 1996). The latter was evident in this study, as sensory tenderness was negatively correlated to WBSF (instrumental tenderness) ($r = -0.791$; $p<0.0001$) (Table 8.4). Impala meat, for example, had the lowest mean value for sensory tenderness and correspondingly highest WBSF, indicating that impala meat was the least tender of the species meat in this study (Table 8.6). A reasonably strong negative correlation also existed between the sensory tenderness and WBSF of springbok meat in Chapter 4 ($r = -0.710$; $p<0.05$), while this negative correlation was moderate ($r = -0.536$; $p<0.05$) for blesbok meat in Chapter 6. Hoffman *et al.* (2007b) also found a strong negative correlation between the sensory and instrumental tenderness (WBSF) of springbok meat ($r = -0.700$; $p<0.01$). However, Hoffman *et al.* (2009b) found no significant correlation between the latter attributes for impala and kudu meat ($r = -0.230$; $p>0.05$).

Consumers will often wrongly perceive a ‘dry’ meat product as being less tender (Miller, 2004); this phenomenon is referred to as the so-called ‘halo’ effect. The latter is due to the influence of moisture content of meat on tenderness perception during mastication (Hughes *et al.,* 2014). The sensory tenderness of the meat derived from the various game species in this study was positively correlated to sustained juiciness ($r = 0.744$; $p<0.0001$) (Table 8.4). The higher juiciness of springbok and blesbok meat could therefore have attributed to higher mean values for sensory tenderness (Table 8.6).

Destefanis *et al.* (2008) classified WBSF values of >52.68 N and <42.87 N as being tough and tender, respectively. In this study the meat derived from springbok, blesbok, red hartebeest and kudu can therefore be classified as tender, whereas gemsbok meat is intermediate in tenderness and impala meat is classified as tough

(Table 8.6). Residue was described as the 'residual tissue remaining after mastication' (Table 8.2) and therefore classified as the opposite of sensory tenderness, as was evident from the negative association of these two sensory attributes on Fig. 8.1, which was verified by a strong negative correlation ($r = -0.893$; $p<0.0001$) (Table 8.4). Impala meat had the lowest sensory tenderness as well as the highest mean value for residue (Table 8.6). It was noticed that impala meat had a very tightly packed muscle fibre structure compared to the meat derived from the other game species which may have contributed to a very dense texture which could adversely influenced the shearing of the meat during mastication and therefore negatively influenced the sensory tenderness and WBSF; this aspect warrants further research.

A strong positive correlation ($r = 0.891$; $p<0.0001$) existed between overall aroma intensity and gamey aroma of the meat derived from the six game species (Table 8.4). The overall aroma, described as the 'intensity of aroma in the first few sniffs' (Table 8.2), can therefore be used as a good indicator of the gamey aroma of the meat derived from game species in this study. The overall and gamey aroma intensities for springbok, blesbok, impala and kudu meat in this study were higher than those found in previous studies involving descriptive sensory analysis (Hoffman *et al.*, 2009b; North & Hoffman, 2015; Chapters 4 and 6). Springbok meat was associated with the sensory attributes overall aroma and gamey aroma (Fig. 8.1) which was confirmed by the significantly higher mean values of these two attributes for springbok meat, as compared to the meat derived from the other game species (Table 8.6). Van Schalkwyk *et al.* (2011) also found that springbok salami had the highest ($p<0.05$) gamey aroma and flavour and therefore differed the most from salamis produced from gemsbok, kudu and zebra meat.

Gamey aroma was associated with gamey flavour (Fig. 8.1). This was verified by the strong positive correlation between the latter two sensory attributes ($r = 0.812$; $p<0.0001$) (Table 8.4). Moreover, gamey flavour was the flavour attribute present at the highest intensity in game meat in this study (Table 8.6). Intramuscular lipids are generally regarded as primary drivers of meat flavour (Melton, 1990). Springbok meat had the highest gamey flavour intensity (Table 8.6), as well as the highest IML content (Table 8.5) as compared to the other species. Moreover, a reasonably strong positive correlation existed between gamey flavour and IML content ($r = 0.645$; $p<0.0001$) (Table 8.4). The latter positive correlation was not found for springbok and blesbok meat in Chapters 4 and 6, respectively. Nonetheless, Hoffman *et al.* (2009b) found such a correlation between the gamey flavour and IML content for impala and kudu meat. It can therefore be accepted that gamey flavour intensity of game meat derived from the species included in this study will increase with an increase in the IML content.

Gamey flavour in this study was also associated with metallic and liver-like flavour (Table 8.2; Fig. 8.2). A strong and moderate positive correlation existed between gamey flavour and metallic (0.834; $p<0.0001$) and liver-like ($r = 0.608$; $p<0.0001$) flavour, respectively (Table 8.4). Gamey flavour of game meat used in this study was therefore linked to metallic and liver-like flavour attributes. The meat derived from female and male springbok had the highest mean values for gamey, metallic and liver-like attributes (Table 8.6; Fig. 8.2), as well as a slight sour taste (Table 8.5).

As mentioned, the meat derived from female and male springbok was associated with herbaceous aroma and flavour, as well as onion-like flavour. This was confirmed by the higher ($p<0.01$) mean values of these attributes in springbok meat as compared to the meat derived from the other game species. Furthermore, herbaceous aroma and flavour were strongly correlated ($r = 0.828$; $p<0.0001$), while herbaceous flavour and onion-like flavour were less strongly correlated ($r = 0.662$; $p<0.0001$) (Table 8.4). The onion-like flavour was thought to be specific to the farm location where springbok where harvested for this study.

In this study the major sensory attributes contributing to the sensory profile of game meat were identified as overall aroma, gamey aroma and flavour, initial and sustained juiciness, and tenderness. Beef-like and metallic aroma and flavour were intermediate contributors, while the rest of the sensory attributes (Table 8.2) were minor contributors to the overall sensory profile of game meat. Nonetheless, all identified attributes (physical measurements, proximate composition and sensory profile) were important contributors to the classification of the meat derived from the six game species as indicated in the DA plots (Fig. 8.2a and b). However, the 'gamey' aroma and flavour of game meat can be regarded as an 'acquired taste' and there is evidence that some consumers prefer non-gamey meat flavours associated with commercially available meat products derived from domesticated species (Pollock, 1969; Hoffman, 2007). Furthermore, metallic and liver-like flavour attributes of meat, in addition to fatty, rancid, oxidised, fishy and sour attributes, are often perceived as off-aroma or flavours (Nuernberg *et al.*, 2005; Meisinger *et al.*, 2006; Rincker *et al.*, 2006; Calkins & Hodgen, 2007). All of these, especially metallic and liver-like flavour notes, i.e. especially associated with springbok meat in this study, could potentially have an initial negative impact on consumer preference of game meat.

8.4.2 Game meat aroma and flavour

The second PCA bi-plot (Fig. 8.3a) was compiled containing IML, selected sensory (aroma and flavour) attributes, in addition to selected fatty acids (C18:1n9c, oleic acid; C18:2n6c, linoleic acid; C18:3n3, α-linolenic acid) and volatile compounds (hexanal, octanal, nonanal, 1-penten-3-ol, 1-octen-3-ol, 2-octen-1-ol, 2,3-butanedione, 3-hydroxy-2-butanone, 2-heptanone, 2,3-octanedione, toluene, benzaldehyde, 2-pentylfuran, acetic acid, butanoic acid, dimethyl sulphone, limonene) as determined in Chapter 7. The selection of attributes included in the PCA bi-plot (Fig. 8.3a) was based on those attributes that have and/or could specifically impact on the aroma and/or flavour of game meat derived from the six species. As taste attributes are primarily defined by non-volatile compounds (salts, free amino acids, peptides, nucleotides, etc.) perceived at different areas on the tongue (Shahidi, 1998), these attributes were not included in Fig. 8.3a. Furthermore, the texture-related sensory attributes, in addition to the physical attributes (cooking loss %, pHu and WBSF) and selected proximate measurements (moisture, protein and ash) were also excluded from this PCA bi-plot (Fig. 8.3a), as these parameters do not contribute directly towards meat aroma and flavour. The three fatty acids included in Fig. 8.3a, e.g. C18:1n9c (oleic acid), C18:2n6c (linoleic acid) and C18:3n3 (α-linolenic acid) are precursors for the formation of the lipid-derived volatile compounds such as aldehydes, alcohols, ketones, benzene compounds and furans (Mottram, 1985; Elmore *et al.*, 1999; Blank *et al.*, 2001; Belitz *et al.*, 2009; Lorenzo,

2014; Marušić *et al.*, 2014). Volatile compounds with low odour threshold values (as deduced from previous research on meat products) and those compounds that have previously been linked to specific aroma descriptions of meat products (Table 7.5) were also included in the PCA bi-plot (Fig. 8.3a).

As the associations between the sensory attributes and treatments (gender per species) have been discussed according to Fig. 8.1, they will not be discussed in detail again for Fig. 8.3a. The meat derived from springbok, blesbok and impala were associated with sensory and chemical attributes on the right side of the PCA bi-plot, while the meat derived from kudu, red hartebeest and gemsbok were associated with the sensory and chemical attributes on the left side of the plot (Fig. 8.3a). However, the majority of the associations between the sensory and chemical attributes, as well as with the treatments (species by gender) were coincidental, as only a few of these were significantly correlated (Table 8.7). Nonetheless, a strong positive correlation existed between the sensory attribute buttery flavour with 2-pentylfuran and dimethyl sulphone ($r = 0.697$; $p = 0.012$ and $r = 0.694$; $p = 0.012$, respectively) (Table 8.7; Fig. 8.3a). 2-Pentylfuran is a compound previously linked to butter-like aroma and/or flavour characteristics in beef (Calkins & Hodgen, 2007). However, dimethyl sulphone has only been associated with sulphur and burnt aroma characteristics, but not specifically linked to the aroma of cooked meat (Acree & Arn, 2004). The sensory attribute buttery flavour was highest ($p<0.01$) in the meat derived from female followed by male kudu, while the average values of this attributes in the meat derived from the other four species was zero (Table 8.5). Furthermore, the percentage 2-pentylfuran was also highest ($p<0.01$) for kudu meat (Table 7.7). The latter volatile compound could therefore be responsible for the buttery flavour of kudu meat.

The sensory attributes beef-like aroma and beef flavour were associated with the volatile compound octanal (Fig. 8.3a). Octanal has been linked to a meat-like aroma description of dry-cured ham (García-González *et al.*, 2008, 2014). The mean values for beef-like aroma and beef flavour were highest ($p<0.01$) for gemsbok meat, followed by red hartebeest and kudu meat (Table 8.6), while octanal was present at the highest ($p<0.01$) percentage in red hartebeest and kudu, followed by gemsbok meat (Table 7.7). Nonetheless, octanal could be responsible for the higher beef-like aroma and flavour characteristics in the meat derived from gemsbok, red hartebeest and kudu, as compared to the other three game species. No volatile compounds were positively correlated to the sensory attributes lamb-like fatty aroma and black pepper-like aroma (Table 8.7) situated on the left side of the PCA bi-plot (Fig. 8.3a).

The volatile compounds 2,3-butanedione (diacetyl), 3-hydroxy-2-butanone (acetoin), acetic and butanoic acids, toluene and limonene were associated with the treatments and sensory attributes on the right side of the PCA bi-plot (Fig. 8.3a). 2,3-Butanedione (diacetyl) and 3-hydroxy-2-butanone (acetoin) were positively correlated to the sensory attributes gamey aroma ($r = 0.716$; $p = 0.009$ and $r = 0.781$; $p = 0.003$, respectively), herbaceous aroma ($r = 0.695$; $p = 0.012$ and $r = 0.604$; $p = 0.038$, respectively), gamey flavour ($r = 0.684$; $p = 0.014$ and $r = 0.742$; $p = 0.006$, respectively), herbaceous flavour ($r = 0.684$; $p = 0.014$ and $r = 0.613$; $p = 0.034$, respectively) and onion-like flavour ($r = 0.661$; $p = 0.019$ and $r = 0.661$; $p = 0.019$, respectively) (Table 8.7). The mean values of the latter sensory attributes were highest ($p<0.01$) for springbok meat (Table 8.6). Moreover, the percentages of 2,3-butanedione (diacetyl) and 3-hydroxy-2-butanone (acetoin) were highest

($p<0.05$) for springbok meat derived from female animals (Table 7.6). However, the latter two volatile compounds have been associated with aroma descriptions such as sweet, butter, caramel, rotten, vanilla, cream, lactic, fruity, diacetyl, yoghurt, fat, sweaty and sour (Table 7.5), none of which can directly be linked to gamey, herbaceous or onion-like characteristics of game meat in this study. Consequently, the correlations between 2,3-butanedione (diacetyl) and 3-hydroxy-2-butanone (acetoin) and the above-mentioned sensory attributes is postulated to be coincidental.

Acetic acid has been associated with sour and vinegar aroma descriptions in beef and country ham (Kerler & Grosch, 1996; Berdagué *et al.*, 2007; Song & Cadwallader, 2008), however, no significant correlations existed between acetic acid and the sensory attribute sour-associated aroma of game meat in this study (Table 8.7). Instead, a strong positive correlation existed between acetic acid and the sensory attribute fish-like flavour ($r = 0.792$; $p = 0.002$) (Fig. 8.3a). The latter volatile compound and sensory attribute was present at the highest ($p<0.01$) mean values in the meat derived from female impala (Tables 7.5 and 8.5). Additionally, the volatile compound butanoic acid was also positively correlated to the sensory attribute fish-like flavour ($r = 0.941$; $p<0.0001$) (Table 8.7). However, similar to acetic acid, butanoic acid has not previously been associated with fish-like aroma or flavour characteristics of meat (Table 7.5). Acetic acid and/or butanoic acid could therefore be responsible for the fish-like flavour of game meat in this study, this association however requires further investigation. The volatile compounds toluene and limonene were not significantly correlated to any of the sensory attributes (Table 8.7).

A major drawback of comparing descriptive sensory analysis data with volatile compounds is that no information is available regarding the actual aroma description of the volatile compounds being compared with sensory attributes, this can only be established through more advanced GC research. Consequently, false conclusions can be drawn from positive associations and correlations between sensory and instrumental data (Chambers IV & Koppel, 2013). The latter should therefore be borne in mind with regard to the above-mentioned associations and correlations between the selected sensory attributes and volatile compounds of game meat in this study. Additionally, multiple volatile compounds can be responsible for a specific aroma and/or flavour attribute, while a combination of volatile compounds can yield very different aroma and/or flavour attributes in comparison to the individual compounds (Chambers IV & Koppel, 2013).

The variation described by the PCA bi-plot (Fig. 8.3a) is not considered high, however, it still gives enough of an indication that the meat derived from the six game species differ to some extent. This is specifically illustrated by Fig. 8.3b, which indicates that the grouping of the mean observations (Table 8.7) for the six game species (per gender) is separate from each other. The inclusion of the dietary information (ratio of grazing vs. browsing) of the six game species on Fig. 8.3b was aimed at identifying whether the sensory attributes and volatile compounds aided in grouping the six game species according to their dietary regimes (grazer, mixed feeder or browser). However, this was not achieved as clearly as anticipated; for example, the kudu a pure browser, was grouped together on the left side of the bi-plot with red hartebeest and gemsbok, which are two mixed feeders of which the diets consists of greater proportion of grazing than browsing (Fig. 8.3b). Additionally, the other two mixed feeders (springbok and impala) with more or less equal proportions of

grazing and browsing in their diets, were grouped together with the pure grazer (blesbok) on the right side of the bi-plot (Fig. 8.3b).

However, it could be argued that the impact of specific volatile compounds on the aroma and flavour of meat is not only linked to their concentrations and odour threshold values, but also to the potential interaction between these compounds, as well as with other chemical compounds found in meat. Furthermore, the impact of the latter factors is further confounded by various factors such as the temperature at which meat is 'cooked' during solid-phase microextraction (SPME) coupled with gas chromatography (GC) mass spectrometry (MS), for the identification of volatile compounds.

8.5 Conclusions

This study provides insight into the sensory quality of the meat derived from six South African game species, so as to prove that they differ from each other. It is therefore recommended, based on the results of this study, that the meat industry should take species into account during harvesting procedures (and marketing) for the commercial production of game meat.

The influence of gender on the sensory quality of game meat was species-specific. Nonetheless, the magnitude of the significant species-specific gender differences was small and it is debatable whether consumers will be able to notice these differences. Consequently, it is recommended that gender need not be taken into account during meat production/marketing from the six game species selected for this study. It should, however, be noted that the magnitude of the influence of species and gender on the sensory quality of game meat could possibly change when other factors come into play, i.e. a different combination of species (other game species than those used in this study), season (vegetation quantity and quality) and farm location (vegetation type, quantity and quality) and age of the animals.

Significant positive correlations existed between 2-pentylfuran and buttery flavour, octanal and beef-like aroma and flavour, and acetic and butanoic acids and fish-like flavour. These selected volatile compounds could be responsible for the above-mentioned aroma and/or flavour attributes of game meat in this study, however, these correlations could just be coincidental. Subsequently, verification of the associations and correlations between sensory and instrumental (volatile compound) data is required. The latter can be achieved by means of gas chromatographic-olfactometric (GC-O) analysis, a method which will establish which volatile compounds are aroma-active in game meat, in addition to establishing the specific aroma descriptions linked to such compounds.

8.6 References

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Chapter 9

General discussion and conclusions

The South African game industry has expanded immensely over the past years, outgrowing other agricultural enterprises such as the dairy and sugar industries (Gouws, 2015). However, the game meat industry still has great potential for growth. With the appropriate marketing and production of game meat, this industry can earn substantial revenue for South Africa, as well as contribute greatly to food security (Gouws, 2015). The South African game meat industry still faces some major challenges, such as a supportive government policy, a functioning game meat scheme and the infrastructure for the professional processing of suitably hunted (no excessive stress) game meat, so as to supply a constant flow of game meat that is of the best possible quality (Gouws, 2015). Yet South African consumers are generally uninformed about game meat, especially with regard to its quality, composition and sensory profile (Cloete *et al.*, 2015). An additional challenge for the development of a successful South African game meat industry is a lack of reliable, scientifically-based information on game meat products.

Game meat is generally derived from various farm locations, situated throughout southern Africa. Additionally, female and male animals of a variety of species are utilised for the commercial production of game meat. However, research on the influence of farm location on the chemical composition and sensory quality of game meat is very limited with most of the research having been done by Hoffman and co-workers (Hoffman *et al.*, 2005, 2007a, 2007b, 2007c, 2007d). Furthermore, research on the influence of species and gender on the chemical composition and sensory quality of the meat derived from a variety of South African game species is also limited (Van Zyl & Ferreira, 2004; Hoffman *et al.*, 2005, 2007a, 2007b, 2007c, 2007d; Mostert & Hoffman, 2007; Hoffman *et al.*, 2008, 2009a, 2009b, 2009c; Neethling *et al.*, 2014a, 2014b).

Two initial studies were therefore conducted to establish the influence of farm location and gender on the fatty acid content and volatile compound profile of the *longissimus thoracis et lumborum* (LTL) muscle derived from two popular and extensively harvested South African game species, springbok (*Antidorcas marsupialis*) and blesbok (*Damaliscus pygargus phillipsi*) (Chapters 3 and 5). A third study investigated the influence of species, as well as gender on the fatty acid content and volatile compound profile of the *longissimus thoracis et lumborum* (LTL) muscle derived from six economically important South African game species: springbok; blesbok; gemsbok (*Oryx gazella*); impala (*Aepyceros melampus*); red hartebeest (*Alcelaphus buselaphus caama*); and kudu (*Tragelaphus strepsiceros*) (Chapter 7). As fatty acids and volatile compounds play an important role in the development of meat aroma and flavour during cooking (Mottram, 1998; Pegg & Shahidi, 2004; Wood *et al.*, 2003, 2008), descriptive sensory analysis (DSA) was conducted so as to verify the impact of the above-mentioned treatments (farm location, species and gender) on the sensory profile of game meat (Chapters 4, 6 and 8).

Farm location and gender had a significant influence on the fatty acid content and volatile compound profile of springbok and blesbok meat in the first two studies (Chapters 3 and 5). Moreover, the fatty acid content and volatile compound profile also differed significantly for the meat derived from the six game species in the

third study (Chapter 7). However, the influence of gender on the fatty acid content and volatile compound profile in the third study was species-specific (Chapter 7). It was therefore postulated that the differences in the fatty acid content and volatile compound profile between farm locations, species and genders could have a significant effect on the sensory profile of game meat. The sensory quality of game meat in this study was defined by selected physical attributes (thaw and cooking loss %, ultimate pH and Warner-Bratzler shear force), proximate composition (moisture, protein, intramuscular lipid and ash), as well as the full sensory profile. Farm location had a significant influence on the sensory quality of springbok meat, although the influence of gender was minor in this study (Chapter 4). Conversely, farm location had a minor influence on the sensory quality of blesbok meat, while the influence of gender was more pronounced (Chapter 6). The contradicting effect of farm location on the sensory quality of the meat derived from springbok and blesbok can be attributed to their individual dietary regimes. As springbok are mixed feeders (Van Zyl, 1965), the dietary regime of springbok could differ greatly between farm locations, especially if the farms are situated in different biomes (vegetation types) (Chapter 4; Mucina & Rutherford, 2006). Blesbok are very selective, pure grazers with a smaller amount of variation in their preferred food sources (dietary regime) between farm locations (Du Plessis, 1972; Bothma *et al.*, 2010; Chapter 6). Furthermore, the influence of gender in the first two studies was contradictory and it was postulated that this is as a result of differences in the behaviour of springbok and blesbok during the mating season (Chapters 4 and 6). The significant differences in the sensory quality of blesbok meat derived from female and male animals were attributable to the mating season and the territorial nature of male blesbok (Lynch, 1971). Additionally, the sensory quality of the meat derived from the six game species in the third study, differed from each other, however, the influence of gender was species-specific (Chapter 8).

It is therefore recommended that farm location be taken into account when harvesting springbok, but not blesbok, for game meat production purposes. In addition, the South African game meat industry should also take species from which the meat is derived into account with the marketing of game meat. Gender does not have to be considered for game meat production, as it was postulated that the magnitude of the species-specific gender differences in the sensory quality of game meat could possibly not be detected by the general game meat consumer. However, the magnitude of the influence of farm location, species and gender on the composition and sensory quality of game meat could possibly change when other factors come into play, i.e. a different combination of species (other game species than those used in this study), farm location (vegetation type, quantity and quality) and season (vegetation quantity and quality).

This research allows for the comparison of the chemical composition of springbok (farm A) and blesbok (farm B) that were harvested in autumn (April and May, respectively) for the first two trials (Chapters 3 and 4; and Chapters 5 and 6, respectively), with the springbok and blesbok that were harvested mid-winter (July) for the third (species) trial (Chapters 7 and 8) from the same farms. For this comparison, the proximate composition (g.100 g^{-1}; moisture, protein, intramuscular lipid and ash), three important fatty acids (mg.g^{-1} of meat; C18:1n9c, oleic acid; C18:2n6c, linoleic acid; and C18:3n3, α-linolenic acid), as well as the fatty acid totals (saturated fatty acids, SFA; monounsaturated fatty acids, MUFA; and polyunsaturated fatty acids,

PUFA) and ratios (polyunsaturated to saturated fatty acid, PUFA:SFA; and omega-6 to omega-3 polyunsaturated fatty acid, n6:n3 PUFA) of springbok and blesbok meat were used (Tables 9.1 and 9.2, respectively).

Table 9.1 Influence of season on the proximate composition (g.100 g^{-1}), the content of selected fatty acids (mg.g^{-1} of meat) and the fatty acid totals and ratios of springbok meat derived from farm A (Means ± SE)

	April (Autumn)	**July (mid-Winter)**
Proximate composition		
Moisture content	73.2^{b} ± 0.239	74.6^{a} ± 0.239
Protein content	22.6^{a} ± 0.201	21.7^{b} ± 0.201
IML content	3.0^{a} ± 0.126	2.8^{a} ± 0.115
Ash content	1.2^{a} ± 0.010	1.2^{a} ± 0.010
Fatty acids		
C18:1n9c	5.3^{a} ± 0.521	6.1^{a} ± 0.497
C18:2n6c	5.1^{a} ± 0.441	4.8^{a} ± 0.441
C18:3n3	1.3^{a} ± 0.109	1.0^{a} ± 0.114
Fatty acid totals		
SFA	16.8^{a} ± 1.163	12.4^{b} ± 1.219
MUFA	5.7^{a} ± 0.542	6.6^{a} ± 0.490
PUFA	9.2^{a} ± 0.801	8.9^{a} ± 0.763
Fatty acid ratios		
PUFA:SFA	0.6^{a} ± 0.094	0.8^{a} ± 0.094
n6:n3 PUFA	3.3^{b} ± 0.159	4.0^{a} ± 0.151

$^{a-b}$Means within a variable with superscripts that do not have a common letter indicate significant differences ($p<0.05$) between seasons; SE, standard error; IML, intramuscular lipid; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

The rainfall at farm A, where springbok were derived from in different seasons (Table 9.1), primarily (>66%) occurred in the summer months between October and April with a peak from January to March (Kruger, 2007). The quality of the vegetation at farm A would therefore have been at its best near the end of the wet season and gradually decreased throughout the winter months. The protein and total SFA content of springbok meat was significantly higher in autumn as compared to winter, while the n6:n3 PUFA ratio was lower in autumn (Table 9.1). The seasonal differences in the protein and total SFA content of springbok meat could be attributed

to the fact that springbok harvested in autumn had a higher plane of nutrition as compared to mid-winter (Table 9.1). Furthermore, the seasonal differences in the n6:n3 PUFA ratio could be attributed to seasonal differences in the dietary regime (graze:browse ratio) of springbok, as Van Zyl (1965) suggested that grazing (high in C18:3n3, α-linolenic acid) is of greater importance to springbok during the wet season, while shrubs and leaves from bushes (browsing) are preferred during the dry season.

Table 9.2 Influence of season on the proximate composition (g.100 g^{-1}), the content of selected fatty acids (mg.g^{-1} of meat) and the fatty acid totals and ratios of blesbok meat derived from farm B (Means ± SE)

	May (Autumn)	**July (mid-Winter)**
Proximate composition		
Moisture content	74.5^{b} ± 0.244	75.8^{a} ± 0.244
Protein content	22.6^{a} ± 0.257	20.4^{b} ± 0.257
IML content	2.2^{b} ± 0.127	2.8^{a} ± 0.127
Ash content	1.2^{a} ± 0.015	1.1^{b} ± 0.015
Fatty acids		
C18:1n9c	2.4^{a} ± 0.424	3.1^{a} ± 0.424
C18:2n6c	4.7^{a} ± 0.440	5.5^{a} ± 0.420
C18:3n3	1.7^{b} ± 0.134	2.1^{a} ± 0.134
Fatty acid totals		
SFA	10.0^{b} ± 0.733	12.8^{a} ± 0.699
MUFA	2.9^{a} ± 0.415	3.4^{a} ± 0.397
PUFA	9.8^{b} ± 0.727	11.9^{a} ± 0.693
Fatty acid ratios		
PUFA:SFA	1.0^{a} ± 0.100	1.0^{a} ± 0.095
n6:n3	2.7^{a} ± 0.084	2.8^{a} ± 0.080

$^{a-b}$Means within a variable with superscripts that do not have a common letter indicate significant differences ($p<0.05$) between seasons; SE, standard error; IML, intramuscular lipid; SFA, total for saturated fatty acids = sum of C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0; MUFA, total for monounsaturated fatty acids = sum of C14:1n9c, C15:1n9t, C16:1n7, C18:1n9c, C18:1n9t, C20:1n9, C22:1n9 and C24:1n9; PUFA, total for polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3; PUFA:SFA ratio, polyunsaturated to saturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C18:3n3, C20:2n6, C20:3n6, C20:3n3, C20:4n6, C20:5n6, C22:2n6 and C22:6n3)/(C14:0, C15:0, C16:0, C18:0, C20:0, C21:0, C22:0, C23:0 and C24:0); n6 PUFA, total for omega-6 polyunsaturated fatty acids = sum of C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6; n3 PUFA, total for omega-3 polyunsaturated fatty acids = sum of C18:3n3, C20:3n3n, C20:5n3 and C22:6n3; n6:n3 PUFA ratio, omega-6 to omega-3 polyunsaturated fatty acid ratio = sum of (C18:2n6c, C18:2n6t, C18:3n6, C20:2n6, C20:3n6, C20:4n6 and C22:2n6)/(C18:3n3, C20:3n3n, C20:5n3 and C22:6n3).

At farm B, where blesbok were derived from different seasons (Table 9.2), it rained more or less throughout the year, with the majority (>66%) of the precipitation occurring between April and September in addition to receiving some rainfall in summer (December to February) and autumn (March to May) (Acocks & Momberg, 1988; Rebelo, 1996; Rutherford *et al.*, 2006; Kruger, 2007). The quality (nutritional value) of the grazing

should therefore have been higher in winter, after a substantial amount of precipitation. The IML, C18:3n3 (α-linolenic acid) and total SFA and PUFA content of blesbok meat were significantly higher in mid-winter as compared to autumn (Table 9.2). It was postulated that blesbok had a higher plane of nutrition in mid-winter and therefore stored more IML, in addition to total SFA and PUFA (Table 9.2). Springbok and blesbok meat therefore had seasonal differences in the chemical composition of the meat, which could in turn affect the volatile compound profile and sensory quality of game meat derived from these species.

The PUFA:SFA and n6:n3 PUFA ratios are important considerations when considering the nutritional properties of meat. The PUFA:SFA ratios of the meat derived from all game species, except for female springbok in the first study (Chapter 3), was above the recommended value of 0.7 (Wood *et al.*, 1999; Raes *et al.*, 2004; Chapters 3, 5 and 7). The higher PUFA:SFA ratios of the meat derived from female springbok (Chapter 3) was attributed to a higher content of total SFA and a lower content of total PUFA. Nonetheless, the n6:n3 PUFA ratios of the meat derived from all game species in this study was below the recommended values of 4.0 (Wood *et al.*, 1999; Raes *et al.*, 2004; Chapters 3, 5 and 7). Furthermore, the IML content of game meat derived from springbok (Chapters 4 and 8; excluding females from the first trial), blesbok (Chapters 6 and 8), gemsbok, impala, red hartebeest and kudu (Chapter 8) was <3.0 g.100 g^{-1}. Game meat derived from the species in this study (with the exception of female springbok of the first study - Chapters 3 and 4) can therefore be classified as being healthy, with regard to the fatty acid content (Wood *et al.*, 1999; Raes *et al.*, 2004), as well as being low in fat (<3.0 g.100 g^{-1}) according to South African regulations (Anon., 2010).

Descriptive sensory analysis is a sensory testing method to determine the sensory profile of a food product by using all of its perceived sensory attributes (Murray *et al.*, 2001) and not only selected attributes. Previous studies investigating the sensory profile of the meat derived from South African game species have made use of DSA, however, only a limited number of sensory attributes were used (Hoffman *et al.*, 2007d, 2009b, 2010; North & Hoffman, 2015). In this study, a significantly larger number of aroma, flavour, taste and texture attributes were included in the DSA of game meat derived from the different farm locations (N = 24) and species (N = 29) (Chapters 4, 6 and 8). Gamey aroma dominated the overall aroma intensity (Chapters 4, 6 and 8). Furthermore, overall aroma, gamey aroma and flavour, initial and sustained juiciness and tenderness were identified as major sensory attributes contributing to the sensory profile of game meat investigated in this study, as based on their presence at notably high intensities (Chapters 4, 6 and 8). Sensory attributes such as beef-like and metallic aroma and flavour were intermediate contributors, while attributes such as liver-like, sweet- and sour-associated, herbaceous, lamb-like, lamb-like fatty and black pepper-like aroma; liver-like, lamb, herbaceous, onion-like, buttery and fish-like flavour; sour, sweet and salty taste; residue, mealiness and liver-like texture were minor contributors to the sensory profile of game meat investigated in this study (Chapters 4, 6 and 8). All of these sensory attributes, whether present at high, moderate or low intensities, contributed to the overall species-specific sensory profile of the respective game species. Based on the species used in this study, it seems that when considering only aroma and flavour sensory attributes, blesbok and especially springbok associate strongly with the ‘gamey’ characteristics, whereas the sensory profile of the other four game species are less ‘gamey’.

Tenderness is an important sensory quality attribute of meat (Wood *et al.*, 1999). A strong negative correlation ($r = -0.710$; $p<0.05$) existed between the sensory and instrumental tenderness (Warner-Bratzler shear force) of springbok meat (Chapter 4), indicating that instrumental tenderness values could be used to determine the toughness/tenderness of springbok meat with reasonable accuracy. However, a moderate negative correlation ($r = -0.536$; $p<0.05$) existed between the sensory and instrumental tenderness of blesbok meat, which means that instrumental tenderness might not always be as good of an indicator of the sensory toughness/tenderness of blesbok meat (Chapter 6). Nonetheless, a strong negative correlation ($r = -0.791$; $p<0.0001$) existed between the sensory and instrumental tenderness of the meat derived from the six game species (Chapter 8). In view of these results, Warner-Bratzler shear force can therefore be regarded as a good indicator of the sensory toughness/tenderness of game meat derived from the six species utilised in this study. Furthermore, Destefanis *et al.* (2008) classified WBSF values >52.68 N and <42.87 N as being tough and tender, respectively. As a result, the meat derived from springbok, blesbok, red hartebeest and kudu can be classified as tender, whereas gemsbok meat is intermediate in tenderness and impala meat is classified as tough (Chapter 8).

In the sensory studies, attempts were made at comparing DSA data with instrumental data (volatile compounds) (Chapters 4, 6 and 8). However, a major drawback of the latter comparisons is that no information was available on the actual aroma descriptions of the volatile compounds that were compared to specific sensory attributes. This was a limitation in this study as invalid conclusions can be drawn from positive associations and correlations between sensory and instrumental data (Chambers IV & Koppel, 2013). The use of gas chromatographic-olfactometry (GC-O) analysis will be valuable in establishing which volatile compounds are aroma-active in game meat and what their respective aroma descriptions are (Resconi *et al.*, 2012). The latter results could be better correlated to the sensory attributes of game meat. In addition, more insight could possibly be gained into the volatile compounds responsible for the 'gamey' and other potential game-like sensory characteristics of game meat.

Another limitation of this study is that the species used and the conclusions derived from the data in this study is only a 'snapshot', as the conclusions and practical implications of the results could change when game species are derived from different farm locations and species. This study should be repeated with larger sample sizes (animal numbers per species), so as to establish whether the influence of gender is even less significant. Furthermore, including larger numbers of animals per species from various regions will include a larger degree of product variation and therefore possibly supply the game meat industry with even more reliable and relevant results to base the marketing of game meat on. There is also a need to identify the target market for game meat, both locally and internationally, and gain much more knowledge on their demands in terms of product quality and range (species). The cultural differences and how it relates to consumer preferences should also be considered within the South African context (Cloete *et al.*, 2015).

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